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Detecting changes in the state of reindeer pastures in northernmost Finland, 1995–2005.

Alfred Colpaert
University of Eastern Finland, Joensuu Campus, Department of Geographical and Historical Studies, BOX 111, 80101 Joensuu, Finland (Alfred.colpaert@uef.fi)
Jouko Kumpula
Finnish Game and Fisheries Research Institute, Reindeer research, Kaamanan, Finland

ABSTRACT. The state of pastures in the Finnish reindeer management area has been monitored since 1995 using remote sensing and field inventory. The first inventory was made in 1995–1996, updated in the beginning of 2000s and repeated in 2005–2008. By comparing results from 1995–1996 and 2005–2008 we can observe clear changes in forest cover, structure and ground lichen abundance. To evaluate pasture/vegetation changes on the basis of separate classifications we have used a grid approach. By implementing a 500 by 500 m grid network and summarizing pasture classes for every grid cell we can visualize and quantify intensity of change. By comparing 1995–1996 and 2005–2008 we can see a clear decrease in the number of cells classified old growth dominated forest, and also an increase of fragmentation can be detected. With a 7.5 ha threshold the amount of old growth forest was reduced by 5%, for 20 ha the decrease was 21%. This indicates a significant change in forest landscape structure, fragmentation and reduction of reindeer winter pasture value in large areas. Pixel wise comparison showed no substantial changes in pasture areas. There is a degree of uncertainty in change detection; changes in remote sensing instrument, changes in processing software and methodology, changes in field methods and ancillary data, and obviously also bias introduced by differences between analysts. When comparing reindeer lichen biomass between 1995–1996 and 2005–2008 on the basis of field site data, the measured lichen biomass has declined in 19 out of the 20 reindeer management districts. Only one district showed slight improvement, in three districts there was a notable drop in lichen biomass, from over 1500 kg/ha to about 500 kg/ha. Also amount of arboreal lichens declined due to felling of old growth forest, confirming the findings on the grid cell level. Consequently grass, shrub and sapling stands increased as felled areas start to grow graminoids and herbs.

Introduction

Regular satellite imagery based inventories of land use/land cover have become standard practices. The European CORINE land cover classification programme is a well known example of this (European Environment Agency 2007). Repeated inventories have the potential to reveal changes in the environment, both natural and anthropogenetic. However, general, large scale mapping programmes seldom provide relevant data related to the special needs and requirements of specific species. Semi-domesticated reindeer (*Rangifer tarandus tarandus*), close relatives to wild reindeer and caribou, are very specialised grazers and their seasonal grazing grounds are therefore not adequately reflected in the CORINE database.

The use of the boreal forest and tundra for reindeer herding is an example of an ecosystem service providing for the production of meat, skins and antlers but also non material products like tourism and social status. The sustainability of reindeer herding became an issue during the 1980s, when winter pastures started to become degraded (Helle and others 1990). To provide insight into the extent and state of reindeer pastures, a satellite imagery based inventory was started in 1995 and the first inventory of the entire Finnish reindeer herding area was completed in 1998 (Colpaert and others 1995, 2003). For an overview of Finnish reindeer herding practices and methods used in the first inventory see Colpaert and others 2003. The northernmost part of the reindeer herding area was again mapped between 1999 and 2003 and, while the outcome was reasonable, many shortcomings and aspects for methodological improvement were observed. During 2005–2008 both field inventory and image classification methods were thoroughly analysed and revised to improve accuracy and reliability (Kumpula and others 2009). To save resources it was decided to divide responsibility for the inventory. As the northern part of the reindeer management area is most important and critical it was mapped by the Finnish Game and Fisheries Research Institute and the Finnish Forest Research Institute (METLA) became responsible for the central and southern part. The inventory of the central and southern parts by METLA (Mattila 2010) is based upon field data derived from the 10th Finnish National Forest Inventory (NFI 10) (Mattila 2010; Tomppo and others 2009).

The goal of the present study is to compare results of the pasture inventories of 1995–1996 and 2005–2008. Hereafter these inventories will be named reindeer pasture inventory (RPI) 1995 and 2005. Classifications are compared using a pixel wise evaluation and a 25 ha grid based methodology. The Finnish Corine land cover inventories of 2000 and 2006 are compared for reference. To validate the analysis we use national parks as reference areas, in particular the Urho Kekkonen National Park (Urho Kekkonen kansallispuisto, UKK). We test both pixel wise and aggregated grid based methods for change detection. The UKK data is also compared with the MHGIS (Metsähallitus GIS) nature vegetation database from the state enterprise Metsähallitus (www.metsa.fi), responsible for the park areas.

