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LICHEN COVER MAPPING IN SOUTHERN NORWAY – AN ANALYSIS WITH REMOTE SENSING AND GIS

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Abstract: Monitoring lichen-rich vegetation types in central and northern Norway during the last decades has revealed a significant decrease of lichen cover over space and time. The possible reason for such a sharp decline could be the simultaneously increasing populations of reindeer. Despite this ongoing development, little knowledge exists about the extent and development of lichen cover in southern Norway. Our research presents a multi-scale approach for mapping lichen cover, aiming at deducing accurate spatial information on lichen cover and change to improve understanding of reindeer-lichen interactions and knowledge about state and condition of lichen cover in southern Norway. The multi-resolution analysis is based on very high-resolution field data (0.3 m) and aerial photos (0.5 m), high-resolution Landsat satellite imagery (30 m) and medium-resolution MODIS datasets (250 m; 500 m). Field data of two study areas in southern Norway was used for method calibration and validation. We applied a non-parametric Random Forest regression trees approach for multi-scale mapping of lichen cover. Further, we conducted Normalized Differenced Vegetation Index (NDVI) time series analysis, based on MODIS NDVI datasets (250 m). Mann-Kendall non-parametric trend test detected significant trends in vegetation change. Hotspots of lichen cover were overlaid with NDVI trends. During the first up-scaling to the resolution of the aerial photos (0.5 m) the Random Forest regression model showed R^2 of 0.51 and a Mean Square Error (MSE) of 0.04. Up-scaling to Landsat data (30 m) displayed R^2 of 0.7 and a MSE of < 0.01. Further up-scaling to MODIS level (500 m) showed R^2 of 0.86 and a MSE of < 0.01. Classification of the resulting prediction map displayed 15.6% of the area as covered by lichens by less than 20% and 7.6% of the area is covered by lichen by more than 40%. Mann-Kendall test revealed that 19.3% of the area in which lichen vegetation is expected, show significant negative vegetation trends. Significant positive vegetation trends appeared in 5% of the area. Overlapping NDVI trends with predicted lichen vegetation structures show increasing vegetation trends as occurring parallel to >40% predicted lichen vegetation per pixel in 19.4% of the area, majorly on higher elevations. The multi-scale approach, as applied in this study, allowed mapping lichen cover at multiple spatial scales. This approach has the potential to monitor vegetation cover not only in arctic-alpine but also in other landscapes.

Keywords: Random forest regression, Mann-Kendall, arctic-alpine vegetation, lichen, reindeer

KARTIERUNG DER FLECHTENBEDECKUNG IN SÜDNORWEGEN – EINE FERNERKUNDUNGS- UND GIS-BASIERTE ANALYSE

Zusammenfassung: Während der letzten Jahrzehnte konnte eine starke Abnahme von Flechtenvegetation in Zentral- und Nordnorwegen verzeichnet werden. Möglicher Grund für diesen Rückgang sind die gleichzeitig ansteigenden Rentierpopulationen. Im Gegensatz zu dem Trend in Zentral- und Nordnorwegen existiert wenig Wissen über Zustand und Entwicklung flechtenreicher Vegetation in Südnorwegen. Unser Ansatz präsentiert eine multiskalare Analyse zur Kartierung von Flechtenbewuchs in Südnorwegen, abzielend auf ein besseres Verständnis komplexer Interaktionen zwischen Rentieren und Flechten. Die Analyse basiert auf sehr hoch aufgelösten Felddaten (0.3 m) und Luftbildern (0.5 m), hoch aufgelösten Landsat-Satellitenbildern (30 m) sowie MODIS-Datensätzen (250 m, 500 m). Felddaten aus zwei Untersuchungsgebieten in Südnorwegen dienen der Kalibrierung und Validierung der Methode. Die multiskalare Kartierung von Flechtenvegetation erfolgt mittels nichtparametrischer Random-Forest-Regressionsbäume. Eine NDVI-Zeitreihenanalyse, basierend auf MODIS-Datensätzen (250 m), sowie ein nichtparametrischer Mann-Kendall-Test eruiert signifikante NDVI-Trends. Hotspots von Flechtenvegetation werden mit NDVI-Trends überlagert. Während der ersten Hochskalierung auf die Auflösung der Luftbilder (0.5 m) zeigte das Random-Forest-Regressionsmodell ein R^2 von 0.51 und eine mittlere quadratische Abweichung (MSE) von 0.04. Die Hochskalierung zu Landsat (30 m) gab ein R^2 von 0.7 und einen MSE von < 0.01 wieder. Hochskalieren auf die Auflösung von MODIS (500 m) präsentierte ein R^2 von 0.86 und einen MSE von < 0.01. Die Klassifizierung der daraus resultierenden Prognosekarte visualisierte 15.6% der Fläche als weniger als 20% von Flechten bedeckt und 7.6% der Fläche zu mehr als 40% von Flechten bedeckt. Der Mann-Kendall-Test präsentierte für 19.3% der Fläche, in welcher Flechtenvegetation angenommen werden kann, signifikant negative Vegetationstrends. Signifikant positive Vegetationstrends traten in 5% der Fläche auf. Sich überlagernde positive NDVI-Trends und prognostizierte Flechtenvegetation in über 40% der Fläche sind in 19.4% des Untersuchungsgebiets zu verzeichnen. Der multiskalare Ansatz dieser Studie erlaubte die Kartierung von Flechtenvegetation auf

verschiedenen räumlichen Skalen. Mit dem vorgestellten Ansatz können potenziell auch andere Landschaften auf verschiedenen Maßstabsebenen kartiert werden.

