Mapping of Intact Forest Landscapes in Sweden according to Global Forest Watch methodology

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Preface

This MSc thesis is about "Mapping of Intact Forest Landscapes in Sweden". The project has been initiated by the non-governmental organisation World Resources Institute (WRI) in Washington and its initiative Global Forest Watch, in order to complete the map-poster "Remaining Wildlands in the Northern Forests" to be presented at the Johannesburg Summit 2002. The idea was to extend already existing maps of undisturbed forests in Russia (The Last Intact Forest Landscapes of Northern European Russia, Yaroshenko et al. 2001; Atlas of Russia's Intact Forest Landscapes, Aksenov et al. 2002) by using the identical methodology and criteria, so the intact areas of the entire boreal zone could be shown.

The main principles and mapping methods were developed by a team of experts involved in various organisations such as Global Forest Watch Russia, Greenpeace Russia, Biodiversity Conservation Centre, and Socio-Ecological Union International. Their work was the first attempt at identifying boreal forest areas of minimal human disturbance (intact) using high-resolution satellite imagery in combination with GIS and field work. I would like to mention Dmitry E. Aksenov, Maxim Yu. Dubinin, Andrey Zh. Purekhovsky who greatly cooperated on the project and afterwards revised the finished map of Swedish intact forest landscapes, and also Lars Laestadius (WRI Washington D.C.) who arranged the financial aid from WRI for my trip to Moscow at the end of July 2002.

The project also serves as the MSc thesis for my Master of Science with a major in Forest Management.at the Swedish University of Agicultural Sciences. The work has been made at the Remote Sensing lab of the Department of Forest Resource Management and Geomatics, using all imaginable technical, material and personal support of people from the Remote Sensing section. It has been an unforgettable experience to be in such amazing working environment for a few months. This study would not have been possible without the great help of my main supervisor professor Håkan Olsson who let me in on the project and widely assisted with many valuable opinions and ideas. Furthermore I would like to mention Mats Högström, my co-supervisor for the GIS part, Heather Reese supervising the Remote Sensing issues and patiently checking my English, and Per Löfgren who helped me with forest ecology questions and showed me what the real Swedish boreal forest looks like. Many thanks to all of you. Your faith and support are much appreciated.

Prague in December 2002 Filip Hájek

An electronic version of this work, including colour pictures, can be found by a search for the report title at the following URL: http://www.resgeom.slu.se/eng/publikationer/

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1. Introduction

Currently, most of the world's forests are directly or indirectly affected by some kind of human activity. More people are getting concerned with the state of tropical forests. However, the international community has not tracked the rate and extent of ecological change in forests of the boreal zone, which is the largest biome in the world and comprise one-third of the world's forest area. Although European temperate forests were transformed centuries ago, there are still some large areas of forest in a relatively natural state left in boreal regions of Russia, Canada, Finland and Sweden. Five years ago, a team of Russian experts associated with non-governmental environmental organisations started to create new maps of Europe's last remaining wilderness forests, using high-resolution satellite images in combination with GIS, existing topographical maps and field work. The result of their effort, "The Last Intact Forest Landscapes of Northern European Russia", was released by the World Resources Institute's Global Forest Watch (GFW) project and Greenpeace Russia in October 2001. The maps were created also for the rest of Russia and the "Atlas of Russia's Intact Forest Landscapes" was released early in 2002.

The project "Mapping of Intact Forest Landscapes in Sweden" was initiated by GFW in May 2002. The GFW Pan-Boreal Mapping Initiative originated as an idea to extend the unique Atlas of Russia's Intact Forest Landscapes (Aksenov et al. 2002) over the World's entire boreal zone. A number of non-governmental organizations and academic institutions in five countries (Russia, Finland, Sweden, Norway and Canada) were involved in creating a map of "Remaining Wildlands in the Northern Forests" as the first result of their cooperation. The map was presented as a poster at the Johannesburg Summit 2002 (26th August - 4th September 2002).

This MSc thesis describes the background context of mapping undisturbed forests in Sweden, as well as the criteria and methods set by the initiating GFW project. Swedish forest conditions are partially covered in the Literature survey chapter, where the history of forest management and the natural characteristics of northern boreal forests are characterised. Previous works about mapping virgin forests in Sweden and related studies dealing with remotely sensed data are mentioned. The essence of the study focuses on the detailed description of the methodology (GIS in combination with the interpretation of satellite data) and the material used to create the map of intact forest landscapes in Sweden. Further, the comparison with other existing old-growth inventories can be found in the Discussion part, where also the significance of the output and the applicability of the Russian criteria to the Swedish vegetation conditions are evaluated.

1.1 Background

1.1.1 Global Forest Watch maps of Russia's Intact Forest Landscapes

Global Forest Watch is a non-governmental network of major environmental and research organizations and is an initiative of the World Resources Institute (WRI). WRI (http://www.wri.org) is an independent centre for policy research and technical assistance on global environmental and development issues. Their particular concerns are with globally significant environmental problems and their interactions with economic development and social equity. WRI tries to build bridges between ideas and actions, meshing the scientific research, economic and institutional analyses, and practical experience with need for open and participatory decision making (WRI 1997). Forests are one of the current areas of work at WRI.

The overall objective of Global Forest Watch is “to infuse transparency and accountability into the decision making processes that determine how forests are managed and for whom”. According to GFW’s website, the main actions taken to promote transparency and accountability are:

1. tracking the actors (corporations, government agencies, individuals) that are sponsoring development activities,
2. mapping out where these actors are operating, and
3. monitoring the degree to which these actors are following national and local management laws and regulations.

GFW began its work in 1997 in four pilot countries: Cameron, Canada, Gabon and Indonesia and later expanded to other countries such as Chile, Venezuela, U.S.A and Russia. The Atlas of Russia’s Intact Forest Landscapes (Aksenov et al. 2002) was released by Global Forest Watch Russia collaborating with other Russian environmental organizations such as Biodiversity Conservation Centre and Greenpeace Russia.

The Atlas of Russia’s Intact Forest Landscapes is an extension of the mapping approach that produced the first GFW Russia report, called “The Last Intact Forest Landscapes of Northern European Russia” by A. Yaroshenko, P. Potapov and S. Turbanova (2001). Before that, no systematic study had assessed the degree to which the forest zone (or any other zone) of Russia was still intact in a natural state. The purpose of the atlas was, according to the authors, to give an accurate picture of the current status of remaining intact forest landscapes in Russia, and of the boundaries of federally protected areas, using a mapping scale that was relevant to practical land management. This map could serve to improve decisions about the conservation and sustainable use of the forest landscape.

In the Russian reports, the term “intact forest landscapes” refers to large mosaics of ecosystems in the forest zone, still in their natural state, minimally affected by human activity and unbroken by infrastructure (Aksenov et al. 2002). A set of criteria was used to identify and delineate intact forest landscapes: Smallest viable area, kinds of disturbance, minimum time undisturbed, forest fire regime and the northern boundary. The same criterieas as used in Russia were adopted as far as possible also in the Swedish study.

Smallest viable area

The size of an intact forest landscape is important to allow all essential components of the intact landscape to be conserved in their natural state, as well as to provide sufficient protection against edge effects. The criteria set for this study were:

- Minimum area: 50 000 hectares
- Minimum width: 10 kilometres

Kinds of disturbance

Intact forest landscapes are not “wild” in an absolute sense anymore, and every place on this planet has been exposed to human influence, either directly or indirectly. Delineation of these landscapes involves drawing a line between more (significant) or less (non-significant) disturbed areas. All ancient types of human activity were considered as background influence, together with some more recent activities listed below:

- Shifting cultivation, hunting, fishing, picking of mushrooms and berries, and fires caused by humans engaged in these activities
- Grazing of domestic and semi-domestic animals
- Harvest of hayfields
- Selective logging
- Activities occurring such a long time ago that their influence is more akin to an evolutionary force than a disturbance (see next section).

Minimum time undisturbed

All disturbances caused before 1930, and without an evident impact, were considered of no consequence for the identification of intact forest landscapes in the Russian study. The time was chosen due to some radical changes in the 1930s such as the rapid increase in the export of forest products, growth in the demand for small dimension and low quality wood (pulp mills), expanding of slash and burn agriculture and sharp increase in the intensity of mineral surveying and extraction that extended to remote areas.

Forest fire regime

Forest fires ignited by lightning are a natural component of the dynamics of boreal forest landscapes, but modern land use affect the fire mosaic of the landscape. Fire scars were identified directly in the satellite images. In order to classify them in a consistent way as “natural” or “anthropogenic”, the following rule was created:

- All areas in which fire scars or fire mosaics occur directly adjacent to a source of disturbance (settlements, roads, clear cuts, industrial facilities, and rivers wider than 60 meters) were assumed to have an “anthropogenic” fire regime, and therefore classified as a non-intact landscape.
- Areas of otherwise intact forest landscapes, in which fire scars or fire mosaics do not reach any source of disturbance, were considered as having a “natural” fire regime. They were therefore classified as intact.

The northern boundary

The term “northern boundary” refers to the borderline separating forests from tundra landscapes in the northern part of the boreal zone. Since intact forest landscape often changes gradually into an equally intact tundra landscape, drawing the northern boundary is a delicate task. The outcome depends totally on the forest definition used and does not reflect any change in the degree of intactness.
In the Russian studies, the northern forest boundary was drawn based on medium resolution (Resurs MSU-SK) winter images, using data from sites with known characteristics as reference. The criteria set for boundary delineation of forest from tundra:

- Minimum tree canopy cover of forest: 20 percent
- Minimum width of forest: 20 kilometres

More narrow strips of forest (e.g., along river valleys), as well as directly adjacent treeless areas (alpine areas and bogs), were excluded from the mapped intact forest landscape.

Methodology of mapping of intact forest landscapes applied in Russia

The procedure was carried out in three steps:

1. Creating a mask which excluded areas around human settlements and infrastructure and residual fragments of landscape smaller than 50 000 ha. The topographic maps of Russia at scale 1:500 000 were used as a base for this method. The result was a candidate set of landscape fragments without roads, in which to look for intact forest.
2. Further exclusion of non-intact areas and residual fragments of landscape smaller than 50 000 ha in the map mask. The medium resolution satellite images of Resurs-O1 MSU-SK (600x600 km scene) with 150 m pixel size and Landsat-7 ETM+ Quicklooks (183x183 km scene) with 300 m resolution were used in this step.
3. Final delineation of intact areas followed by fine-tuning of boundaries. High-resolution satellite images, Landsat-7 ETM+ (183x183 km) with a resolution of 30 meters, TERRA ASTER (60x60 km) with a resolution of 15 meters, and Resurs MSU-E with a resolution of 35 meters served as a base in this step.

All satellite images used in the Russian project had their acquisition dates between 1999 and 2001.

Additional information, such as forest inventory maps and other thematic maps were used at all stages of the analysis. Verification was done through a number of field expeditions and by using high-resolution images (Landsat 7 ETM+, and also SPOT HRVIR satellite images in a few cases) for checking the interpretation of intact forest areas.

1.2 Literature survey

1.2.1 Forest history of northern Sweden

Sweden has total land area of 41.1 million ha. More than half of Sweden's land area is covered by forests. Productive forest land defined as stands with annual production of more than 1 m^3 wood volume/ha, has an area of 22.6 million ha. An additional area of 6.6 million ha is composed of the high-altitude conifer forests and forests inaccessible for harvesting machinery, both with an annual production of less than 1 m^3/ha (Essen et al. 1997). The tree species composition is dominated by conifers. Prevalent domestic species are Scots pine, *Pinus sylvestris*, and Norway spruce, *Picea abies*. Common deciduous trees are *Betula pendula, Alnus incana, Polulus tremula, Salix caprea* and *Sorbus aucuparia* (Engelmark & Hytteborn 1999). The subalpine birch forest dominated by *Betula pubescens* ssp*. czerepanovii*, situated between the conifer-dominated forests and alpine regions, forms a subalpine woodland belt of the northern boreal zone. Currently, 48% of the total tree volume is cut as a pulp wood, 45% constitutes sawlogs and the rest is used as a fuelwood, and for other purposes.

Fennoscandian forests have been exposed to human influence for a very long time. Generally, a few major steps can be distinguished in history of Swedish forests utilization. The first step was the gradual opening of forest landscape for cattle grazing and agriculture. This process started in the Neolithic period (about 5000 years BC) and resulted in the deforestation of large parts of southern Sweden during the 17th century (Essen et al. 1997). Later on, during the 17th and 18th centuries, the rapid expansion of the mining industry together with an increase in human population led to the local overexploitation of forests in some parts of central Sweden, and consequently resulted in expansion of settlements in northern Sweden at the end of the 18th century. The further description of the history in utilization of forest resources will mainly focus on the northern boreal part of Sweden. High density of roads, settlements and other types of infrastructure, together with relatively frequent human activities, cause the southern parts of the country to not meet the criterias used in the Russian studies for mapping undisturbed forest landscapes.