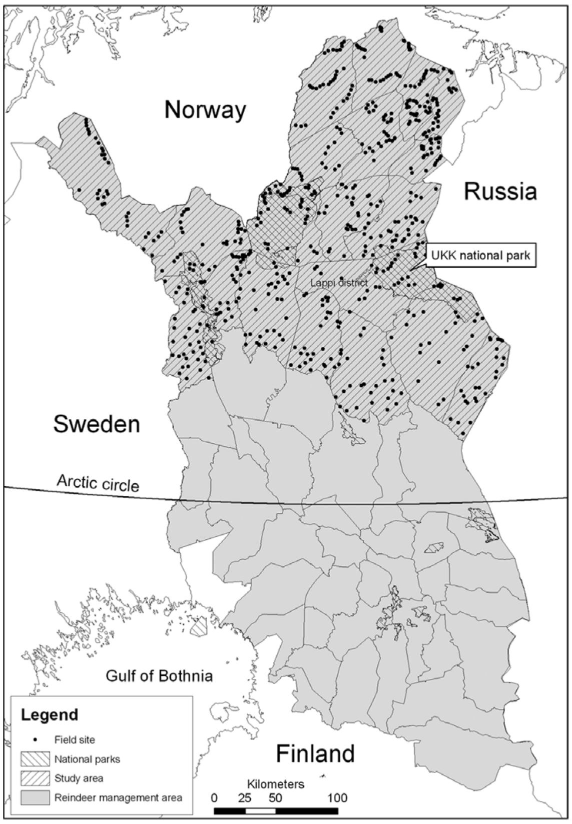

Fig. 1. The Finnish reindeer management area and the study area with 625 field sites located on lichen pastures.

Study area

The study area comprises the 20 northernmost reindeer herding districts in Finland (Fig. 1). This area has the highest numbers of reindeer and reindeer densities and is traditionally the most important area of the reindeer management area. This area includes also all 13 Sami reindeer herding districts. Reindeer herding in the area has a special preferential status (reindeer herding act) providing additional protection for this form of livelihood. The area includes both the treeless tundra and boreal forest biomes. Three large national parks in the area act as reference areas. In the west the Pallas-Yllästunturi National Park, near the Norwegian border the Lemmenjoki National Park and in the east the Urho Kekkonen National Park. Apart from the national parks most of the forest is in use by forestry. Most of the land belongs to the state, but is formally owned by the State Enterprise Metsähallitus.

Northern Finland belongs to the Precambrian Fennoscandinavian shield, post-glacial geomorphology is characterised by extensive swamps, fluvio-glacial sediments and glacial till deposits and many rivers and lakes. Topography is mainly gently undulating, with low mountains (fells) reaching up to 600 m, the highest mountains are found in the north-eastern 'arm' of Finland with mountains over 1000 m.

Vegetation is characterised by northern coniferous forests (*Pinus sylvestirs, Picea abies)*, higher areas are dominated by sub-Arctic heather and sub-alpine birch woodland (*Betula pubescens, Betula tortuosa, Betula nana*). The barren areas above the tree line have alpine vegetation with heather, lichens and grasses. Fens and mires characterise the lower poorly drained areas.

The climate is sub-Arctic, with a mean annual temperature of -1.0°C, mean annual precipitation between 400 amd 500 mm, growing season 120 days, snow cover days 200–210 (Autio and Heikkinen 2002). The altitude of the treeline varies from 300 to 450 m, depending upon exposition and aspect (Autio and Colpaert 2005).

Development of the reindeer herd and thus of grazing pressure in the study area is characterised by a steep increase after the 1970s, caused by a number of factors like parasite control, calf slaughter, mechanisation of transport and favourable climatic conditions (Colpaert and others 2003). The summer stock in the study area increased during the 1980s from 100,000 animals to 250,000 animals in 1990 (summer herd, before autumn slaughter). From 1990 to 2000 the number dropped to 150,000, to increase again to 190,000 in 2008. In 2008 the density of reindeer varied in the study area from 1.6 to 3.3 reindeer per km^2 on land area (winter herd).

Reindeer herding is allowed inside the national parks and most of the UKK area is in use as winter pasture of the Lappi district. The number of reindeer effects ground lichen pastures directly, by trampling during summer and grazing during winter. Trampling during summer is a major problem, and a pasture rotation cycle was adopted in the Lappi district in the mid of 1990s, by constructing a fence between summer and winter pastures.

Materials and methods

The satellite imagery for the first inventory (1995) consisted of 22 full and quarter Landsat 5 TM scenes obtained during the months June–August of the years 1987 to 1994. To cover some gaps and cloudy areas three older images dating form 1984 were used. The classification method was based on the supervised maximum likelihood classifier, using ER Mapper software (Earth Resource Mapping 2000). To improve accuracy a peat land mask was used in a post classification correction algorithm. The peat land mask is a binary 25 m grid raster, produced by the Finnish Land Survey from topographical map data. For a detailed description of image classification and field inventory methods see Colpaert and others (2003). For the first inventory RPI 1995, 3050 field sites were visited in the study area, of which 2362 on winter pastures and 688 on summer pastures.