Schlüsselwörter: Random-Forest-Regression, Mann-Kendall, arktisch-alpine Vegetation, Flechten, Rentiere

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1 Introduction

Reindeer herding is a form of land use in Fennoscandia, taking up about 40% of the total land area (Tyler et al. 2007). Reindeer *(Rangifer tarandus)* have a high significance in Norway, ecologically as well as culturally and economically (Pape & Löffler 2012). Further, reindeer husbandry is strongly integrated into the socio-cultural identity of the Sámi, the indigenous people inhabiting arctic areas of Finland, Norway, Sweden and Russia. Also, it is an important branch of the Scandinavian economy. Availability of well-conditioned ranges affects body weight, calf production and mortality of wild and (semi-)domesticated reindeer. To meet demands, such as survival, reproduction and nutrition, the animals rely on the access to natural pastures (Pape & Löffler 2015). Being an important fodder resource during winter, the quantity and

Data	Spatial Resolution	Date	Role
Field Data Filefjell	0.3 m	August, 2010	Input Data for random forest regression
Field Data Vågå	0.3 m	July/August, 2010	Input Data for random forest regression
Norge i Bilder	0.5 m	Hedmark Nord 2009 Sogn 2010	Upscale
Landsat L4-5TM	30 m	05.09.2010	Upscale
MODIS MOD09A1	500 m	29.08.2010	Upscale
MODIS MOD13Q1	250 m	01.07.2000 – 01.09.2016	NDVI Trend Analysis