The typical pre-settlement forest in northern Sweden was characterized by old pine stands on various soil types. Spruce or spruce/pine forests often dominated mountain slopes and other moist sites, the birch and aspen forests could rather rarely be found at this time, perhaps except for at fire sites. The agricultural impact on the northern forest prior to the 19th century was rather limited and concentrated to the more densely settled areas near the coast. In the year 1800, the population density was less than one person per square kilometre in Swedish northern counties (Östlund 1993), so the large inland forest areas were left relatively unaffected. Firewood (often in the form of dead standing trees) was usually gathered in close surroundings of the villages. Cattle grazing started to have a direct effect on forest regeneration, depending on the kind of animals and grazing intensity. Slash-and-burn cultivation practices considerably altered the natural fire regime in forests. Even if fodder production for cattle was the basis of the ancient rural economy, man gradually began to utilize the boreal forests for the production of exports. The birch potash production together with tar, produced from the large pines, reached its maximum around 1850, and became an important factor influencing the forest environment also in sparsely populated areas (Essen et al. 1997).

A new era in forest exploitation began in the 19th century and during the first hundred years of sawmills, several significant changes occurred. Larger amounts of timber were cut in areas previously untouched. Aiming the exploitation to the large diameter high quality pine timber, almost all old-growth pinewood was removed from the forests. This shift around 1860 from predominantly domestic use of forest resources to industrial use has been characterized as a “timber-frontier movement”. Despite many new sawmills built along the Bothnian coast even earlier in the 18th century, export was still limited by the policy of the Swedish state. The restricting laws were abolished only at the beginning of 19th century.

The rapid increase in the demand for sawn and square-cut wood products in developing western European countries, the new technology with a new means of communication (steam-driven saw mills, telegraph) together with utilization of waterways for floating logs and several institutional changes driving the export of timber, caused the fast expansion of the Swedish sawmill industry. Consequently, most of the virgin old-growth forest of Sweden has been cut-over at least once at the end of 19th century. Also, the first chemical pulp industry was started in 1867 (Nilsson 1990). Both domestic and industrial consumption has been increasing continuously until the early years of the 20th century. Further development of pulp mills caused the higher demand for small diameter wood, where especially spruce started to be an important industrial article.

After years of political pressure, the first real silvicultural law was introduced in 1903 (Nilsson 1990). This resulted in treating Swedish forests in a more sustainable way. Intensive silviculture included a wide spectrum of measures carried out in accordance with detailed management plans and also clear-cutting, which started on a large scale after selective logging had been forbidden on state forests in 1950 (Ebeling 1959, Axelsson 2001). Generally, 20th century forest management practices increased overall growth-rate and also standing volume has been getting back to a pre-exploitation volume level. It has also an ecological price. From the 1950s forest tracks have increasingly fragmented the landscape with an extensive network of roads and ditches, and riparian and adjacent upland forests have been inundated by reservoirs. Only 3%

of the productive forest land has escaped intensive harvesting, and wetlands have been drained over large areas (Östlund et al. 1997). The current forest patches are larger in size and the multi-aged matrix has been replaced by a mosaic of forest stands of various ages (Axelsson 2001). Most stands younger than 100 years are characterized by straight linear boundaries, clearly distinguishable from the landscape structure created by natural processes. Other anthropogenic boundaries are not as evident and occur over larger scales (forest fires). Plantation forestry resulted in a significant shift of natural ranges for different tree species.

The overall accumulation of clear–cut areas, promotion of single tree species and even-aged forest stands, and a consequential decrease of old-growth forests characterized the process of forest transformation in the past. The present Forestry Act from 1994 prescribes that conservation of biological diversity is of an equal importance to commercial timber production. Swedish forestry is now striving towards sustainable landuse. The idea is to use forestry operations in a way similar to how natural disturbances act in time and space. Forest management methods have been developed with the aim of maintaining natural forest characteristics and the planning at the landscape level has been introduced within most large forest companies. Currently 40% of Swedish forest land is certified under the FSC (Forest Stewardship Council) system. Forest owners certified under the Swedish FSC standard must set aside at least 5% of ecologically valuable forest land or representative habitats from productive forest land. These areas are considered above and beyond already protected forest land.

National parks and natural reserves represent 3.8% (872 400 ha) of all productive forest land area in Sweden. Only some 20% of the protected land area is productive forest land (Rolf Löfgren, pers.com.). In fact, only 173 000 ha or 0.8% are situated outside of the mountain forest (in Swedish: fjällnära) category and less than 1% of the productive forests are protected in Swedish southern boreal and hemiboreal regions (Aksenov et al. 1999). Mountain forests are considered as low productive forests, and actually do not represent diverse ecological and biological values of Swedish productive forest as a whole. Besides national parks and nature reserves, there are two other forms of protection specially designed to protect smaller areas of valuable forest. Biotope protection agreements and Nature protection agreements with private forest owners protect another 7 400 ha of productive forest land.

Sweden's Environmental Quality Objective Sustainable Forests specify a sustained protection of another 900 000 hectares of productive forest land. The responsibility of the state represents 400 000 ha, but the major part (500 000 hectares) of the goal is expected to be fulfilled by voluntary actions of forest owners. The voluntary protection is considered as a challenge for the Swedish protection system in the nearest future.

Table 1. Estimated area of legal forest protection (productive forest land) in hectares by the end of year 2010 (The Swedish Environmental Protection Agency 2002).

Protection	Year 2000	Estimate year 2010
Nature reserves etc.	872 400	1 172 400
Biotope protection	4 300	32 300
Nature conservation agreements	3 100	52 400
Total	879 800	1 257 100

1.2.2 Swedish northern boreal forests

When undertaking the first step of this study, excluding the human infrastructure with its corresponding zones of disturbance, the whole country of Sweden was analysed. The result map covers the boreal part of Sweden, which were predominantly areas along the mountain regions in the western part of the country (Figure 1.). The following description will concentrate on typical forests of northern Scandinavia, and also undisturbed boreal forest characteristics will be defined.

The boreal landscape is characterised by a mosaic of forests, mires and lakes. The natural structure of Scandinavian boreal forest is relatively homogenous due to the overall dominance of two conifer species, Scots pine *(Pinus sylvestris)* and Norway spruce *(Picea abies)*. Both conifers have extremely broad habitat amplitudes. In general, spruce occurs on moist soils and sites with lower fire frequency, while pine prevails on the dry sites with continental climate and high fire frequency. Moreover, spruce has lower temperature demands for regeneration and consequently reaches higher altitudes along the Scandinavian mountain chain than pine (Engelmark & Hytteborn 1999). The birch *Betula spp.* is the dominant broad-leaved tree in both middle and northern boreal zones, and the mountain birch *Betula pubescens* ssp. *tortuosa* characterizes forests in the western mountainous regions. According to Essen et al. (1997), shrubs play lower significance in Fennoscandian boreal forests compared to other boreal areas. Shrub species such as willow, *Salix starkeana,* and juniper, *Juniperus communis,* often define earlier successional stages, while saplings of rowan *(Sorbus aucuparia),* and goat willow *(Salix caprea)* constitute characteristic features on mesic sites. The field layer is usually dominated by dwarf shrubs such as *Vaccinium vitis-idaea* and *Vaccinium myrtillus* (mesic to moist sites), and *Calluna vulgaris* on dry places. The incidence of herbs and ferns is rather low except for moist or wet sites with moving ground water. In contrast, bryophyte and lichen species occur considerably more often than vascular plants on the forest floor. Common feather mosses *Hylocomium spledens* and *Pleurozium schreberi* are typical for low productivity spruce forests, and lichens in the genus *Cladonia* often dominate the bottom layer in pine forests on dry, sandy ground (Oksanen & Ahti 1982; Engelmark 1999).

Forest, naturally developing without any catastrophic human disturbances over many tree generations, is a complex mosaic of independently formed patches of various sizes and ages. These patches are exposed to many impacts of more or less random nature. Natural disturbances are an important factor behind forest regeneration and dynamics. Disturbance dynamics are affected by climate, and also the range of other factors determining the disturbance interaction with the environment (type, frequency, magnitude, etc.). Forest fires and storms are the most important natural disturbances initiating forest succession in Fennoscandia (Essen et al. 1997). In addition to forest fires, long undisturbed forest continuity and the occurrence of course woody debris are meant to be the important factors conserving the biological and structural diversity in boreal forest ecosystems.

Forest Fire Dynamics

Many ecological studies have documented the importance of fires in the development of forest structure and dynamics in the boreal landscape. The fire affects important forest characteristics, including tree species composition, the age structure, the intensity of tree death, the amount of fallen trees and organic debris on the ground, as well as composition of lower forest layers. In Sweden, regularly burnt sites with the exposure of periodic fires are dominated by pine, while spruce dominates at sites where fires occur rarely or not at all, for instance, at high altitudes or in maritime areas along the Scandinavian mountain chain (Arnborg 1990; Engelmark & Hytteborn 1999). Other shade-intolerant species such as *Betula pubescens* and *Populus tremula* can also easily regenerate on burnt areas. The bottom layer is often covered by continuous carpets of *Cladonia*, *Empetrum* and *Vaccinium* species, which are important in promoting surface fires. Natural Pine stands are often uneven-aged, with surviving tall individuals having evident fire scars. Spruce stands commonly burn as crown fires and few trees survive. Those may die as a result of fungal attack. Post-fire spruce stands are usually formed in the shade of abundantly regenerated deciduous species. Taiga periodically exposed to fires is characterised by a presence of fallen trees of different diameters and the absence of a thick organic layer with rather small amount of wood debris.

Most fires are naturally caused by lightning, but man has also increased fire frequency. On the other hand, fires have been passively and actively suppressed by human activities during the 20th century, which resulted in drastic reduction of both frequency and extent of fires (Essen et al. 1997). Fewer fires, together with changed land use, led to overall decrease of an extent of deciduous forests in boreal Scandinavia (Anon. 1995)

Storm-felling and gap dynamics

Gap dynamics refers to another basic self-maintaining process in taiga forests characterised by the absence of catastrophic external influences. It is associated with fall of individual old trees or a small group of trees, so the minor openings in canopy are created. Tree felling can be caused by variety of factors, such as strong winds in combination with fungi, insect attacks, or a heavy snow load (Engelmark & Hytteborn 1999).

Storm damage is especially important in the dynamics of old-growth stands. Gaps in the forest canopy are usually enlarged by the fall of surrounding trees, which radically change the environmental conditions for the forest floor community by altering the light regime and creating colonisable space (Poulsen & Platt 1989; Essen et al. 1997). The formation of gaps consequently results in a mosaic of cohorts of different ages, and in a wide spectrum of different microhabitats. Decaying logs, pits and mounds serve as seedbeds, where regeneration often exceeds the number of seedlings and saplings growing directly on the ground. The ample amount of course woody debris in form of logs, stump and dead standing trees is also very important for preserving diversity of birds, invertebrates and cryptogams in old-growth forests. The quantity of accumulation of dead wood on the ground is therefore a significant indicator in assessing biodiversity and forest continuity (Berg et al. 1993).

Forests with equilibrium gap dynamics are defined by uneven age distribution of woody species (trees of all ages are present), varied ground vegetation and overall characteristics of sustainable population. Such stands are extremely robust and stable over time.

Figure 1. Decaying log, a significant characteristic of the old-growth forest. Kvikkjokk region. Photo: F. Hajek

1.2.3 Previous studies about mapping undisturbed forests in Sweden

Nearly all forest areas in Sweden have been subject to cutting in the past. Most of the current forests are directly influenced by human activities resulting in loss of fundamental natural characteristics such as multi-layered tree structure, tree-species composition corresponding to stages of natural succession, or a considerable amount old trees and dead wood. According to Aksenov et al. (1999), less than 5% of old-growth forests still remaining in Fennoscandia should no longer be exposed to any human activity (e.g. forestry), destroying their natural conservation values. In order to improve maintenance of such values, notable areas of undisturbed forests must be identified. Several studies of varied quality and depth have been compiled in this field.

In Sweden, there was a nation-wide inventory of virgin forests arranged in the 1980's (*Urskogar: inventering av urskogsartade i Sverige;* Skogsstyrelsen & Statens naturvårdsverk, 1982). Unfortunately, many valuable forests were not included due to very strict criteria excluding forests with any indication of human impact (Askenov et al. 1999). For the present project, a very relevant study called *Gräns För Storskaligt Skogsbruk i Fjällnära Skogar – förslag till naturvardsgräns* (Border for Large-scale Industrial Forestry in the Mountain Forests – Recommendation for Nature Protection Border) was compiled by Ulf von Sydow in 1988 (von Sydow, 1988). The work was done for the Swedish Society for Nature Conservation with the aim to separate more or less undisturbed forests from commercially managed forests. According to the author, the most important criterion was to delineate forests with ecological functions identical to those in “real” virgin forests. The basic borderline was identified using infrared aerial photos at scale 1:60 000, which were five to ten years old. Afterwards, the line was checked through interpretation of Landsat TM images from 1985 and 1986, and re-drawn if new clearcuts were identified. The outcome was a map with interpreted boundaries separating forest land managed with clearcut practice from large undisturbed forest ecosystems along the western mountain chain (von Sydow, pers. com.).