The second inventory during the years 2005–2008 used basically the same pasture classes as the first inventory. In total 625 permanent field sites were established (of which 334 sites were established in 1995–1996) and studied in more detail than in the first inventory. Of these permanent field sites 356 were located on winter range areas and 269 on summer range areas. Field methods, although measuring the same parameters, were improved markedly, both accuracy of GPS measurements and accuracy of lichen biomass. Satellite imagery consisted of three Landsat 5 TM images, nine Landsat 7 ETM images and six Aster scenes, obtained during the years 2000–2006. The classification technique used was based on a semi-unsupervised method, also employed by Johansen and Karlsen (2002) and Johansen (2004). The method starts by masking peat land (organic soils), water and fields, using CORINE (Finnish Environment Institute 2005, 2009) and digital topographical data (vector) from the Finnish National Land Survey. The unsupervised Erdas Imagine classifier starting with 90–120 initial classes, using an iteration parameter of 95 (iteration stops after 95 % of all pixels remains in the same cluster). The unsupervised classifier produces unknown classes, which are identified and clustered according to the classification scheme. Splitting and joining of classes is accomplished using the dendrogram and grouping tools from the Erdas software. All scenes were classified separately as in the first inventory; therefore there was no need for atmospheric correction (Rees and others 2003, Tømmervik and others 2003, 2004). The outcome of the classification produced 18 land cover/pasture classes which conformed to the original 21 of the first inventory. Pine and spruce forest were aggregated into one class, as separation was not very successful. The class 'lichen rich pine forest' was included into the class 'lichen pine forest'. The class 'cloud' was dropped as all cloudy areas were patched producing a cloud free mosaic. The accuracy of both inventories exceeds 82,2%, and is usually in the order of 85% (Table 1.).

Table 1. Accuracy of main pasture classes of the 1995 and 2005 inventories. Note: arboreal lichen pasture is forest classified as mature (age>80).

Accuracy (%)	1995	2005
Ground lichen pastures	87,84%	83,6–93,9%
Arboreal lichen pastures	94,29%	82,2–88,9%
Summer pastures	85,33%	82,9–94,8%
Bare mountain area	100 %	96,0–97,3%

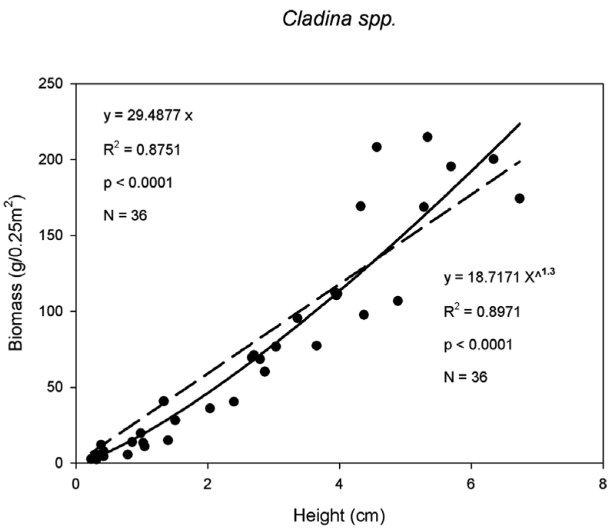

Fig. 2. Biomass regression estimates for northern Finland of all *Cladina* spp. reindeer lichens using the grid mesh method (see Moen and others 2007).

Field inventory methods were updated and improved. GPS accuracy of field sites improved from ±300 m during the first inventory to ±15m in the second inventory, due to the ending of GPS-signal scrambling by the US military in the year 2000. A major improvement of reindeer lichen biomass assessment was the introduction of the non-destructive method described by Moen and others (2007). The method is based upon a 0.5 × 0.5 m frame divided by wires into 25 intersections. The length of the living part of lichens is measured in each intersection. Zero measurements are included in the length data. The average length is calculated and correlates with the lichen biomass of the particular test area. The correlation is obtained from a large set of samples of known biomass. Fig. 2 shows the regression equation for Finland calculated by Kumpula and others (2006). For details on the relation between reindeer lichen biomass and volume see Kumpula and others 2000. The total number of field sites was 625 (Fig. 1), and for every site ten circular (radius 3.99 m) areas were evaluated along a 200 m transect. In every circular test area there was