Table 1: Data types used for the multi-scale analysis

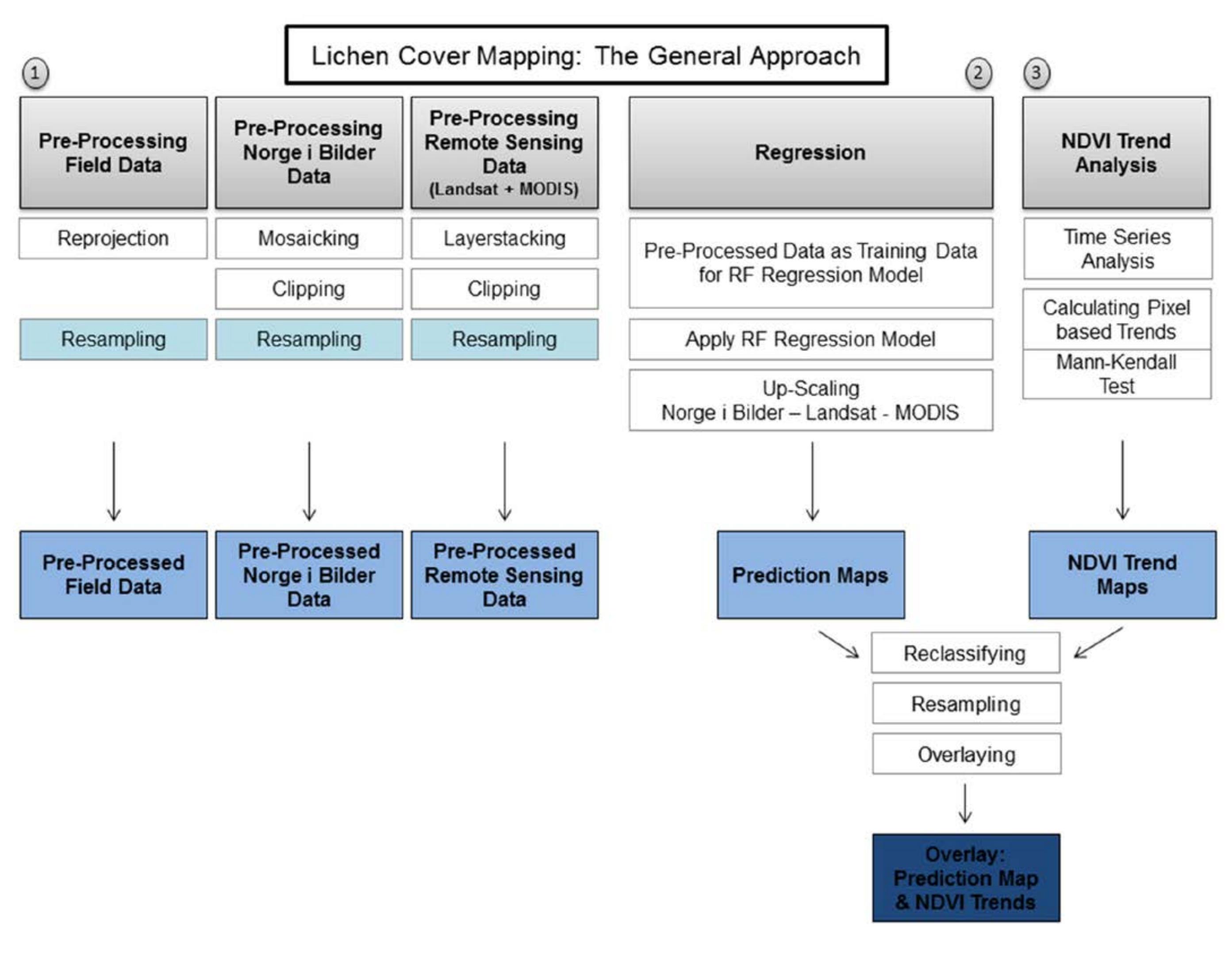

Figure 1: Lichen cover mapping in Southern Norway: The general approach

quality of lichen mats is, therefore, very important, economically as well as environmentally (Kumpula et al. 2000). Reportedly, lichen cover declined strongly across northern Norway during the last decades (e.g. Johansen & Karlsen 2005, Kumpula 2001). Many studies relate this trend to the simultaneously increasing populations of reindeer for this development (e.g. Kumpula et al. 2000, Bernes et al. 2015). Increasing reindeer stock sizes are assumed to jeopardize the satisfaction of the animal's needs. Natural fluctuations due to variances in reproduction and mortality and also slaughtering every year might weaken these threads, but statistics show a distinct increase in reindeer numbers since the 1940s (Bernes et al. 2015). Nowadays, approximately 250.000 herd animals live in Norway, the majority of them in Finnmark (Statsministerens Kontor 2015). According to Johansen & Karlsen (2005) lichen occurrence within reindeer districts in Finnmark among 1973 and 2000 has declined from more than 30% to less than 7% within winter districts and from more than 15% to less than 1% within spring and autumn districts. Traditionally reindeer herding in Finnmark has been managed in balance with the availability of natural resources, but management changed to being more profit-orientated (Johansen & Karlsen 2005). Today, increasing population sizes are seen as an environmental problem with potential cascade effects. Migrations between summer and winter pastures can be a tool to give the fragile pastures the chance to recover. Herders are trying to avoid lichen-rich areas during the drier summer to protect them from damages (Rees et al. 2008).

Despite the ongoing development in northern Norway, little knowledge exists

Vågå and Filefjell (2010)		
Norge i Bilder	R^2	0.51
	MSE	0.04
Landsat	R^2	0.70
	MSE	0.01
MODIS	R^2	0.86
	MSE	<0.01

Table 2: R^2 and MSE of RF regression for Norge i Bilder, Landsat and MODIS for 2010

about the extent and development of lichen cover in southern Norway. The analysis of the state and condition of lichen cover is supposed to reveal new information about the relationship between pasturing and the decline of lichen cover and bring about new knowledge regarding the situation not only in northern, but also in southern Norway. Our research presents a multi-scale approach for mapping lichen cover, aiming at derivation of accurate spatial information on lichen cover and cover change to improve understanding of reindeer-lichen interactions and knowledge about state and condition of lichen cover in southern Norway. The study is based on field data recorded in two different study areas as well as on different types of remote sensing data. Accordingly, the following research questions arise:

- Does the state of lichen cover in southern Norway differ from the one in northern Norway and how is reindeer herding correlated with this situation?
- Are remote sensing and GIS techniques appropriate tools for mapping lichen cover in arctic-alpine ecosystems?

Whilst reindeer stock sizes in northern Norway multiplied within the last decades, reindeer population sizes in southern Norway have been more stable. Referring to less mechanical damage by trampling and grazing, we expect the fragile lichen vegetation in Southern Norway to be less threatened compared to the one in North-Norway.

2 STUDY AREA

We base our analysis on field data from two study areas, both located in southern Norway. For a better understanding of the impact of reindeer grazing on lichen vegetation, we chose two areas with different grazing intensities: One ungrazed site (Vågå) and one site grazed by reindeer (Filefjell). Vågå covers an area of approximately 420 km² and is located within the low alpine belt of southern Norway, showing mountainous topography. The continental climate of this region leads to low annual precipitation of about 300 – 650 mm in the valleys. Environmental factors such as soil types, evapotranspiration, snow accumulation or insulation differ along fine-scale topographical gradients, resulting in locally varying vegetation types (Löffler 2004). Filefjell Reinlag is the southernmost reindeer husbandry unit in Norway with ranges covering an area of approximately 2,000 km² (Reindriftsforvaltningen 2016). Reindeer ranges are distinguished between summer pastures and winter pastures. Herds mainly follow natural seasonal migration patterns, changing their grazing grounds from summer to winter ranges (Benjaminsen et al. 2015). Whilst the summer pastures are located within the northwestern part of Filefjell Reinlag at high elevations around 740 and 1,978 m above sea level, winter pastures can be found in the southeastern part at low elevations between 140 and 1,290 m above sea level (Pape & Löffler 2015). A closer look at the development of the reindeer population size during the last decade reveals that the number of reindeer has been stable at about 3,000 animals, ranging from a minimum of 2,899 animals in 2006/07 up to a maximum of 3,424 animals in 2013/14. In the following seasons the number of animals decreased slightly down to 3,182 animals in 2015/16 (Reindriftsforvaltningen 2016).

3 MATERIAL AND METHODS

3.1 DATA

Published research on reindeer-lichen interactions shows that remote sensing techniques are appropriate tools for detecting land cover change (e.g. Falldorf et al. 2014, Théau & Duguay 2004, MAS 1999, Tømmervik & Lauknes 1987). Field data for Vågå was collected during July and August 2010, field data for Filefjell during August 2010. The plots themselves are chosen as representatives for the local-