Another publication called The Last of the Last: The Old-growth Forests of Boreal Europe by Aksenov et al. 1999 resulted from the international cooperation between ten non-governmental organisations participating in the Taiga Rescue Network (TRN). The main goal was to alert people as to the state of the last remaining old-growth forests in Fennoscandia and European Russia, and to provide necessary information to all authorities to ensure better conservancy and forest management decisions in the future. The maps of the Swedish old-growth forests (Figure 2) were compiled at the national level (coordinated by Fredrik Wilde), using the previously published inventories, unpublished NGO inventories and the field visits as the source of information (Aksenov et al. 1999). The following definition for old-growth forest was used:

"Old-growth forests are characterized by stands originating through natural successions with a significant contribution of old trees and dead wood, often with a multi-layered tree structure. These forest contain globally, regionally or nationally significant concentrations of biodiversity values (e.g., endemism, endangered or threatened species, endangered or threatened ecosystems, refugia), or are large landscape level forests, where viable populations of most if not all naturally occurring species exist in natural patterns of distribution and abundance."

The TRN research covered the boreal region of Sweden. The minimum size of areas has been 100 ha (75 ha in southernmost parts). The unfragmented mountain-near forests shown in that NGO study were based on von Sydow’s report from 1988 (see above), while the phone interviews with representatives of local groups of the Swedish Society for Nature Conservation, municipalities, counties, the Swedish Forest Administration, and forest companies served as the main source of information in all other cases. According to the authors, there are some old-growth forest areas missing, due to the lack of updated inventory information on Swedish old-growth forests, and also the aversion of some forest companies to share data concerning their land holdings. Moreover, it has been noted that there were some forests of high conservation value, which did not fulfil the old-growth definition used in the Aksenov report.

Figure 2. The Old-growth Forests of Sweden as shown in the TRN report from 1999

Since 1993 the Swedish Forest Administration has conducted a survey of woodland key habitats on commission from the Swedish government. The goal is to find, delineate and describe habitats of importance for red-listed species (Skogsstyrelsen 2002). The term woodland key habitat (WKH) indicates an area with high conservation value. The Swedish definition of woodland key habitat refers to "an area where one or more red-listed species occur, or where the nature of forest indicates the strong likelihood to find the red-listed species". The key habitats can often be found as fragments of a natural landscape, or a forest stand with the long forest continuity, while their size is not of main importance. According to the Swedish National Board of Forestry (Skogsstyrelsen) website, the survey is carried out in two steps:

1. The surveyors search for potential key habitats by compiling information from a variety of sources, e.g. infrared aerial photographs, forest inventories and forest

management plans, information from landowners and non-governmental organisations and different types of maps.

2. Potential areas are visited in the field. Areas that are assessed to fulfil the requirements of a woodland key habitat are delimited and described. Three main aspects on the key habitat quality are considered:

- stand history
- current stand structure
- occurrence of signal species and red-listed species

During the first phase of the project (1993-1998), 40 071 key habitats with a total area of 118 661 hectares were found. In year 2000, the systematic control survey indicated that only 1 out of 5 key habitats were found during the first phase. The results showed that the proportion of key habitats varied between 0.3 % and 4.7 % of the productive forest area between different counties. As the survey proceeds, the new information is continually registered, and the results are presented in an interactive GIS database on the internet (http://karta.svo.se/).

1.2.4 Satellite remote sensing for forestry – summary of some studies

A large amount of research has been done using satellite remote sensing data for forestry. The objects of interest, as well as results vary considerably. However, the usage of optical remote sensing in forest inventory related estimates tends to be the major goal. Satellite data can be useful in modern forestry management. Moreover, the satellite data have remarkable implications for overviews by various authorities, NGO's etc.

Each pixel in the satellite data has a DN (digital number) specifying a spectral reflection of the sensed object in a specific spectral band. Different feature types manifest different combinations of DNs based on their inherent spectral reflectance and emitance properties (Lillesand and Kiefer, 2000). Spectral pattern refers to the set of radiance measurements obtained by the various wavelength bands for each pixel. We can also recognize the spatial pattern of objects when trying to interpret remotely sensed data. That typically involves the categorization of image pixels on the basis of their spatial relationship with pixels surrounding them. Spatial classifiers consider aspects such as texture, feature size, shape directionality and content.

There is a relationship between forest stand parameters and particular spectral bands, at least for moderately stocked stands. For stem volumes above 250 m^3/ha, the relationship between spectral mean values and stand volume tends to saturate. The choice of spectral bands is a broadly discussed issue in the literature. Five of the seven Landsat TM bands studied by Brockhaus and Khorram (1992) (bands 2, 3, 4, 5, and 7) were found to be significantly correlated with basal area as well as age class, where as TM5 and TM7 were especially useful. Immature pine plantations less than 10 years old were observed to be spectrally distinguishable from older mature stands. Their investigation of two different satellite sensors (Landsat 5 TM vs. SPOT HRV Multispectral) showed the six TM band data sets to meet the minimum accuracy requirements when using remotely sensed data in forestry applications. According to Ardö (1992), there is a strong negative correlation between the stem volume of the forest compartments and the spectral radiance in all bands except TM4. The shortwave infrared spectral region (SWIR) represented by TM bands 5 and 7, seems to be particularly sensitive to forest vegetation density, especially in the early stages of clearcut regeneration (Horler and Ahern, 1986). They also noted that when it comes to softwood class discrimination, the blue band (TM 1) could be very useful (especially in northern conifer forests). Its main disadvantage is rather low dynamic range and high sensor noise compared to bands TM5 and 7, which produce excellent dynamic range and low noise.

The response in all TM bands seem to be influenced by the shadow of the trees (Ardö 1992), to which Horler and Ahern (1986) also stated that shadowing is suggested as a factor at least as important as leaf moisture content in influencing the spectral reflectance of forests.

Besides estimating forest stand parameters, an evaluation of structural characteristics of forested landscapes is also considered an important and valuable use of remote sensing data. The influence of forest management on forest landscapes requires evaluating changes to landscape patterns, since these changes can have impacts on wildlife habitats and forest-dwelling species (Rempel et al. 1997, Elkie and Rempel 2000).

A "landscape" is comprised of several landscape elements, which appear as patches that vary markedly in size, shape, type, heterogeneity and boundary characteristics. Each of these characteristics has its own significance in an ecosystem and is important in evaluating landscape structure (Oliver and Larson 1990, Ravan and Roy 1996). The structural analysis of a landscape helps in problem identification, which is useful in planning ecosystem management. Ripple et al. (1990) stated those properties of forested landscapes, such as patch size, the amount of edge, distance between habitat areas and the connectedness of habitat patches has a direct influence on flora and fauna. For these reasons, models and monitoring schemes are urgently needed for prescribing the location, size and shape of future harvest units and old-growth habitat patches. Using high-altitude infrared images (scale 1:60 000) they classified the elements of the system as either managed or natural, where managed path consisted of one, or more than one unit that was clearcut in the past. Patch size, patch abundance, patch shape, patch spacing and matrix characteristics were among the landscape statistics considered as sufficient to quantify landscape heterogeneity and pattern.

Ravan and Roy (1996) analyzed an impact of disturbances on landscape structure using Landsat TM data and GIS in Madhav National Park of India. The vegetation map derived from satellite imagery was used for analyzing landscape elements, while the patch characteristics of vegetation like size, shape, porosity and patch density were also studied. The patch size and porosity were considered as the most important parameters to discriminate ecological status differences.

Automated classification methods provide sufficient accuracies when mapping forestry harvest activities, as proved by Cohen et al. (1998). Further, methods based on generalization require less time and effort than conventional methods and as a result may allow monitoring of larger areas or more frequent monitoring at reduced cost (Woodcock et al. 2001).

Automated, spectrally oriented classification procedures include supervised and unsupervised classification. In supervised classification, an image analyst specifies various land cover types for the computer in a categorization process. Training areas (sample sites of known cover type) are used to compile a numerical "interpretation key" that describes the spectral attributes for each feature type of interest. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of category it "looks most like" (Lillesand and Kiefer 2000). Unsupervised classification involves data aggregation into natural spectral groupings (clusters) in the first step, while the image analyst identifies these spectral groups as certain land cover types using ground reference data in the second step.

Using thematic maps derived from Landsat TM imagery, Elkie and Rempel (2001) tried to define a relevant scale of landscape patterning, comparing two regions with a different history of disturbances in northwest Ontario. They found that current forest harvest practices focusing on landscape alteration at a single scale are creating new landscapes that are different from the natural landscapes.

Another valuable use of Landsat imagery is for monitoring environmental change (Woodcock et al. 2001). Many remote sensing studies have shown that clearcut logging can be readily detected using Landsat imagery, mainly because this type of cover change in forestland is expressed as a large spectral contrast in a multi-temporal image data set. Some of the efforts in change monitoring are based on visual image interpretation (using one, or a pair of images respectively), while other methods involve computer-based analysis.

1.3 Aim

The aim of this study was to create the “Map of Intact Forest Landscapes in Sweden” as a part of the GFW pan-boreal mapping initiative, and document the methods used in the project. The criteria and methodology were set by GFW in order to produce an identical outcome for the entire boreal zone. The poster called “Remaining Wildlands in the Northern Forests” compiled the effort of experts from five countries, and it was presented at the Earth Summit 2002 in Johannesburg.

Further, the report aims to discuss the meaning and implication of the map in connection to Swedish conditions. As the historical background varies among the individual countries, the purpose of such a map (made in accordance with principles generally determined for the whole boreal zone) can also be very different. Also the methodology as defined by GFW has several imperfections and limitations. Moreover, there are some existing inventories of undisturbed forests in northern boreal Sweden, so comments can be made by putting this study into context of previous works done in this field.

2. Material and Methods

2.1 Material

Various material and data sources were used in the project. These include the GSD “Blue Map” dataset, as the main source of different digitized objects. In addition, other existing GIS layers (GSD Nature Conservancy Objects and SVO datasets) and Landsat 7 ETM+ satellite imagery were used a base for the image interpretation.

2.1.1 GSD Blue Map (Road Map)

The Swedish National Land Survey GSD Blue Map database coverage was used for buffering of different types of infrastructure during the first phase of the project. The GSD - Geographical Sweden Data is the general name for the Swedish National Land Survey’s geographical databases with a common foundation of map data for landscape information. GSD maps include primarily information which is based on and updated from original maps, for example the Terrain map (Terrängkartan) and Overview maps (Översiktskartan), but also has additional landscape information which is requested by users of the data. The Blue Map (scale 1:100 000) was introduced in 1985. Production of the first edition of the map in southern and central Sweden was partly based on digital methods, including text, roads, railways, boundaries and power transmission lines. In connection with the revision of these sheets, which was started in 1993, complete databases for all of Sweden were produced.

Production of the Blue Map for northern Sweden was started in 1992 and was completed in the beginning of 1998. The production of the 70 sheets in the counties of Norrbotten and Västerbotten was fully digital and databases were created parallel with the production of paper maps. The coordinate system was the 2.5 gon V RT 90 national system and the altitude was specified by the national RH 70 system. According to the latest Lantmatäriet terminology (February 2002), the Blue Map is now called "GSD - Road Map". The three main categories of Blue Map data were used in this project:

1. Administrative divisions
   National, territorial, county, local authority and parish boundaries.

2. Communications
   • Public roads: motorways, primary trunk roads and three road classes based on road width. The coding in the database also includes the classifications of national and other roads. Most of the roads have the road number and load carrying capacity as attributes.
   • Streets and roads in urban areas.
   • Private roads classified as better quality motor road, motor road and poorer quality motor road. Entry roads to properties are also included.
   • Hiking trails, cycle paths and footpaths.
   • Railways and railway stations.
   • Power transmission lines.
   • Airports.
   The roads, railways and power lines form geometric networks.

3. Land cover and land use
   Closed polygons together with an Id point and combination-coded limits for the land cover and land use classes: built-up areas, water bodies, forest areas, areas of mountain birch, mountain areas above the tree line, glaciers and open areas. Marsh areas and bogs are shown in three classes in northern Sweden and one in southern Sweden. Clear-cuts in forest areas are stored as closed polygons in a separate layer for the northernmost counties of Västerbotten and Norrbotten.

Roads and railways were digitized by the Land Survey manually from manuscripts produced from the feature separations for the Green Map (1:50 000), and supplemented with information taken from orthophotos and editorial sources. The orthophotos that were used were produced from imagery at scales of 1:60 000 and 1:150 000 and were not older than 2 years. Watercourses, forest clear-cuts and other areas are captured by scanning, using the manuscript based on image interpretation. The map originals are scanned in some cases.

The contents of the digital GSD Road Map are revised in conjunction with the revision of the printed maps. The interval between revisions is 4-8 years except for the greater part of the road network, which is done four times per year. Areas are stored as closed figures with an object code for each area within a Green Map (25x25 km grid square). Volume of data is 10 - 25 MB per 50 x 50 km map sheet.

2.1.2 Other GIS layers used

GSD Nature Conservancy Objects

The Swedish National Land Survey GSD Nature Conservancy Objects geographic coverage was used as an additional source of information when interpreting satellite data. Practically, only Natural Parks and Natural reserves boundaries served as a reference data in searching for disturbances. Nature conservancy objects are created in vector format and include following categories:

- National Parks
- Nature reserves
- Nature conservancy areas
- Wildlife protection areas
- Natural monuments
- Crown Lands and Forests
- A number of private reserves

Various data sources with different scales were used to compile these boundaries. The method of data capture involved manual digitizing of national map series, such as the Landuse map (1:10 000), the Yellow Map (1:20 000), the Green Map, Blue Map or the Mountain Map (1:50 000/1:100 000) series. The objects are stored as points and closed polygons and are continuously revised in accordance with National Environment Protection Board (Lantmäteriet 1997). The volume of the Nature Conservancy Objects database is approximately 13MB.