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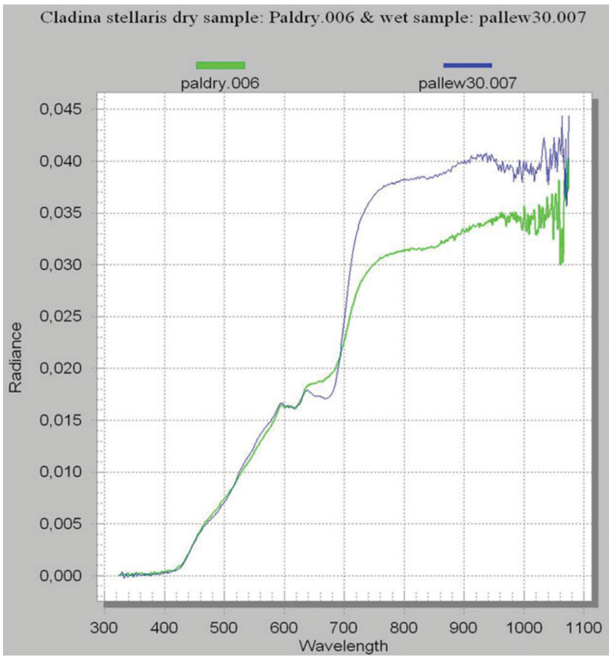

Fig. 3. Reflectance curves of wet (dark line) and dry (grey line) reindeer lichens (*Cladina Stellaris*), (A. Colpaert and T. Kumpula, unpublished results).

one lichen biomass grid, in addition number of trees and abundance of arboreal lichens was measured.

Reindeer lichens are also very susceptible to changes in moisture content. The lichens become dormant during the drying process, shrink, that is their length and diameter decrease, and also the reflectance values change (Fig. 3). Reflectance values for both wet and dry samples were obtained using an ASD FieldSpec handheld Pro spectrometer using the same setup as described by Rees and others (2004). The light incidence angle was 30° and samples were analysed in dry and wet condition. The samples were allowed to absorb moisture for several hours to reactivate the chlorophyll. The measured reflectance spectra are similar than those given by Petzold and Goward (1988) and Rees and others (2004). The effect of moisture however, seems to be more pronounced. Lichen moisture content influences both biomass calculations and classification of remote sensing data. Biomass values obtained in the field during dry conditions were corrected by multiplying the measured length by the factor 1,114 and wet samples by 0,9276 (moist lichen samples being the reference value = 1) (Kumpula and others 2006).

Change detection between separate inventories is not an easy task and in this paper we test a grid based approach versus pixel wise comparison. The grid based approach is implemented in a set of ArcGIS python scripts. First the whole study area is divided into smaller blocks to overcome memory restrictions. Then for each block a 500 × 500 m grid mesh is applied and the total area for each land cover class is calculated for every grid cell. The outcome is a vector shape file with 500 m grid cells containing aggregated data for each land cover class in hectares. All blocks are afterwards joined to produce one vector file for the whole study area. To evaluate results we used the national parks in the area as reference areas, assuming no major fires or other disturbances have occurred.

Results

Pixel wise comparison

Both classifications use the same land use/cover classes and methodology, and first we will make a pixel wise comparison for change detection. Pixel wise means that the areal extent for every land cover/use class is tabulated for the entire study area.

There is a slight difference in land area between the classifications due to the fact that a more precise ancillary data for water bodies was used in RPI 2005. Ground lichen pastures on dry sandy soils, (dry pine forests, dry lichen heather, dry alpine woodland and dry clear cut) have changed +1.5%, which is probably related to the decrease in bare mountain, that is improved classification of mountain areas (Table 2). Old growth, coniferous forests, spruce and pine arboreal lichen pastures have decreased 0.3% which is less than expected, as felling occurs mainly in old growth forests. Forest growth, however, is continuous and during the ten year monitoring period tree gowth compensates for felling losses. Tree growth has accelerated since the 1970s as a response to forestry practices, felling of old and poorly growing forests (Tomppo and others 2005). Also climatic warming has improved growing conditions. Summer pastures and peat land have changed only marginally, differences can be attributed mostly to the use of more accurate ancillary data (peat land mask, digital elevation

Table 2. Pixel wise comparison of classifications of the complete study area. Percentages shown are expressed as proportion of total land area. Note that lichen classes spatially overlap. Note: arboreal lichen pasture is forest classified as mature (age>80).

Class	1995 km^2	2005 km^2	Change km^2	Change % class	1995 %	2005 %	Change % (land area)
Arboreal lichen	16112	15791	−321	−1, 99	29,71	29,42	−0, 29
Ground lichen	11176	11879	703	6, 29	20,61	22,13	1, 53
Summer pasture	25378	25555	177	0, 70	46,79	47,61	0, 82
Peat land	13967	13628	−339	−2, 43	25,75	25,39	−0, 36
Bare mountain	3631	2379	−1252	−34, 48	6,70	4,43	−2, 26
land area	54234	53672	−563	−1, 04			

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Table 3. Pixel wise comparison of classifications of the UKK Park area. Percentages shown are expressed as proportion of total land area. Note that lichen classes spatially overlap.