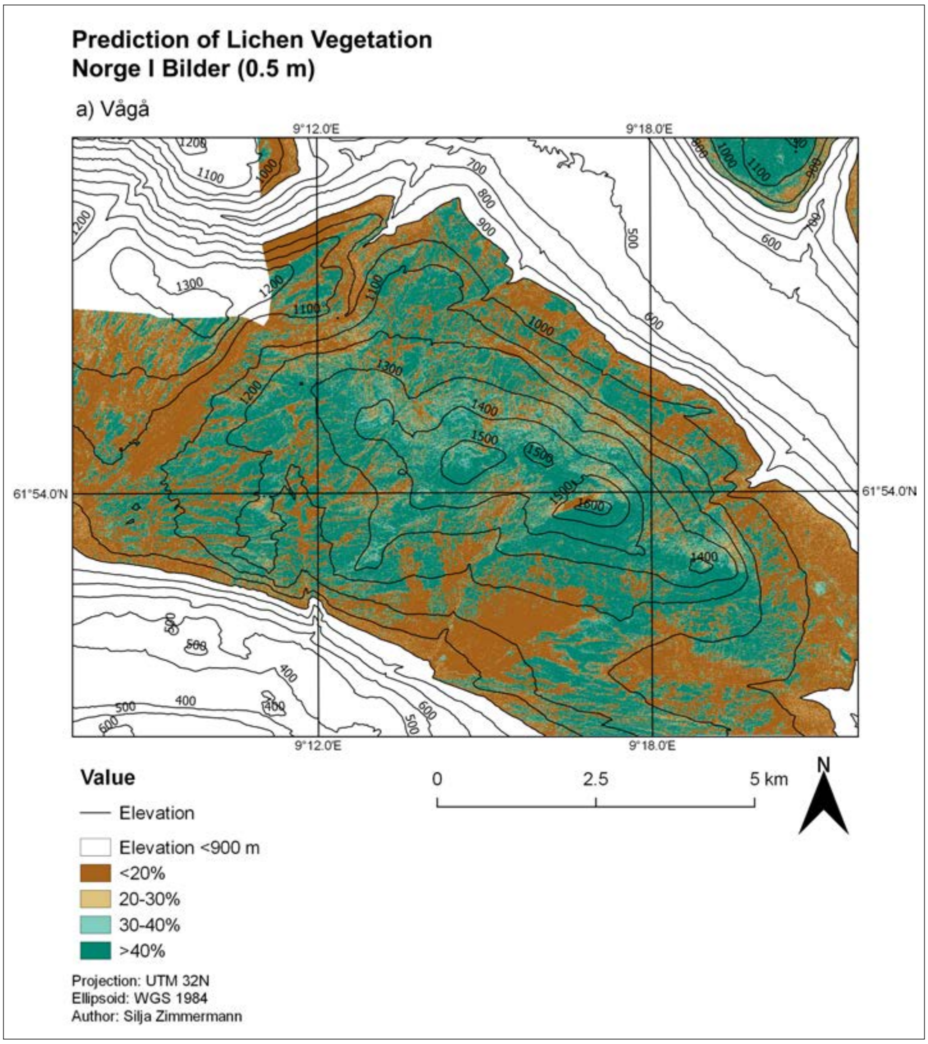

Figure 2: Prediction of Lichen Vegetation based on 2010 field data for Vågå in southern Norway. Upscaling from resolution of field data (0.3 m) to resolution of Norge i Bilder data (0.5 m) using RF regression, a machine learning approach programmed in R. Percentage area covered with lichen vegetation per pixel is visualized.

ly varying characteristics of the Vågå and Filefjell area. The "Point-Intercept Method" was used for the acquisition of this data. Within a sampling plot with a fixed grid pattern of 30x30 cm size, 30 pins are inserted vertically, one through each grid point. At each pin-point the species, vegetation type or ground cover which intersect the point are recorded as hits. Information about 114 sampling plots in Vågå and about 65 sampling plots in Filefjell is available. Exact coordinates (UTM Zone 32N) and elevation are given for each of these sampling plots. Within these plots all plant species are identified and further organized into categories. Plant species are therefore categorized as deciduous woody plants, evergreen woody plants, herbaceous plants, grasslike plants, mosses, lichens or lycophytes. Lichen cover in % was calculated using the following equation:

lichen cover (in %) = (#*hits lichen species* ÷ *total #points*) · 100

Additionally, three different levels of remote sensing data are used. "Norge i Bilder" is a venture realized in collaboration between the Norwegian Road Administration, the Norwegian Institute for Bioeconomy (NIBIO) and the Norwegian Mapping Authority (Norge i Bilder 2017). The website offers orthophotos of Norway from a wide range of different projects for digital download. Further, Landsat and MODIS tiles are used for up-scaling. Table 1 lists all types of data, which are used in the analysis. To ensure best comparability between datasets we took remote sensing data that were taken as close as possible to the acquisition date of the field data. Field data as well as the remote sensing datasets are processed within QGIS (Quantum GIS Development Team 2017), ArcMap (ESRI 2017) and ENVI (Exelis Visual Information Solutions 2017). All data is then further calculated in R (R Core Team 2017). To conduct an NDVI time series analysis, numerous NDVI datasets are needed. To include only as uniformly distributed data as possible, all datasets between the 1st of July and the 30th of September for 2000 – 2016 were taken into account. MODIS satellites derive one dataset every 1 – 2 days with a re-visit every 16 days.