Border for final felling (Föryngringsgränsen)

The SVO Border for final felling was as an additional source of information when interpreting satellite data. It was created from the result of an inventory made by the Swedish National Board of Forestry (Skogsstyrelsen). The data has been collected by County Forestry Boards and then assembled by SKS. Different sources and ways of data capture were used to create the border.

The purpose of this border was to get support for decision making whether or not to give permission to regenerating-cutting in areas close to the upper tree line. The border does not have any effect on the law, but it is currently used as a trial-basis in the permit process.

ESRI Europe Roads dataset

The Environmental Systems Research Institute (ESRI) dataset for European roads was used for the buffering of major roads in Norway. The map is created as a vector file and has a geographic data projection (decimal degrees coordinate units). The largest scale when displaying the data is 1:250 000.

2.1.3 Satellite Images

Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) imagery with acquisition dates entirely from summer months made the basis for the image interpretation. All Landsat scenes were selected to cover the areas to be interpreted in the first phase of mapping undisturbed areas.

Landsat 7 was launched on April 15, 1999. The design of the ETM+ extends features of previous Landsat sensors (4 and 5) and it uses similar orbits and repeat patterns in order to provide data continuity (Lillesand and Kiefer 2000). The ETM+ sensor collects six bands of data in the visible, near infrared, and mid infrared spectral regions at resolution of 30 meters, as well as a new 15 meter spatial resolution panchromatic band and a 60 meter resolution thermal IR channel. The scene size covers an area of 183 x 170 kilometres, which is approximately 34 000 square kilometres. The price of Landsat 7 ETM+ imagery is lower than older Landsat 4 and 5 data and is also lower than the cost of SPOT-4 HRVIR (High Resolution Visible - Infra Red) data (Reese and Nilsson 2000).

In total, ten Landsat 7 ETM+ scenes from 2000/1999 and one Landsat 5 TM scene from 1990 were used in the analysis. The scenes were all geometrically precision corrected, so no further corrections were needed (Table 2.).

Table 2. Eleven Landsat scenes with their characteristics used during the interpretation phase of mapping undisturbed forests.

Satellite	Path / Row	Acquisition date	Bands
Landsat 7 ETM+	195-012	2000-07-27	TM 1 – 5 & 7
	195-013	2000-07-27	TM 1 – 5 & 7
	195-014	2000-07-27	TM 1 – 5 & 7
	196-016	1999-08-01	TM 1 – 5 & 7
	197-012	2000-07-25	TM 1 – 5 & 7
	197-012	2000-07-25	Panchromatic
	197-013	2000-07-25	TM 1 – 5 & 7
	197-013	2000-07-25	Panchromatic
	197-014	2000-07-25	TM 1 – 5 & 7
	197-017	2000-08-26	TM 1 – 5 & 7
Landsat 5 TM	196-015	1990-07-15	TM 1 – 5 & 7

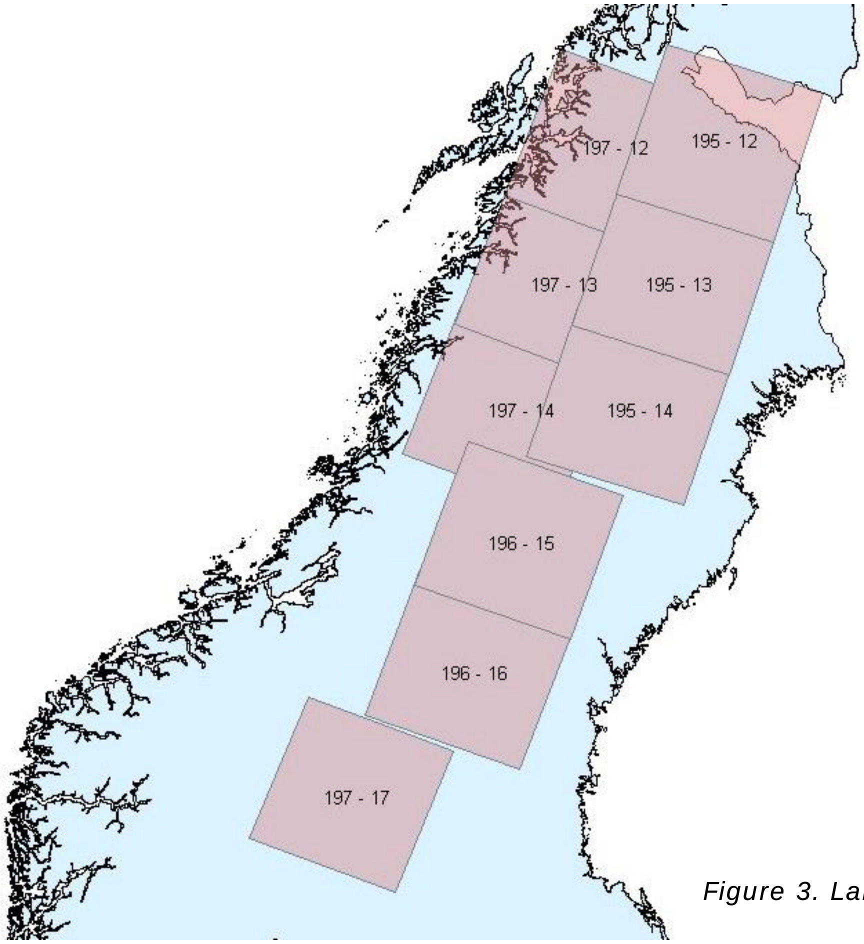


Figure 3. Landsat 7 TM satellite scene coverage

The summer images only were found appropriate enough to classify species composition, and to detect different kinds of human impacts on the natural pattern of forest landscapes.

Basically, three different colour combinations were used in image interpretation. A band combination of TM bands 5, 4, 2 (RGB) was usually checked using a parallel image with 4, 2, 1 (RGB) band combination. The one channel panchromatic data (0 – 256 shades of grey) were also used in two cases. Such colour band combinations allowed several feature categories to be distinguished:

Objects with low brightness in reflected light such as deep clean waterbodies, water-filled swamps, bogs and old coniferous forests. Objects with high brightness in the mid-infrared and near-infrared range could be detected, such as deciduous birch–aspen forests in logged and burned areas, mountain birch forest above the tree-level line, riverside meadows and agricultural fields, and objects with generally high brightness such as grounds in freshly cut areas, roads and settlements. Dry surfaces of exposed mineral soil, naked rocks and fire sites have typical very bright red-pink in the colour combination of 5, 4, and 2 (RGB).

Also the morphological and textural attributes of the objects were identified using high-resolution panchromatic ETM+ images. These feature objects included various separated and dispersed disturbances such as selective cuttings, dried mires, as well as linear anthropogenic objects such as high-voltage power lines, motor roads and railways

2.2 Methods

2.2.1 Buffering

According to the GFW methodology, the first step in the process of Mapping of Intact Forest Landscapes is to exclude obviously disturbed areas from consideration using information already existing in topographic maps. In Sweden,there is complete information available in the GSD Blue Map (1:100 000) covering the whole country.

The aim of buffering was to create a coverage of areas larger than 50 000 hectares further uninfluenced by means of infrastructure. Major infrastructure elements were taken into account. Their maximum zones of disturbance were discussed during the preliminary meeting with our Russian colleagues at the Department of Forest Resource Management and Geomantics, SLU Umeå at the end of May 2002. The assumed areas of disturbance were presented with a full-width buffer zone for each type of infrastructure discussed for Sweden. The buffer distances were created for the features in the GSD Blue Map (Table 3).

Table 3. Various types of infrastructure with corresponding buffer zones, as used in the initial stage of the mapping process.

Type of Infrastructure	Buffer width (m)
Public Roads / Public roads under viaducts	
Motorway	1 000
Road > 7 m wide	1 000
Road 5 – 7 m wide	1 000
Road < 5 m wide	1 000
Private roads / Private roads under viaducts	
Better class road	500
Poorer class road	500
Approach road	500
Railways / Railways roads under viaducts	
Standard (narrow) gauge double track, electrified	1 000
Standard (narrow) gauge single track, electrified	1 000
Standard (narrow) gauge double track, not electrified	1 000
Station	1 000
Communications	
Limits of runway	1 000
Cableway	500
Main power transmission line (>200 000 V)	500
Regional transmission line (20 kV – 200 kV)	500
Distribution line (<20 000 V)	500
Planimetric object (symbol)	
Mast, symbol	500
Tower, symbol	500
Wind generator, symbol	500
Land cover, landuse & hydroghraphy (Area)	
Body of water (area larger than 75 km^2)	1 000
Build-up area	1 000

These objects were considered as major sources of disturbance, and the width of the buffer zone (1 000 or 500 meters) expresses their assumed impact on the natural environment. Other objects displayed in the GSD Blue Map (listed in the List of codes) were not taken into account at this stage. Those considered as “background,” or human influences include: Public footway, hiking trail, Footpath, Cycle trail, Snow scooter trail, Reindeer fence, Reindeer corral, Chimney, Hut, Windshield, Outlook.

Method description

The entire buffering procedure was carried out in ESRI ArcGIS 8.1 - ArcInfo environment. The relatively short time available to do the task, together with the unusual amount of data, supported this choice.

Geographical Sweden Data (GSD) is digitally stored in the form of ArcInfo coverages. The “coverage” is the framework for vector data storage in ArcInfo. It generally represents a single set of geographic objects such as roads, parcels, soil units or forest stands in a given area. Coverage supports the georelational model - it contains both the spatial (location) and attribute (descriptive) data for geographic features. Each GSD coverage represents one Blue Map sheet at 1:100 000 scale. There are around 150 sheets covering Sweden for every basic category of infrastructure.

The Roads and Railways category was the first one to process. The ArcInfo command BUFFER was used to create buffer polygons around the specified input coverage features. Road category coverages included different transport routes such as motorways, private roads and railways. In order to specify a buffer distance for each buffer item (type of infrastructure), an INFO lookup table was created (Appendix 1). In the next step, an AML script (Appendix 2) was written to perform an ArcInfo repetition process (150 coverages in each category). The ARC Macro Language (AML) is the language used in the ARC environment to write programs. AML allows automation of frequently performed actions and creation of customized commands. Finally, all buffered coverage files were merged together to make one file covering the whole country. In order to preserve the features in overlapping areas (border between two map sheets), an UPDATE command was used during this process. UPDATE replaces the input coverage areas with the update coverage polygons using a cut-and-paste operation (The AML file used for updating is given in Appendix 3). The ESRI dataset was used for buffering main roads in Norway. The result coverage was updated with road-buffer coverage for Sweden to create dataset for all of Scandinavia.

The “Lines”, were the next category of infrastructure for buffering. This included mainly power transmission lines, skylines as well as larger dam complexes. A similar procedure to the road buffering was used. The “Symbols” includes masts, tower and wind generators. These POINT objects were buffered using POINT option. Again, the methodology used was the same as the buffering of roads.

A completely different situation came up when bodies of water and built-up areas had to be buffered. These objects belong to Land cover - Landuse and Hydrography feature category, from the Blue Map raster dataset. It contains 13 sub-classes (see GSD – Blue Map in Material section), the first (Id = 1) is “water” and the second (Id = 2) is “urban”. The Land cover - Land use raster was recoded in ERDAS IMAGINE 8.5 software into three classes:

1 = Water
2 = Urban
0 = all else

The recoded GRID file was converted into separate shapefiles (selected by VALUE) using ESRI ArcView 8.1 - ArcMap “Spatial Analyst” extension. The lakes with an area larger than 75 square kilometres were selected, and buffered as one coverage file in ArcInfo. Urban polygons were all buffered with the same buffer distance (1 000 meters).

The last step was to merge all created layers correctly together without losing important attributes, especially the INSIDE item. The INSIDE item created during the buffering process specified the inside/outside area (value 0, or 1) of each polygon, and later assisted to remove unwanted inward buffer polygons from the map. In the case of four categories (Roads, Lakes, Urban and Planimetric-symbol), the UPDATE command was used to merge object buffers. The Planimetric-lines (mostly power lines and wires) were merged to the rest as the last layer, using the ArcInfo command IDENTITY. IDENTITY computes the geometric intersection of two coverages. All features of the input coverage, as well as those features of the identity coverage that overlap the input coverage, are preserved in the output coverage. The resulting dataset represents all major elements of infrastructure with corresponding buffer zones around them. Roadless areas larger than 50 000 ha were then selected by using the AREA attribute. The finished map draft shows large landscapes remaining in Sweden (areas greater than 50 000 ha), located beyond the major elements of infrastructure (Figure 4.).