Class	1995 ha	2005 ha	1995 %	2005 %	Change %
Ground lichen	49501	69201	19.52	27.37	7.85
Arboreal lichen	137848	129482	54.35	51.21	−3.14
Summer pasture	143383	132473	56.53	52.39	−4.14
Peat land	35168	36957	13.87	14.62	0.75
Bare mountain	25587	14235	10.09	5.63	−4.46
Land area	253639	252867			−0.30

model, digital topographical data and CORINE 2000 data).

To verify the observed change between RPI 1995 and 2005 we used the UKK as reference area. The park is situated near the eastern border with Russia, and covers nearly half of the Lappi reindeer herding district. Table 3 shows the results of the analysis; the amplitude of change is much greater, as the area gets smaller the effects of minor differences in accuracy between classes become more important.

The grazing intensity has decreased due to a reduction in the number of reindeer, but the effects are clearly visible in the park. Near the Russian border in the eastern part of the park lichen biomass values are 709 kg/ha, while in the ungrazed fenced border zone biomass is 1884 kg/ha (unpublished measurements 2009). The marked increase in ground lichen pasture (+7.8%) can be attributed partly to the decrease in grazing activity since the 1980s. The amount of all reindeer (adult and calves) during summer in the Lappi reindeer herding district was over 21,000 in 1990, fell below 10,000 in 2000, but rose again to 12,000 in 2008. But clearly an improvement of lichen pastures in the winter range area between 1990 and 2005 is plausible; this is confirmed by field site lichen biomass calculations.

The decrease of arboreal lichen forest, being old growth forest is more difficult to explain. Fire, insect or storm damage occurs only very locally and is of no importance and change in classification methods is a more likely cause. Decrease in bare mountain, summer and arboreal lichen pasture are all most likely due to changes in image processing techniques, although environmental and climatic changes can not entirely be ruled out. It must also be noted that these sparsely vegetated areas are spectrally very similar, leading to confusion between classes. The use of more advanced classification methods and better ancillary data has increased accuracy, especially in the higher areas, which cover most of the park.

The CORINE database

At present two CORINE land cover data sets are available, dating from 2000 and 2006, which can be used to evaluate the findings of the reindeer pasture inventories. The CORINE inventory has a four level classification scheme, and one national implementation that differ slightly from the European version. We used this national version with a 25 metre resolution. The vegetation data has no stand age information, but forests are divided into coniferous, deciduous and mixed forests, again divided into stands on mineral, organic and rocky soils. The CORINE database does not differentiate between dry and mesic vegetation types.

It is clear that the time span between the two inventories is too short to show changes caused by natural forest growth or clear cut regeneration, but rapid changes like clear cuts and increase in infrastructure should be clearly visible. Table 4 shows the cover of the various land cover classes for 2000 and 2006 in the UKK Park. It seems that forest classified as mixed forest in 2000 moved to the coniferous class in 2006. Other classes changed marginally, between one and two percent, which can be attributed to classification variability. The total forest area changed very little between the classifications. For

Table 4. Finnish national CORINE classification CLC 2000 and 2006, UKK park area. Percentages expressed as proportion of total area.

CORINE UKK	2000 ha	%	2006 ha	%	Change %
Coniferous	93495	36.68	120409	47.24	10.56
Deciduous	11317	4.44	6758	2.65	−1.79
Mixed	64741	25.40	36075	14.15	−11.25
Bare ground	1529	0.60	5886	2.31	1.71
Peat	26563	10.42	30728	12.05	1.63
Water	1497	0.59	1349	0.53	−0.06
Open forests	39878	15.64	31016	12.17	−3.47
Heather	15844.50	6.22	22641	8.88	2.66
Infrastructure	32.06	0.01	33.69	0.01	0.00
	254899.19	100.00	254894	100.00	

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Table 5. CORINE classification for the whole study area. Percentages expressed as proportion of total area.

CORINE classes	CL 2000 Km^2	%	CL 2006 Km^2	%	Change %
Coniferous	11937	20.68	18489	32.06	11.38
Deciduous	5922	10.26	3952	6.85	−3.41
Mixed	9325	16.16	4677	8.11	−8.05
Bare ground and rock	85	0.15	1130	1.96	1.81
Peat	9767	16.92	11438	19.83	2.91
Water	3780	6.55	3694	6.41	−0.14
Open forest	11534	19.99	7618	13.21	−6.78
Heather	3841	6.66	6344	11.00	4.34
Infrastructure	198	0.34	231	0.40	0.06
Fields	78	0.14	98	0.17	0.03
Sparse vegetation on mineral land	1205	2.09			
Unknown	40	0.07			
Total	57712	100.0	57672	100.0	

the whole study area the CORINE classification shows the same trends, increase in coniferous and decrease in deciduous and mixed forest stands (Table 5). However, the total amount of forest land is stable, as the CORINE inventory does not distinguish between forest age classes. As with the reindeer pasture inventory changes in classification methodology have introduced an uncertainty component varying from two to three percent.