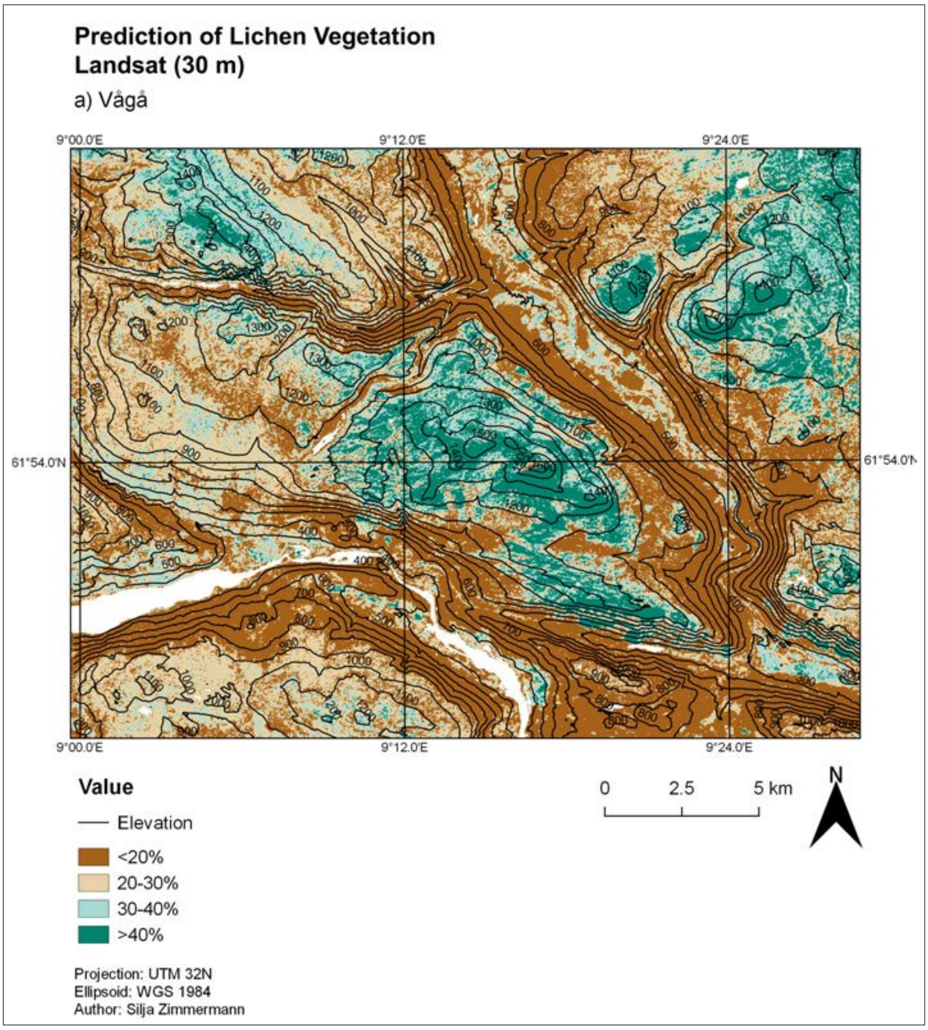

Figure 3: Prediction of Lichen Vegetation for Vågå based on 2010 field data from two study areas (a) Vågå and b) Filefjell) in southern Norway. Up-scaling from resolution of Norge i Bilder (0.5 m) to resolution of Landsat data (30 m) using RF regression, a machine learning approach programmed in R. Percentage area covered with lichen vegetation per pixel is visualized.

Landsat data was downloaded via USGS Global Visualisation Viewer (GLOVIS). Regarding the acquisition dates of the other datasets, Landsat satellite imagery was chosen which was nearest to the acquisition dates of the other remote sensing and field datasets. Due to a minimum amount of cloud cover and other disturbances within the image, Landsat L4-5 TM satellite imagery, dated in September 2010 was picked. Minimum cloud and snow cover are needed for minimizing disturbances and misclassifications. Pre-processing of the data further aimed at minimizing disturbances and ensuring comparability between different datasets. Pre-processed data was then ready-to-use as input data for the random forest regression model. Reprojection of the data using GIS software ensured every input layer as being geo-referenced based on the same coordinate system. All input imageries were reprojected to the UTM 32N coordinate system. The red, green and blue bands of Norge i Bilder images were used to gather further information on the structural properties of the land surface. Based on these, focal means, standard deviations and Visible Vegetation Index (VVI) were calculated, to distinguish between vegetated and non-vegetated surfaces. Out of all seven bands, a Layerstack was created and transformed into a True Color Composite (TCC). The data was available as Level 1T product (standard terrain correction; systematic radiometric and geometric correction); hence atmospheric correction of Landsat imagery was not needed. Via MRT Web Tool, MODIS tiles were available as Level 3 products and consequently ready for use in GIS software. Again, a layerstack of all bands was created and displayed as True Color Composite (TCC).

3.2 METHODS

We derived lichen cover maps using a multi-scale analysis, based on a Random Forest (RF) regression approach, with remote sensing data and GIS. Random Forests are a combination of various tree predictors, with each tree "depending on the values of a random vector, sampled independently and with the same distribution for all trees in the forest" (Breiman 2001, p. 5). Within this study, RF regression was used as a tool to detect lichen-rich vegetation types by investigating the percentage area covered by lichen vegetation per pixel. The regression approach derived information of every pixel and linked its spectral information and values to semantic information. Processed field data, Norge i Bilder and remote sensing data were used as input data for the model. High-resolution field data was used as training data for the model and further aggregated to the resolution of Norge i Bilder images. Resulting from this, the model provided lichen cover values with 0.5 m resolution. The regression model was further applied to the second up-scaling using Landsat and to the third level using MODIS products. Lichen cover (as the dependent variable), was estimated by means of multiple remote sensing metrics (as independent variables). Test runs displayed increasing accuracy with increasing ensemble size but stabilized at some point at which around 500 trees were included. Within the procedure of bagging, an internal validation ("out-of-bag") on a training set including 75% of the data samples was made. An external test contained the remaining 25% of the data samples. For accuracy assessment of the validation, R^2 and Mean Standard Error (MSE) were calculated for each up-scale. The random forest models were run with R 3.3.2 (R Core Team 2017) by using the package randomForest (Liaw & Werner 2002) and biganalytics (Emerson & Kane 2016). Figure 1 displays the general approach for lichen cover mapping in southern Norway incrementally. Within the first step, all input datasets were pre-processed. Field data was reprojected and Norge i Bilder datasets were mosaicked and clipped to the extent of the study areas. Layerstacks of all bands of the Landsat and MODIS tiles were created and clipped. In the following, a machine learning approach was used to detect lichen-rich vegetation types within the area of interest. A Random Forest (RF) regression model for the first up-scale from the resolution of field data (0.3 m) to the spatial resolution of Norge i Bilder data (0.5 m) was created. Information of the field data was linked to the respective pixel of the Norge i Bilder dataset. Based on this, a prediction map for the Norge i Bilder dataset, showing the percentage area covered with lichen vegetation per pixel was generated. The dataset was resampled using bilinear interpolation and a RF regression model for the second up-scale, based on pre-processed Landsat satellite imagery, was created and applied. The resulting dataset was resampled using bilinear interpolation again and linked to the information of the pre-processed MODIS tile. An RF regression model for the last up-scale from the resolution of Landsat (30 m) to the resolution of MODIS (500 m) was applied. A prediction map, showing the percentage area covered with lichen vegetation on MODIS level, digitized the final output of the RF regression approach.