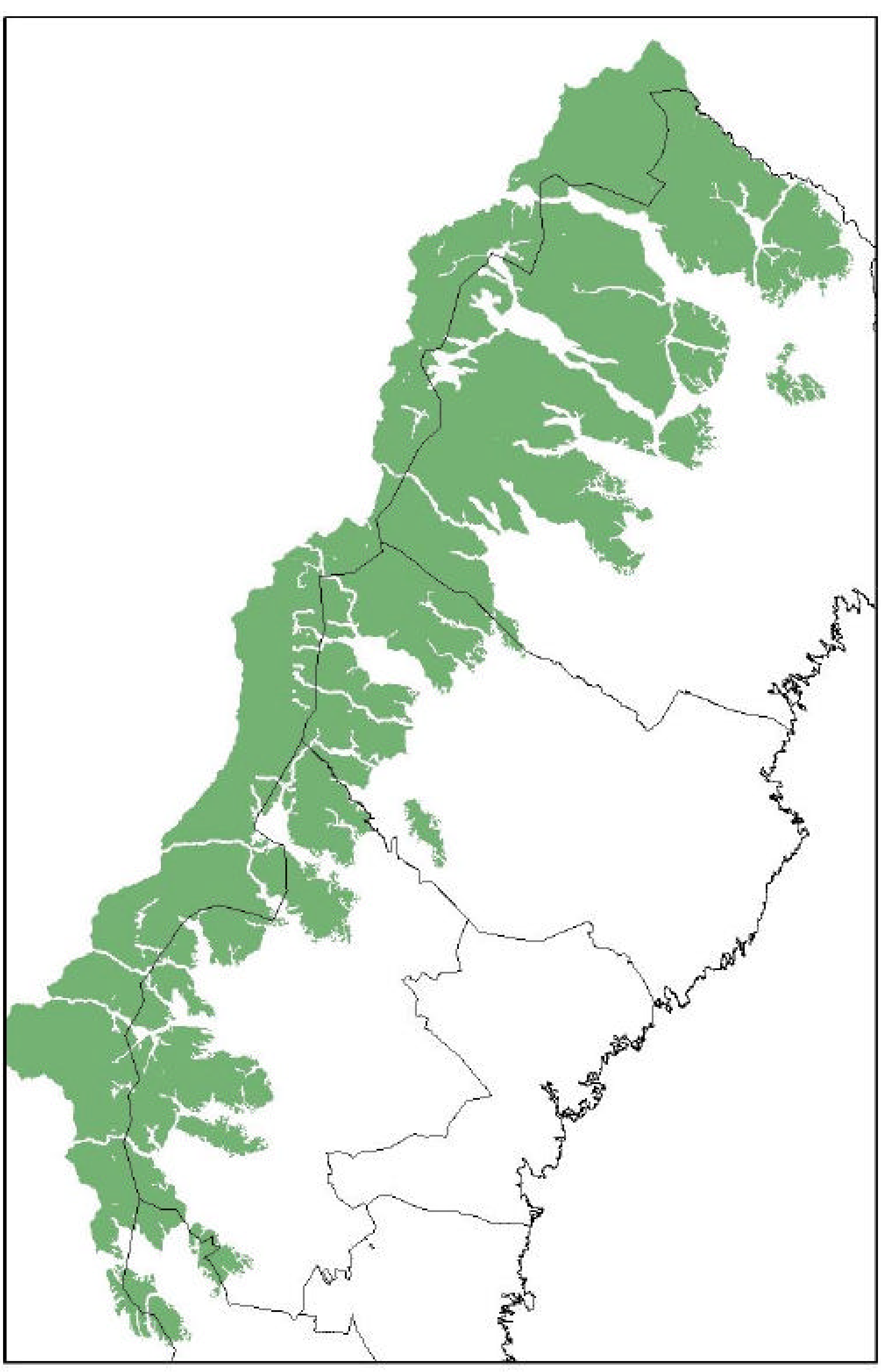


Figure 4. The result of the first phase of analysis: The map of areas larger than 50 000 hectares, further undivided and directly unaffected by permanent roads, settlements, and other major elements of infrastructure.

2.2.2 Interpretation of satellite data

The second phase included several tasks, as required by GFW methodology:

1. Exclusion of areas disturbed by intensive forest harvesting practices and other evident human activities identified in high-resolution satellite imagery. These involved logged areas, agriculture fields, quarries and building sites.
2. Elimination of narrow patches of forest (other intact landscapes respectively) located among clearcuts, old cut-overs, or elements of infrastructure, if less than 2 kilometres wide. Also, large undisturbed areas connected together with narrow strips (less than 2 km wide) were separated at this stage.
3. Exclusion of visible fire scars, if directly connected to any major type of infrastructure (classified as “anthropogenic”, see Introduction chapter)
4. Final revision of remaining infrastructure, as well as borders of intact forest landscapes.

Manual interpretation “on screen” was the major method used when interpreting the satellite data. Eleven Landsat ETM+ scenes were used in combination with the other GIS layers such as Natural reserves boundaries, or a Border for final felling. The interpretation process was carried out in the ESRI ArcGIS 8.1 - ArcMap environment. The program allowed rapid switching between various layers of data, changing spectral bands of interpreted satellite images, adjusting the display of satellite data by histogram manipulation, and user-friendly digitising of the boundaries for the map. As a reference, paper topographical Blue Map (Road Map) sheets 1:100 000 were also referred to, when help was needed to clarify the general situation in particular places.

The purpose of the satellite data interpretation was to identify areas affected by rather evident human activities. According to Yaroshenko et al. (2001), the main kinds of disturbance in forests remote from permanent human infrastructure are logging and fire (recently disturbed areas covered by grass, or exposed mineral soil), changes in the species composition (from coniferous to deciduous or mixed coniferous-deciduous), and intensive selective cuts, sometimes associated with changes in the ground cover. In the case of Sweden, recent clear-cut areas and old cutovers were those of main interest. There were several image characteristics taking into account in the process of clear-cut detection: Colour, Morphology and Texture.

The colour attributes were used to characterize species composition (coniferous/deciduous ratio) and ground vegetation in intensively thinned areas. In a few cases not only Multispectral ETM+ images were used, but also the Landsat 7 ETM+ 15 m panchromatic band.

Morphological attributes (spatial pattern) were considered very useful in detection of the clearcut areas and identifying other anthropogenic objects not indicated on geographic maps. Size and shape of such ground features can be recognized in 30-m-resolution imagery well enough to get an overview about the actual extent of cutting. With two scenes, the 15-meter resolution panchromatic data turned out to be an excellent tool to combine with multispectral imagery. The Panchromatic band does not contain as large an amount of spectral information as 3-band data, but its higher spatial resolution allows an interpreter to recognize morphological attributes of the objects more accurately. Especially shape of logged areas with an evident border to uncut forest could be seen very clearly by checking the ETM+ panchromatic band. Textural attributes played main a role in detecting some heavy selective cuttings, marshes or large bogs.

Method description

In order to work in the most efficient way, the ETM+ scenes were loaded one at the time, and pyramids (the function used for quicker display in ERDAS/ESRI image viewers, where blocks of data are used instead of the whole line-by-line image) were built in ArcMap software. The "smaller" parallel ETM+ Panchromatic scenes were used in two cases. All scenes were visually checked for geometrical correctness by comparing with the neighbouring scenes. The desired colour bands (5, 4, and 2) were selected in Raster Properties and the image was visually spectrally stretched using an automated Standard Deviation stretch. The image appearance was approved using Custom histogram equalization if needed (Figure 5).

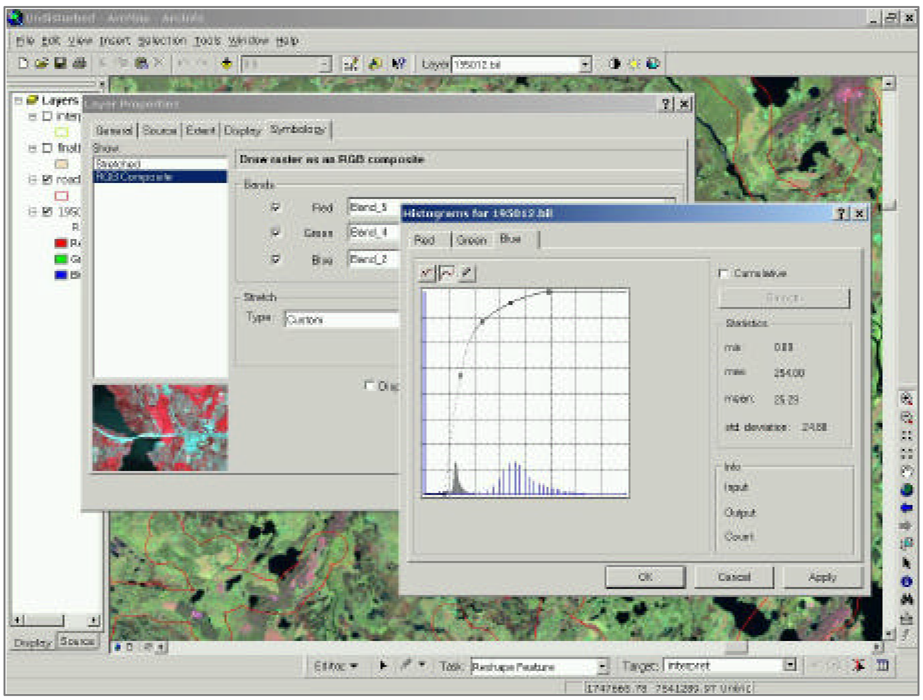


Figure 5. The ArcMap image interpretation environment.

The visually stretched image was overlaid with several GIS layers, including National Parks boundaries, Natural reserves boundaries (GSD Blue Map), Final legal felling boundaries (Skogsstyrelsen) and the roadless areas, a polygon dataset created in the first phase of the project.

The list of interpretation characteristics for various types of disturbances, based on Yaroshenko et al. (2001) terminology (Table 4), with a steady interpretation scale, were set to assure equal criteria over the entire mapping area. The scale 1:50 000 was used, changing down to 1:25 000 for accurate line drawing.

Table 4. Interpretation characteristics of various types of human disturbances as identified in high-resolution satellite imagery

Type of disturbance	Interpretation characteristics	Comments
Recent individual clearcuts	• Artificially straight boundaries • Regular shapes • Exposed mineral soil appearance • Logging and secondary transport roads	Additional information from topographical maps and existing GIS layers used to verify interpretation
Older cutovers and clearcut clusters	• Linear structures • Old logging restricted areas boundaries • Significant change in dominating species	Presence of old logging roads verified using topographical maps data.
Recently burned areas	• Presence of exposed mineral soil • Signs of firebrand and ashes • Non-linear structures	Areas classified as disturbed only if adjacent to infrastructure
Agricultural fields	• Grassy vegetation appearance • Neighboring settlements and river valleys • Artificial shapes and straight boundaries	Hay fields along smaller rivers considered as background disturbance
Mines & quarries	• Exposed mineral soil appearance • Transport roads and other infrastructure	Presence and type of infrastructure verified using topographical maps data.

The boundaries for the roadless areas (result of the initial infrastructure buffering) were edited in ArcMap to delineate undisturbed landscapes. ArcMap contains sophisticated, CAD-based editing tools that help construction of features while maintaining the spatial integrity of the geographic information system (GIS) database. Editing in ArcMap, the geometric shape of every selected feature is represented by the “sketch”. This lets you perform various editing tasks such as adding new features, modifying features, and reshaping features. To modify a feature, you must modify its sketch.

The Reshape Feature task was considered as the most suitable to change the shape of the existing polygon dataset. This tool allows reshaping a polygon by constructing a sketch over the feature. When a polygon is being reshaped, if both endpoints of the sketch are within the polygon, the shape is added to the feature. If the endpoints are outside the polygon, the feature is cut away (ArcGIS Desktop Help). The snapping environment settings ensured that the vertex connects precisely to the transformed feature. It also helps to locate a line in relation to surrounding features. The Point mode was combined with the Stream mode during the digitizing process.

Additional information from paper topographic maps 1:100 000 (GSD Blue Map) was available to verify satellite image interpretation (Figure 6). It displays common types of infrastructure, topography, as well as some important land cover categories, such as mires, forest/mountain forest boundaries and clearcut areas. The actual correctness of the location and extent of clearcut areas very much depends on the issue date of each particular map. Most of the maps used were not older than 1997.