Grid based comparison

Pixel wise change detection is clearly not very effective if the amount of change is less than the inherent classification error, as error vectors are in different directions producing uncertainty that is very difficult to quantify. Post classification processing techniques like majority filters can improve the product, but error introduced by changes in classification methodology can hardly be removed.

To remove random behaviour of individual pixels and study the internal dynamics of forest development in the study area a grid based method was developed. The raster based data was aggregated into 500 × 500 m vector cells. Grid cells can be classified on the basis of the area of a certain land cover class. By comparing stable reference areas (national parks) and area in use by forestry industry, trends in forest development can be detected. Initial trials comparing parks and normal forestry area showed that the class mature and mixed forest were defined differently, and the mixed class had to be included into the mature forest class. Table 6 shows the results for different thresholds; increasing threshold results in a greater decrease in the amount of area of old growth forest. This indicates clearly that forests inside national parks are stable, and fragmentation does not occur. Old growth forest in areas in use by forestry is diminishing and patch size is decreasing, as the proportion of old growth forest diminished steadily with increasing threshold. Fig. 4 shows the change in old growth forest using a 15 ha threshold. Grid cells with old growth forest exceeding 15 ha have decreased by 6.9%, while the total area decreased by 993 km^2 (10.9 %).

Lichen biomass change

On the district level the calculated lichen biomass decreased statistically significant in 12 districts, in seven districts there was a non significant decrease and only in one district (Lappi) increase was observed, however this was not statistically significant. Fig. 5 shows a kriging interpolation of the biomass data for both the 1995 and 2005 data. The decrease in lichen biomass is clearly visible, the increase in the Lappi area, although not statistically significant is noticeable. The mean value for the all winter pasture field sites of the 20 districts (ground lichen pastures) was 604 kg/ha in 1995 and 290 kg/ha in 2005, standard deviation values were 50 to 90% of the calculated mean values, indicating a high variability. For

Table 6. Statistical information of 500 × 500 grid data using 7.5 and 12.5 ha thresholds for old growth forest in national parks and unprotected forests (other).

Threshold		33.33 % 7.5 ha Park	Other	50 % 12,5 ha Park	Other	75 % 20 ha Park	Other
2005	Total ha	225035	1108129	194308	804323	109336	297460
	Mean	17.2	14.6	19.47	17.8	22.8	22.3
	Median	17.7	13.87	19.8	17.4	22.9	22.3
	SD	5.2	4.8	3.7	3.5	1.5	1.5
1995	Total ha	228352	1170408	196706	886571	114335	389666
	Mean	17.3	15.19	16.6	18.4	22.9	22.6
	Median	17.8	14.56	20	18.12	23.2	22.6
	SD	5.3	5.1	3.8	3.7	1.5	1.5
Change in total area	%	**−1.45**	**−5.32**	**−1.22**	**−9.28**	**−4.37**	**−23.66**

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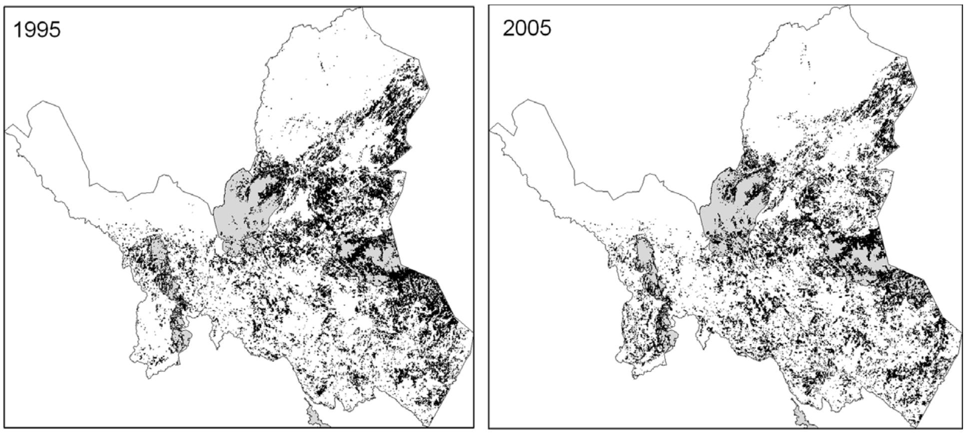

Fig. 4. Amount of grid cells (size 25 ha) containing at least 15 ha of old growth forest, 1995 N = 45455, total 9094 km^2, 2005 N = 42312, total 8101 km^2.

the Lappi district the values were 420 kg/ha SD = 260 and 827 kg/ha SD = 747, the high SD value indicates considerable uncertainty. The decrease in lichen biomass seems to be true for most of the whole study area, although high spatial variation between filed sites is evident.