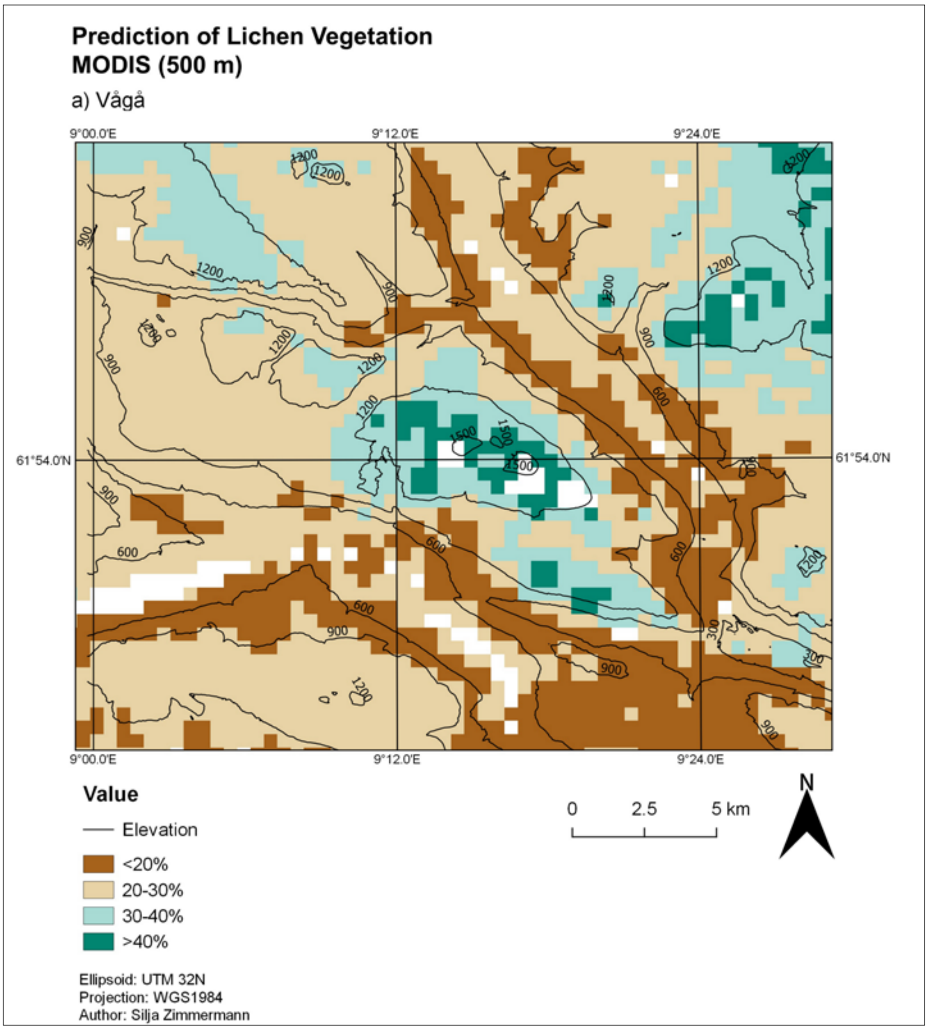

Figure 4: Prediction of Lichen Vegetation for Vågå based on 2010 field data from two study areas (a) Vågå and b) Filefjell) in southern Norway. Up-scaling from resolution of Landsat (30 m) to resolution of MODIS data (500 m) using RF regression, a machine learning approach programmed in R. Percentage area covered with lichen vegetation per pixel is visualized.

The Normalized Differenced Vegetation Index (NDVI) was calculated for a distinct time span, based on MODIS NDVI imagery. NDVI time series analysis over a 17-year period was programmed in R using the packages "timeSeries" (Rmetrics Core Team et al. 2015) and "Kendall" (McLeod 2011). Time series of MODIS NDVI with a spatial resolution of 250 m, summed over the summer seasons of 2000 – 2016, were used to derive vegetation trends within the study area. Further, the Mann-Kendall test was applied to the processed time series to detect significant trends in the vegetation composition (tested against an alpha-level of 0.1). The Mann-Kendall trend test estimates the presence of a monotonic single direction trend in the time series and is often used in vegetation studies (Tüshaus et al. 2014). Kendalls *Tau* statistic is shown by *Tau*, which ranges from −1 to +1 and reflects the direction of the trend. A steady negative trend would be indicated by −1, whereas +1 would display a consistent positive trend. A *Tau* value of 0 would represent no trend. Following Johansen (2009), NDVI trend was analyzed for all pixels in which lichen vegetation was recorded. Accordingly, pixels not belonging to classes "Exposed Ridge Tops: Bedrock, Debris", "Ridge Top: Graminoids", "Ridge Top: Dwarf Shrub Dominated" and "Lichen Heath" were masked to minimize potential misclassifications. Finally, the prediction map for lichen vegetation on MODIS level and the NDVI vegetation trend map, were reclassified, resampled and overlaid with each other, aiming at detecting hotspot areas of changing lichen vegetation.