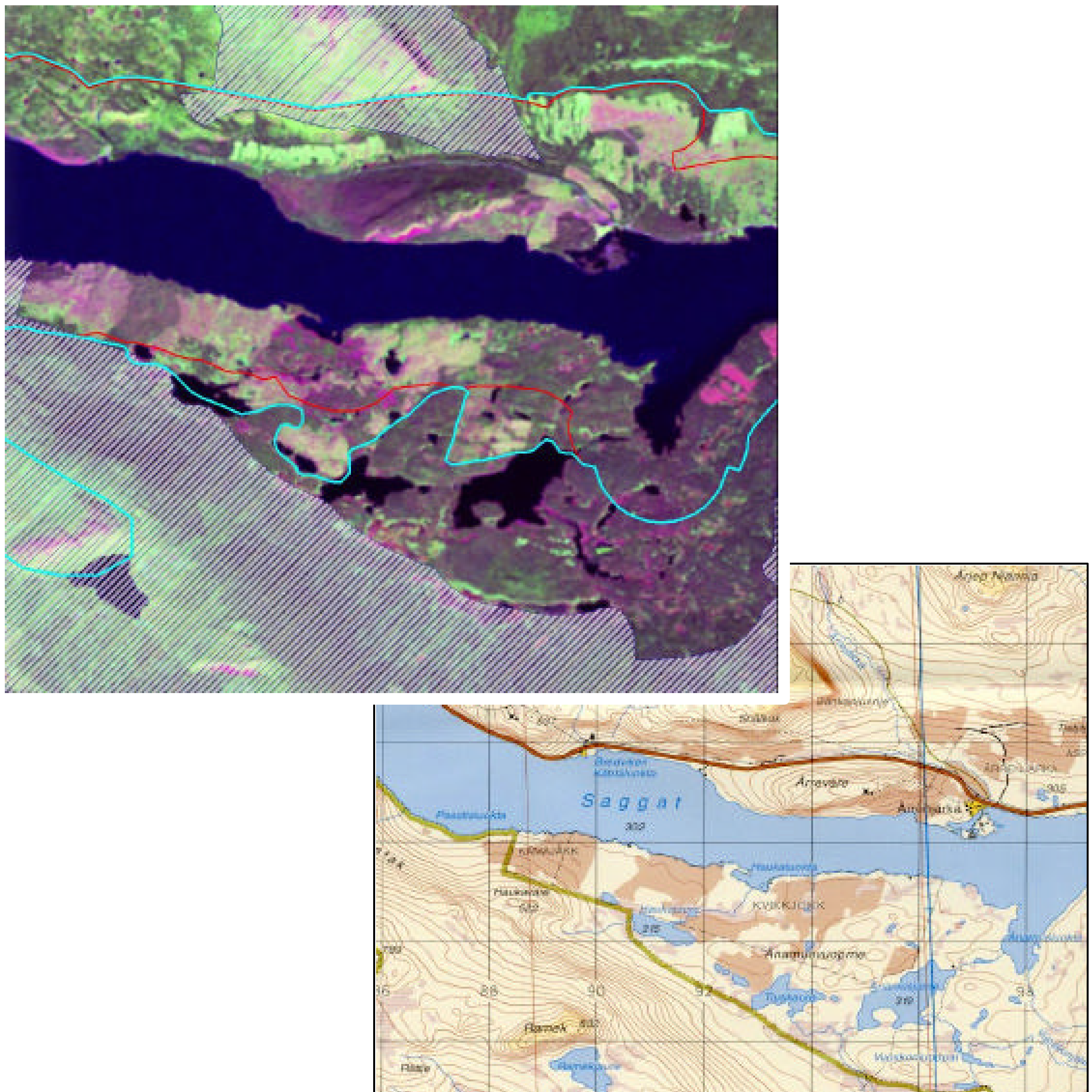


Figure 6. Topographic maps used as reference data for satellite image interpretation. The red line (1 000 m buffer around the lake) is modified by the sketch represented by the blue line, cutting off all evident human disturbances. Strip overlay shows Natural reserves boundaries.

The result areas from the interpretation phase were checked in the second round, and then once again by one of the authors of the Atlas of Russia's Intact Forest Landscapes, the experienced image interpreter Andrey Purekhovsky from Moscow.

Forest-Subalpine boundary of intact forest landscapes

The very last step of the project involved manual delineation of forest-subalpine boundaries, in Russian studies referred as the Northern boundaries of intact forest landscapes. The formal line separating Forest land and Subalpine woodland was created using Blue Map's Land cover - Land use coverage. The Land cover - Land use raster was recoded in ERDAS IMAGINE 8.5 software into three categories:

03 = Forest
10 = Mountain Birch forest
00 = all else

The Forest category includes all productive forests with a standing wood volume over one cubic meter per hectare. The Mountain birch forest (Fjällbjörkskog) category represents all forests over the coniferous tree boundary (single coniferous trees can occur) with a tree height at least 1.5 meters. The "forest line" was manually delineated as a border between the two forest categories, using Create New Feature in ArcMap's editing environment and the viewing scale at 1:100 000.

It should be mentioned, that an evaluation of the GSD classification of Forest land was done by Persson (1998), finding that the large extent of rock surface was classified as forest in the "Blue map". Thus, presumably some proportion of what is classified as forest land here is not forest land according to the definition used in Sweden. On the other hand, for the whole of Sweden, 60% of the rock surface area and 30% of the boggy wasteland is forest land according to Fridman et al. (1999).

The created line was used to intersect the output areas from image interpretation analysis. The areas over 50 000 ha were selected at the end. This resulted in total of 13 areas of intact forest landscapes larger than 50 000 hectares in the whole country of Sweden.

Note:
The resulting dataset was additionally modified by the Russian colleagues in order to indicate intact forest vs. intact non-forest areas on the final poster for Johannesburg. Using the 1 km resolution Global Land Cover Data Set, UMD (University of Maryland), the yellow overlay mask was created to show areas other than forests. The coarse resolution dataset was used due to the lack of time before the presentation in Johannesburg, with the intention to redo all areas within the continuation of the pan-boreal project (Maxim Dubinin, pers. com.).

3 Results

3.1 Maps

Two different Maps of Intact Forest Landscapes in Sweden are shown here. The first one displays the 13 undisturbed areas larger than 50 000 ha as mapped according to the GFW methodology (Figure 7). In comparison, the second map shows all intact areas without the 50 000 ha size restriction, in other words, as it looks without the final removal of areas smaller than 50 000 hectares (Figure 8).

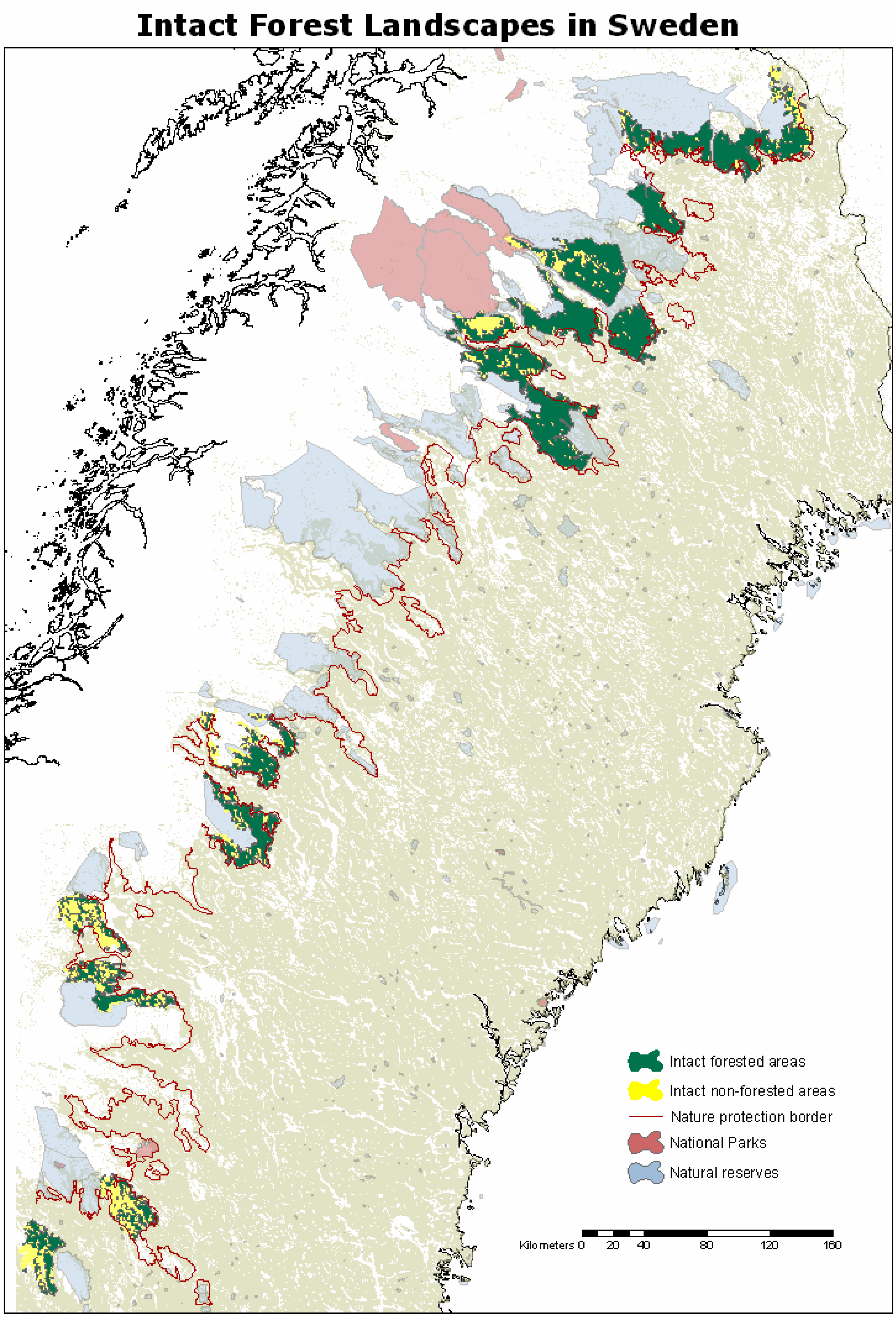
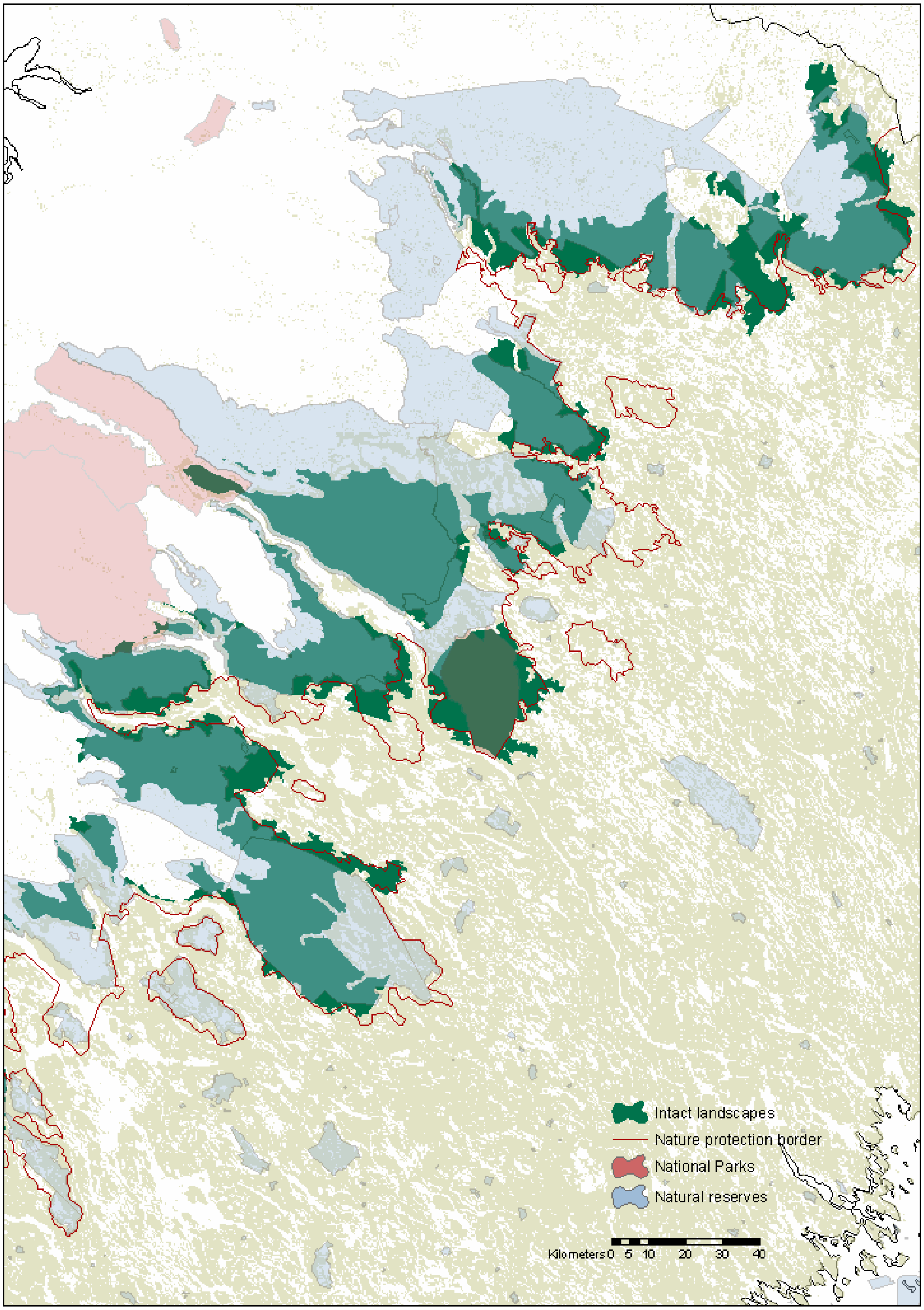
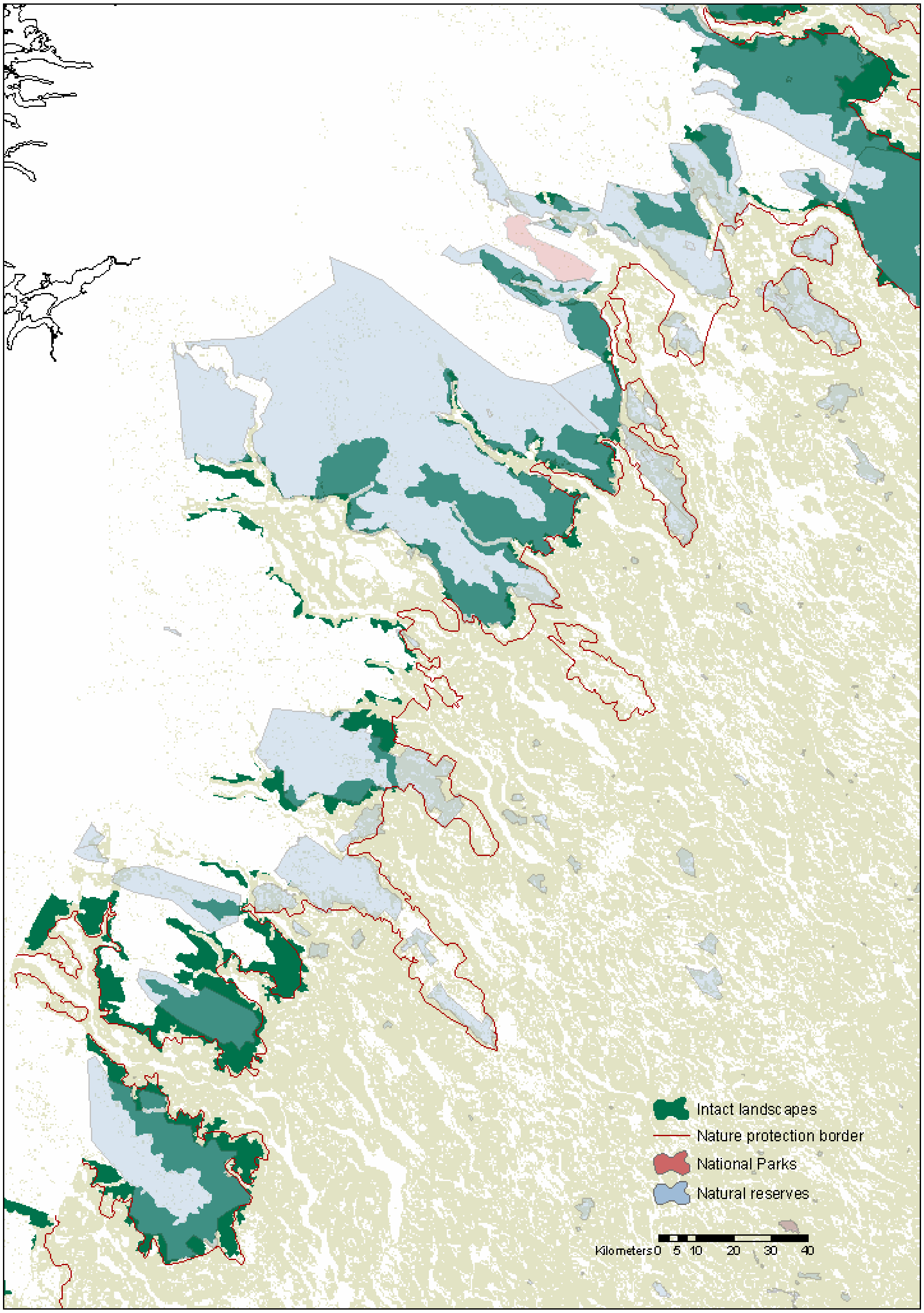