Field site measurements (Fig. 5) show a marked decrease in ground lichen biomass. However, the classification results show an increase of lichen pastures by +1.5% for the whole study area and +7.8% for the UKK reference area. Clearly an improvement of lichen pastures in the UKK park between 1990 and 2005 is plausible; this is confirmed by field site lichen biomass interpolations shown in Fig. 5. But for the whole area this is less evident, and even if the area has slightly extended the quality of the lichen pastures has decreased.

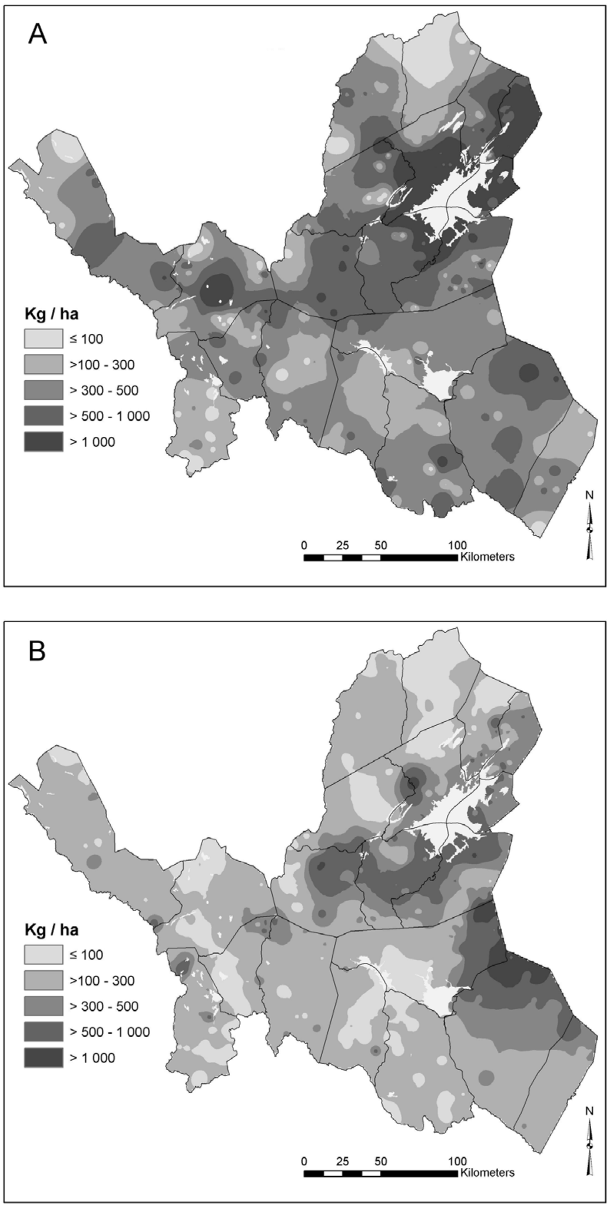

Fig. 5. Kriging interpolation of ground lichen biomass 1995 (A) and 2005 (B).

Discussion

During the period 1995–2005 no fires, storm or insect damage of any significance have occurred in the UKK Park (Sakari Kannkaanpää, personal communication, 14 December 2010). Therefore it can be assumed that no substantial changes in forest stands have occurred during the period 1995 – 2005, and most observed change between separate inventories must be caused by classification error.

A comparison with the traditional vegetation inventory made by Metsähallitus in 1996–1998 (MHGIS) gives a possibility to compare satellite based and conventional vegetation mapping data. We compare the MHGIS data with the latest CORINE and reindeer pasture inventories, as these are probably the most accurate (CLC 2006 and RPI 2005 classifications).