4 RESULTS AND DISCUSSION

The prediction based on combined field data of both study areas, revealed the best results. Accuracy of these results is related to two factors: The highest amount of ground-truth data, as well as the availability of high resolution Norge i Bilder datasets (0.5 m). Table 2 lists the calculated R^2s and Mean Square Errors (MSE) for each model. The model is run with 500 regression trees. Our calculations showed that R^2 was increasing with the number of trees used by the model, while MSE was decreasing concurrently. To validate the model and assess its overall performance, field data samples were randomly divided into training samples (75%) and validation samples (25%). The validation results showed coherence of the accuracy of the predicted data and the scope of available field data.

The prediction maps, as the main output of the RF regression, are visualized in the following, taking Vågå as an example. Lichen vegetation with less than 20% is shown by brownish patterns, beige patterns indicate pixels with 20 – 30% predicted lichen vegetation. Light green patterns show areas with 30 – 40% lichen cover and dark green patterns refer to more than 40% lichen vegetation. Figure 2 illustrates the prediction of lichen vegetation for the resolution of Norge i Bilder (0.5 m) for a) Vågå. Figure 3 and Figure 4 show the prediction maps for a) Vågå for the second and third up-scale to the resolution of Landsat (30 m) and MODIS (500 m). Figure 5 images the prediction of lichen vegetation for the resolution of MODIS satellite imagery (500 m) for the whole area of interest. Statistical evaluation of the prediction map in Figure 5 on MODIS level showed a maximum value of 52.9% lichen cover, a minimum value of 17.2% lichen cover and 26.2% lichen cover as a mean value. Standard deviation is 7.3%. The analysis revealed the presence of lichen cover as strongly correlated with the elevation of the perspective area. Whereas in the valleys lichen cover is mainly about 20 – 30% per pixel, lichen cover ascends up to more than 40% per pixel in higher elevations.

Visualized NDVI vegetation trends, for pixels in which lichen vegetation is assumed to appear according to Johansen (2009), are the main output of the NDVI trend analysis based on the 2000 – 2016 time-series of 250 m resolution MODIS vegetation indices. Figure 6 shows the trends for lichen vegetation according to the Mann-Kendall correlation coefficient *Tau* for Vågå in detail, whereas Figure 7 illustrates Mann-Kendall *Tau* for the whole area of interest. *Tau* ranges from −1 to +1 with values of −1 indicating continual negative and values of +1 indicating stable positive vegetation trends. Values of 0 indicate no trend. The range of Mann-Kendall *Tau* is shown by means of a gradient, bearing from red, referring to low values to green, showing high values. Spatial statistics of the NDVI trends based on Mann-Kendall *Tau* show negative vegetation trends for 42.9% of the area and positive vegetation trends for 56.1% of the area. 1.0% of the area shows no trend.

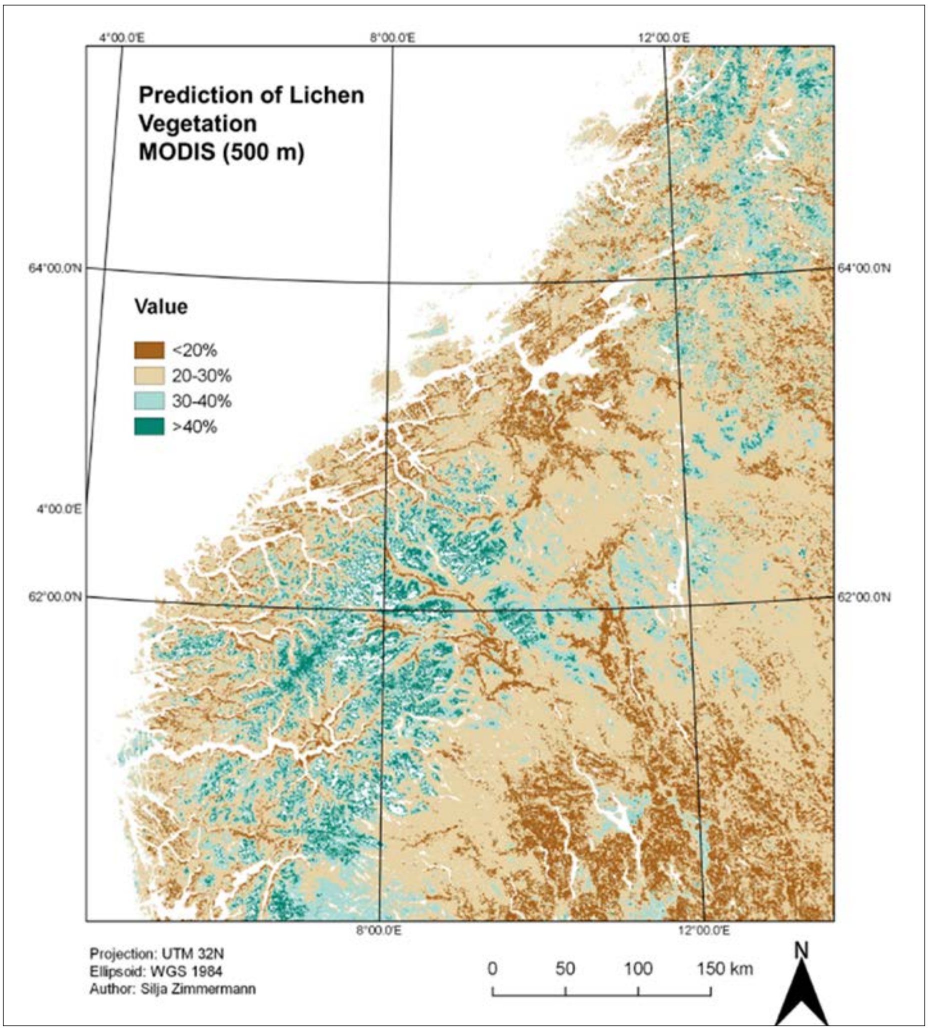

Figure 5: Prediction of Lichen Vegetation based on 2010 field data from two study areas (a) Vågå and b) Filefjell) in southern Norway. Up-scaling to MODIS resolution (500 m) based on Norge I Bilder and Landsat satellite imagery using RF regression, a machine learning regression approach programmed in R. Percentage area covered with lichen vegetation per pixel is visualized.