Figure 7. The Map of Intact Forest Landscapes in Sweden as created according to the GFW methodology

Intact Forest Landscapes in Sweden



Intact Forest Landscapes in Sweden



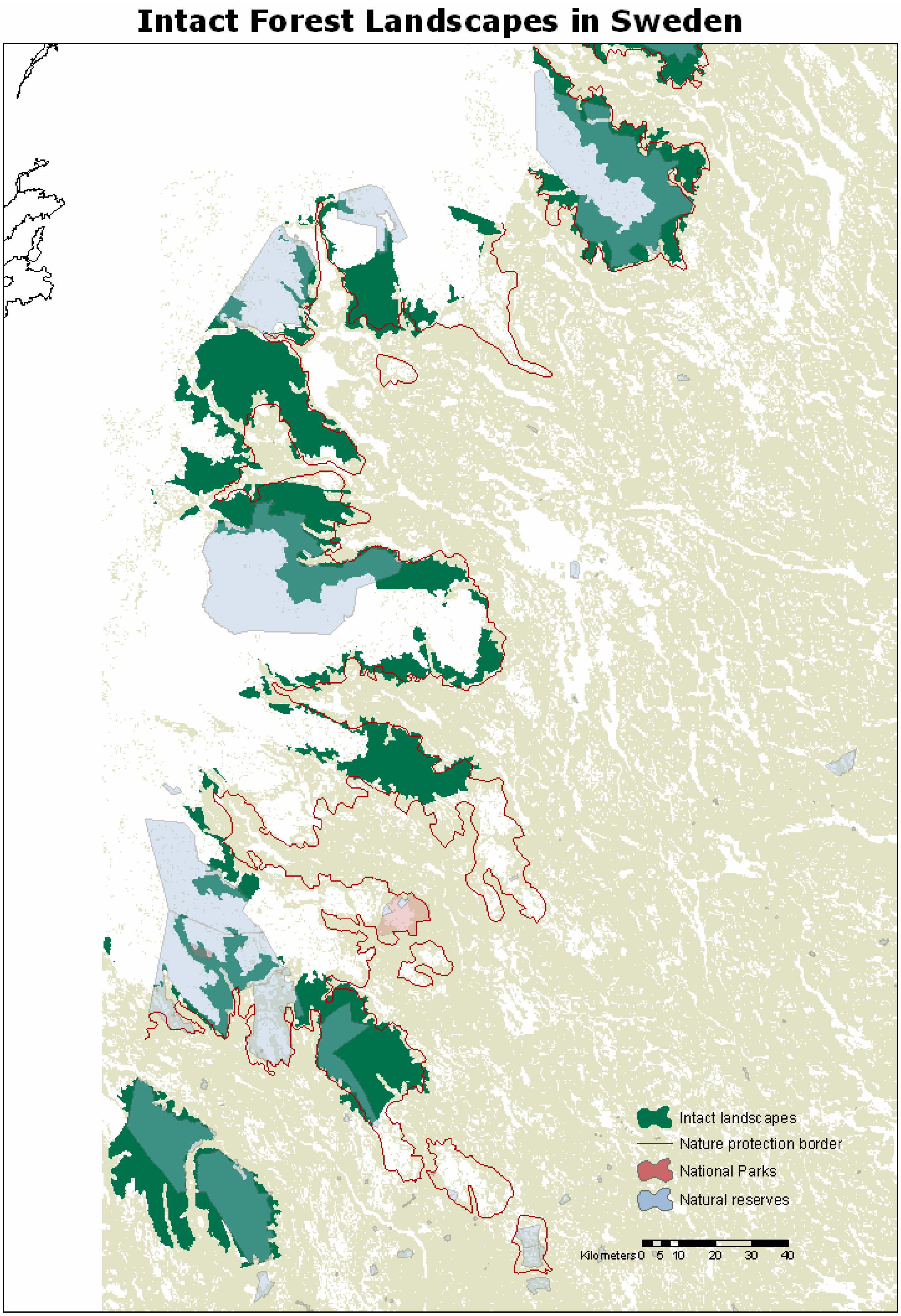


Figure 8: The Map of Intact Forest Landscapes in Sweden as it looks without the final removal of areas smaller than 50 000 ha.

3.2 Areas

The resulting map shows the 13 areas in Sweden that fulfil the GFW criteria of intact forest landscapes. All of them exceed the minimum area of 50 000 ha. The smallest is 56 418 ha and the largest is nearly 272 370 ha. This large area is actually 3 large areas connected with the narrow tracks. The average size is 105 273 ha. The sum of all 13 areas is more than 1 368 546 hectares (13 685.5 km^2), which represents approximately 3.3% of the Swedish land area.

The map also indicates the intact forested areas (Shown in green) together with intact non-forested regions (yellow) within the result polygons. These non-forested areas, basically comprised from mountains and bogs, represent a significant proportion (in a few cases more than one-third) of the intact landscapes, especially in the southern parts. Therefore the estimated share 4.7% of total forest land in Sweden (non-productive forests included) would not be correct.

4 Discussion

4.1 Experiences from the field trip

Once the final map was ready, all 13 areas of intact forest landscapes were briefly discussed with ecologist Per Löfgren (SLU), and afterwards the locality appropriate for the field visit was chosen. The field trip did not aim at a statistical evaluation, but more to study the overall natural characteristics of the forest in selected parts of the mapped area, especially then the old-growth (more or less undisturbed) forest areas typical for the mountain-near areas of northern boreal Sweden. In addition, the signs of human disturbances in the forest were particularly studied during the excursion.

The selected area was situated approximately 120 kilometres north-west from Jokkmokk, between the two large lakes Saggat and Peuraure. The entire locality is currently treated as a natural reserve. The tour started on the 30-years old clearcut area close to the village of Njavve, which was positively identified and removed from the map of undisturbed forest during the image interpretation phase. Continuing across the area mapped as intact forest, some evident characteristics of human activity could be found (tracks, stumps from selectively felled trees). Furthermore, signs of forest fires with an uncertain cause could be seen along the way, but the general features of a boreal virgin forest were apparent. The tree species composition (Pines surviving fires mixed with the smaller spruces) correspond to the natural successional stages, some very old and large trees, and the amount of dead wood on the floor indicate old-growth (Figure 9a). Bogs with patchy tree vegetation alternate in the forests. Overall, the areas meet the Russian criteria for inclusion in mapped intact forest landscapes.

The situation changed considerably moving closer to Lake Peuraure. A number of high stumps indicated extensive cutting activities (Figure 9b) nearby the lake shore and the signs of cutting expanded towards to inland. The lake probably served as the waterway to flow logs towards the coast in the beginning of the 20th century (Per Löfgren, pers.com.). The height of the stumps (about 80 cm) and the distance from the shore signalled the use of a two-man handsaw in combination with transport by horses. The GFW criteria classify this also as undisturbed forest landscape. Besides, such kind of small-scale disturbance cannot be distinguished using ETM+ satellite data. However, the actual intactness of the similarly managed forests is a question.

Figure 9a, 9b. Relatively undisturbed old-growth forest, and forest affected by the extensive cutting activities near the Lake Peuraure, Kvikkjokk region.

The last stage of the trip characterized the gradual move from the coniferous forests along the lake to the mountain birch vegetation (Figure 10) covering the upper parts of the hills. These forests have been excluded from the map in the last step, when the forest-subalpine boundary separated the two forest categories.

Figure 10. Mountain birch forest. Kungsleden, Kvikkjokk region. Photos: F.Hajek

4.2 The limitations and imperfections of the GFW methodology

Although the map created in accordance to criteria of the Russian colleagues has an undisputed meaning and implication, there are a number of imperfections to point out. These are mainly in consequence to the methods employed:

a. One-date visual image interpretation

The visual image interpretation of high-resolution satellite data with one acquisition date is the cheapest, quickest and perhaps easiest way to identify the type of cover change as obvious as recent clearcuts, crop fields, etc. It only requires a certain level of knowledge and experience of the interpreter. However, detecting older cutovers, selective logging, and fire scars (mostly based on a change in tree-species composition) can be a delicate task, and becomes very subjective when using one-date image data. In a change image produced from satellite data from different years, especially clearfelled areas will show up much more evidently.

b. Drawing boundaries across transition zones

The transition going from the forest-tundra to tundra in the north (as well as the one from forest to subalpine woodland in the west) is extremely gradual. It usually stretches for many kilometres, and the demarcation of any borderline between forest and non-forest areas is dependent on the decision rule used. The GFW methods included delineation of the Northern borderline using medium-resolution satellite images, so the quality and season of an image were also important. In the Swedish case, the forest-subalpine boundary of intact forest landscapes was manually redrawn from an existing map of forest cover, which means that the formal decision was taken by someone in the past. Such boundaries will therefore have a varying quality.

c. The choice of the minimum viable area

It is clear that the intact forest landscapes have to be large enough to conserve all features in their natural state. According to the Russian authors of GFW maps, they selected the minimum viable area of 50 000 ha relying heavily on an expert opinion. However, they admit an uncertainty in the knowledge base and recommend the issue should be further examined in future work.

Moreover it should be mentioned that the GFW definition of intact forest landscape includes also non-forest areas into the 50 000 ha minimum mapping unit. De facto it means the 500 ha of forest patch within a 50 000 ha area of bare mountains will be considered as an intact forest landscape. This fact should be recognized when this map is being considered for habitat studies. Thus, the choice of definitions for minimum viable area as well as the nature types included in this unit will have a large impact on the final map.

d. The disturbance principles identical for entire region under study

The use of consistent criteria allowed the creation of a standardised map of intact forest landscape, so the degree of natural taiga degradation in various regions of boreal zone could be shown. On the other hand, the natural conditions and historical consequences of human activities differ considerably between countries as well as individual places. Many valuable intact areas smaller than 50 000 hectares, as well as areas with values distinct from intactness were not identified in this project. Also, the need and purpose of such a map may differ in each country.