Water areas in the MHGIS total 2050 ha, in the CORINE 1349 ha and the RPI 2022 ha. Peat land (mires, fens pine bogs) MHGIS 38201 ha, CORINE 30728 ha and the RPI 36957 ha. Bare areas (bare rock and sand) MHGIS 7129 ha CORINE 5886 ha and the RPI 14235 ha. Water and peat land areas show a very good correlation between MHGIS and our reindeer pasture inventory. Bare

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areas show that the reindeer pasture inventory indicates twice the amount of MHGIS, most likely because it also includes areas classified as scarcely vegetated areas in MHGIS. Heather totals 65717 ha for MHGIS, 22641 ha for CORINE 2006 and 21622 ha for the reindeer pasture inventory. The MHGIS class bare mountain is obviously not identical to the heather class in the RPI or the CORINE classifications, it evidently contains all open areas above the tree line. Coniferous forests in the MHGIS total 138138 ha, 156484 ha for the CORINE (coniferous + mixed) and 144955 ha for the reindeer pasture inventory, old growth forest (age > 80) MHGIS 111676 and RPI 129482 ha (no data for CORINE on stand age). Ground lichen pastures MHGIS 15186 and RPI 69201 ha, here the MHGIS gives no adequate data for treeless mountain area. Summer pastures (all mesic and sub-mesic areas) MHGIS 126531 and RPI 1326473 ha. Deciduous forest stands comprise 3579 ha in the MHGIS, 6758 ha in CORINE and 2954 ha in the reindeer pasture inventory. Although difficult to compare satellite image based classifications with conventional vegetation inventories, these figures show a fair correlation between the MHGIS and the RPI classification.

It is clear that even with fairly accurate classifications (overall accuracy>85%) there are substantial changes between spatial properties of land use/cover classes. Change detection error is difficult to quantify, but is certainly greater than the individual uncertainty of the separate classifications. Change detection between forest and clear cut is relatively easy, but subtle changes of greening of bare mountain areas, changes in lichen cover and vegetation succession are difficult to quantify on a time span of only ten years. Clearly the 0.3% decrease in old growth (arboreal lichen) forest for the whole study area is underestimating the effect of felling by forest industry, and obviously this figure refers to mature coniferous forests (age > 80), not real old growth forest (age > 140). For the 'stable' national park area the present study showed a fair amount of 'random variation', clearly inherent to changes in classification process and satellite instruments. Therefore changes indicated by overlaying separate classifications have to be evaluated with caution.

The grid based approach removes part of the 'noise' and reveals the increasing fragmentation of forests in the study area. The average and median values (ha per grid cell) of old growth forest patches area significantly larger for park areas than those forests outside the parks. For a threshold of 7.5 ha, the mean value for park forests is slightly over 17 ha, while in other areas it is 14.5 to 15 ha. Change between 1995 and 2005 within the park areas is only −1.4% but outside the parks −5.3%, this difference increases with increasing threshold (Table 6).

The decrease in bare mountain area is interesting and noted also in oteher parts of Fennoscandia. Tømmervik and others (2004) noted that climatic changes and changes in grazing pressure have significant impact upon vegetation. Although Karlssen and others (2009) did not report any increase of the length of growing season for the study area since 1982, climatic warming is still evident. According to the Finnish Meteorological Institute (2011) the mean annual temperature has increased two degrees Celsius since 1980 (Sodankylä station). Climatic change therefore, can be a cause for the reduction of bare mountain areas, i.e. a greening effect (Karlsen and others 2009).

Conclusions

When evaluating change by comparing separate satellite land use/cover classifications it must be noted that much 'noise' is introduced by minor changes in image processing methodology and data sources. These changes include:

- change in satellite imagery data, and changes in instrument
- changes in computer hardware
- changes in processing software (algorithms)
- changes in field inventory techniques
- changes in processing methodology
- changes in ancillary data
- changes in staff (experience, bias).

All these changes introduce minute differences that produce minor changes in classification accuracy and direction of error vectors. This will influence the outcome of change detection analysis, and this error is very difficult to quantify by any means. To secure reliable and consistent information about land use/cover change the temporal frame should be considerable, and is related to the rate of change, slow change will need a longer recurrence time than phenomena with a faster change rate.

In the pixel wise comparison the clear cutting of forest is barely noticeable for the whole area, as regeneration and cutting are in equilibrium. Also changes in other land use/cover classes are marginal and can be attributed to variability in image processing methodology. Both the reindeer pasture and the CORINE inventory indicate that there are only marginal changes, which are mostly due to data error. Comparison of different inventories is difficult due to the differences in class definitions and specific objectives of the classification schemes. Mixed forest seems to be a problem for both RPI and CORINE classification, and should be treated as coniferous. The results of grid analysis show the decrease in mature and old growth forests outside national park areas. For the 7.5 ha threshold the area decreases 5% and with a 20 ha threshold, 24 %. Patch size of old growth forest outside national park areas is also decreasing, indicated by the decrease in mean and median values of the patch size, showing ongoing fragmentation. This is possibly the result of felling practices that nowadays treat relatively small areas. Lichen biomass seems to decrease steadily in the winter pastures of the study area, with one exception, the Lappi herding district.

The two most important issues for reindeer management in the near future seem to be the organising of functional pasture rotation schemes, maintaining a sufficient amount of old growth forest (arboreal and ground lichens) and setting more sustainable numbers of the maximum size of reindeer herds.

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