4.3 Comparison with other studies

Although several studies on identifying the Swedish old-growth forests were previously compiled, the only map absolutely relevant and comparable with this study is the one from von Sydow's report *Gräns För Storskaligt Skogsbruk I Fjällnära Skogar – förslag till naturvardsgräns* (Border for Large-scale Industrial Forestry in the Mountain Forests – Recommendation for Nature Protection Border; von Sydow, 1988). Using aerial photography and Landsat TM data, it aimed to show the boundaries between the forest land dominated by clearcuts and the relatively undisturbed forests. However, the mapping criteria were quite different and so divergences between von Sydow's map and the one created here occur.

Compared to this analysis, evidently more surface area is classified as undisturbed forests in von Sydow's map (Figure 11). This difference has some understandable reasons:

- Many valuable forests were omitted during the first phase of this analysis, when areas beyond the infrastructure and smaller than 50 000 ha were excluded. The land became very fragmented due to the buffering of many different types of infrastructure, such as roads, railways and powerlines.
- The GFW methodology prescribed the elimination of narrow patches of forest located among clearcuts, old cut-overs, or elements of infrastructure, if less than 2 kilometres wide. This caused many large "pockets" of potentially intact landscapes to be cut off.
- The most crucial loss of the extent of undisturbed forest landscapes was caused by the final exclusion of the interpreted areas smaller than 50 000 ha, or with the average width less than 10 kilometres.

There is also nearly 15 years time difference between both maps and it is possible that some new logged areas as well as other new disturbances have occurred. In such cases, the classification of newly disturbed forests as non-intact is absolutely relevant. Further, the result of mapping of intact forest landscapes seems to be a bit more detailed, which is probably brought about with the generalisation of the Nature Protection Border (Svenska Naturskyddsföreinngen, source Sveaskog), or maybe the different method of image interpretation in some cases. However, it means a few more small localities are identified as intact, compared with von Sydow's study.

Both this project and von Sydow's map from 1988 were made using remote sensing methods with the different principles involved. In comparison, the criteria set by GFW appear to be radically strict for the Swedish conditions, consequently resulting in a number of intact forest areas (often already protected) being omitted.

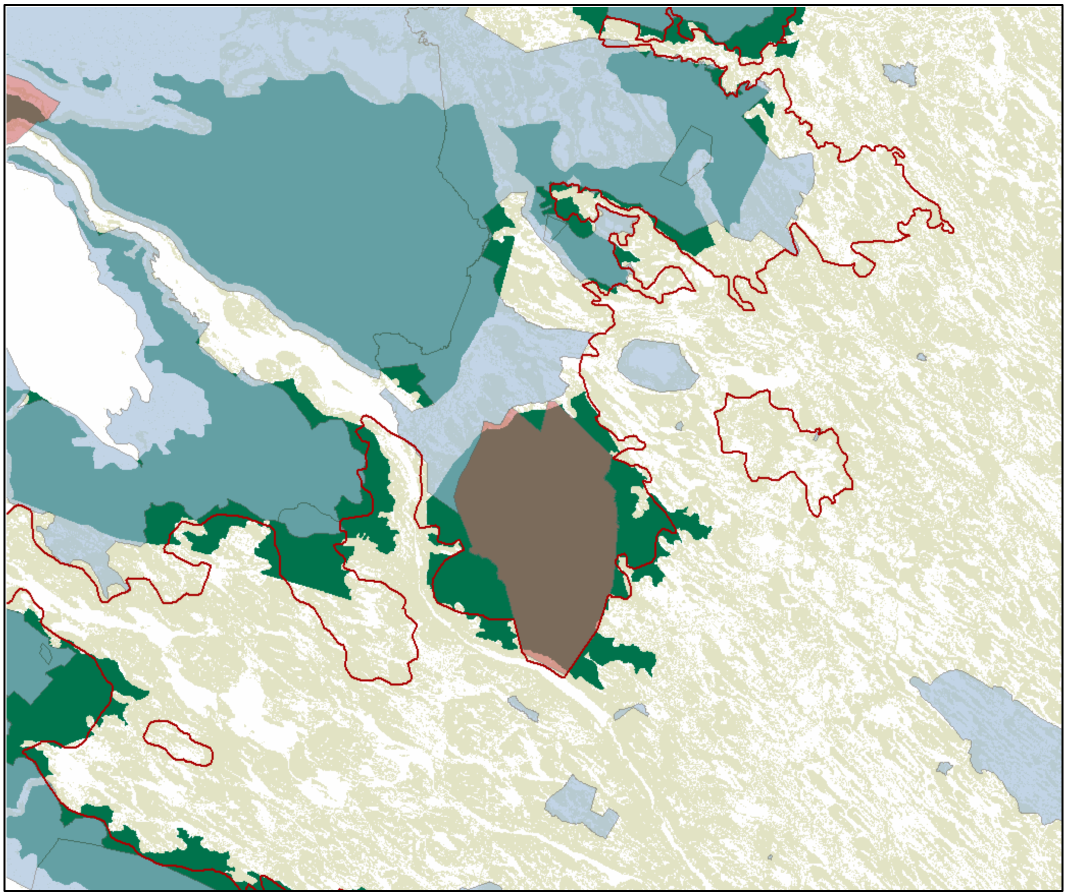


Figure 11. Comparison of sample areas identified as intact in this project (dark green and dark blue) with the undisturbed forest areas from von Sydow's map denoted by the Nature Protection border - Svenska Naturskyddsföreningen (red line). Light blue overlay represents Nature reserves and National Parks boundaries.

4.4 The meaning and implication of the results

Thirteen extensive areas with the total surface area of 1.4 million ha was the result of the project identifying intact forest landscapes in Sweden. The mapping rules, as set by the GFW, were primarily formulated for the conditions in boreal Russia, where the overall aim was to alert people to the state of the undisturbed forests, and to provide the essential information to improve decisions about conservation and sustainable forest management. However, the meaning of such a map is not the same in Sweden, due mainly to the diverse historical circumstances.

If the radical changes in forest exploitation (the rapid increase in the export of forest products, growth in the demand for pulpwood, etc.) in Russia occurred during the 1930s, in Sweden this happened somewhere around the 1850s. Most of the Swedish boreal forests have been cut-over at least once at the end of 19th century and heavy selective cuttings are common in many mountain-near forests. The remaining intact 3% of the productive forest land fall upon areas inaccessible for forestry machinery, or are forests with lower production. The level of threat is also rather low, since most of these forest areas are nowadays protected. Moreover, the undisturbed forests have been previously mapped (von Sydow, 1988) and the result successfully implemented in decisions about nature conservation in Sweden.

The map of Swedish intact forest landscapes from this study was made in order to complete the poster “Remaining Wildlands in the Northern Forests” to be presented at the Johannesburg Summit 2002 (Appendix 4). The principal meaning is therefore to show the extent of undisturbed forests in Sweden in context to intact forests in the other countries of the boreal zone. In addition, the results could be of relevance for the ongoing nature protection process in Sweden, where the environmental quality objective specifies the protection of another 900 000 ha of productive forest land within the next few years, giving an estimated total area of 1 257 100 ha of protected land by 2010. In some cases, the dataset could possibly be used as a reference to improve the accuracy and topicality of the Swedish Nature Protection Border.

4.5 Possible error sources

Most of the error sources result from the interpretation method based on one-date satellite imagery. The bogs can only with difficulty be distinguished from selectively logged areas, and older cutovers can be classified as a fire scare when using one acquisition date image. Overall, the analysis tends to overestimate the remaining intact area. The reason is to presume the locality to be intact unless signs of disturbance can be detected. It is more likely to miss some disturbance than to find one by mistake, although this alternative cannot be ignored either. The minor errors sources include the quality of the images (geometric correction, cloud cover, etc.), interpreting scale, the color band combination, and the correctness of the reference data (topographic maps).

4.6 What could be done better

Disregarding the most controversial GFW criteria about the minimum mapping unit of 50 000 ha (the issue with the ecological considerations about this limit goes beyond the scope of this study), and the drawing of boundaries across the transition zones, there are other factors influencing the result with a rather disputable significance. Within the Swedish circumstances, the map would probably have been more meaningful if:

1. The powerlines were considered as a background disturbance with low impact (no buffer zones) on the natural forests
2. No, or smaller buffer zones were defined around the large lakes and dams
3. Non-forested mountain areas were not classified as intact (not included in the minimum mapping unit) due to the frequent use of snowmobiles and recreational activities during the winter months

The other group of problems is related to time and financial abilities rather than the methodology itself. The use of a change image produced from satellite imagery from different years would assure a higher level of objectivity, and fewer errors connected to image interpretation. The verification of the result using infrared aerial photos, as well numerous visits in the field, would also enhance meaning of the study and its relevance for the identification of undisturbed forests in Sweden.

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Appendixes

Appendix 1:

kkod	dist
254	0
259	0
264	0
265	0
268	0
289	0
336	0
5040	0
5045	0
5060	500
5061	500
5070	500
5071	500
5082	500
5091	500
5860	500
5861	500
5870	500
5871	500
5882	500
5891	500
271	1000
272	1000
273	1000
274	1000
275	1000

*An INFO lookup table was created in order to specify a buffer distance for each buffer item (type of infrastructure). The buffer item is specified by its GSD Blue Map k-code and buffer distance by corresponding number (1 000 or 500 meters). The tables were saved as *.DBF files (dBaseIV) and exported as an INFO table in Arc Catalog.*

Appendix 2:

The AML file created for automated buffering of 150 road coverages in the ArcInfo enviroment. The ARC Macro Language (AML) is the language allowing automation of frequently performed actions and creation of customized commands. The basic AML commands are: w=change directory; lc=list changes; sv=set variable.
The ArcInfo command BUFFER is inserted into the AML program loop, which allowes to process the whole set of data with the specified attributes.

%cov%, %num%, %covers% = set variables

```
/* check coverages
&sv covers := [filelist e:\lmv\gsd_blue\road\bv_10* covers.txt -cover]
&TYPE Number of coverages in filelist: %covers%
&TYPE

&IF [null %covers%] &THEN
  &RETURN !!! THERE ARE NO COVERAGES THAT MATCH THE SPECIFIED TEMPLATE !!!

&sv filunit := [open covers.txt open1 -read]

/* Check for error in opening file.
&IF %open1% <> 0 &THEN
  &RETURN &WARNING Error opening file covers.txt.

/* Read from file list
&sv cov := [read %filunit% readstatus]
&IF %readstatus% <> 0 &THEN
  &RETURN &WARNING Could not read file covers.txt.

&sv num := 1
&DO &WHILE %readstatus% = 0
  &TYPE Processing coverage %cov% %num% of %covers%.......
  buffer e:\lmv\gsd_blue\road\%cov% buf_%cov% kkod road_lut2
  &sv num = [calc %num% + 1]
  &sv cov := [read %filunit% readstatus]
  &TYPE
  &TYPE
&END

/* Close file list.
&sv closelist = [close %filunit%]
&IF %closelist% ne 0 &THEN
  &RETURN FILE CLOSE ERROR %closelist%

/* Delete file
&sv delstat = [delete covers.txt]
```

Appendix 3:

Similarily to the buffering process, the AML scrip was used to merge all buffered files together using ArcInfo command UPDATE. In this case, the procedure was done in two steps: First, the two coverages were updated to create the file called TEMP1. Secondly, this file entered the program loop where the TEMP1 file was updated with another buffered coverage, and the result file was renamed back to TEMP1.

```
/* check coverages
&sv covers := [filelist buf_bv_1* covers1.txt -cover]
&TYPE Number of coverages in filelist: %covers%
&TYPE

&IF [null %covers%] &THEN
  &RETURN !!! THERE ARE NO COVERAGES THAT MATCH THE SPECIFIED TEMPLATE !!!

&sv filunit := [open covers1.txt open1 -read]

/* Check for error in opening file.
&IF %open1% <> 0 &THEN
  &RETURN &WARNING Error opening file covers1.txt.

/* Read from file list
&sv cov := [read %filunit% readstatus]
&sv covx = [read %filunit% readstatus]
update %cov% %covx% temp1
&IF %readstatus% <> 0 &THEN
  &RETURN &WARNING Could not read file covers1.txt.

&sv num := 1
&sv step := 2
&DO &WHILE %readstatus% = 0
  &TYPE Processing coverage %cov% %num% of %covers%.......
  update temp%num% %cov% temp%step%
  kill temp%num% all
  &sv num = [calc %num% + 1]
  &sv step = [calc %step% + 1]
  &sv cov := [read %filunit% readstatus]
  &TYPE
  &TYPE
&END
&sv step = [calc %step% - 1]
rename temp%step% temp1
/* Close file list.
&sv closelist = [close %filunit%]
&IF %closelist% ne 0 &THEN
  &RETURN FILE CLOSE ERROR %closelist%

/* Delete file
&sv delstat = [delete covers1.txt]
```

Appendix 4:

The poster "Remaining Wildlands in the Northern Forests" as presented at the Johannesburg Summit 2002