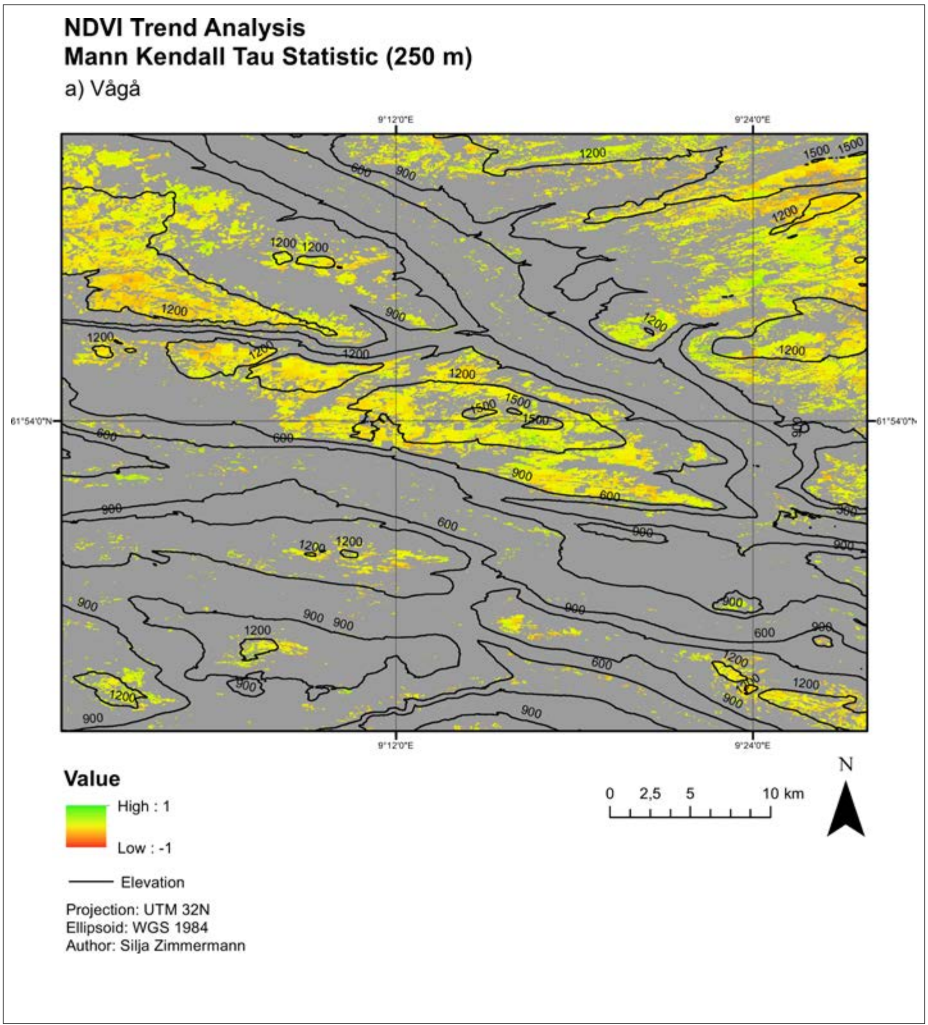

Figure 6: Lichen vegetation trend map for Vågå, based on 2000 – 2016 time-series of 250 m resolution MODIS vegetation indices. Mann-Kendall Tau ranges from –1 to +1, indicating the respective negative or positive vegetation trends. Pixels in which lichen vegetation is assumed to appear according to Johansen (2009) are shown.

Significant negative vegetation trends were detected within 19.3% of the area of interest, whereas only 5.0% of the area indicates significant positive NDVI trends (Table 3). A closer look at the study areas in specific reveal only 0.2% significant negative and 1.1% significant positive vegetation trends for Vågå. In the area of *Filefjell*, 0.6% significant negative and 2.1% significant positive trends could be detected. In comparison to the situation in northern Norway, lichen vegetation seems to be less affected by degradation in southern Norway. The possible reason for such a situation in southern Norway might be more stable reindeer-lichen interactions. Whereas reindeer stock sizes increased enormously in northern Norway, reindeer population sizes in southern Norway remained stable, not leading to excessive damages caused by grazing and trampling.

A high number of field data samples to validate the underlying model, as well as high-resolution remote sensing data as a first input dataset are highly relevant. The quality of the models increases and uncertainties decrease with the number of field data samples used for calibration and with the resolution of the remote sensing data on the first remote sensing spatial scale. Field data samples should further represent vegetation composition at all elevations. Considerable information loss due to up-scaling to coarser resolutions (MODIS 500 m) is unavoidable and needs to be taken into consideration. Misclassifications might appear within the time-series analysis of NDVI vegetation trends as spectral reflectance of plants and other types of land cover is influenced by various factors. Even though lichens show high spectral separability, other forms of vegetation may produce NDVI values, which lead onto misinterpretations (Petzold & Goward 1988). MODIS datasets are only available since 2000. Therefore, the time-series analysis in this study covers only the period from 2000 – 2016. Additionally, the Mann-Kendall non-parametric test, which has been used to assess the significance of the vegetation trends, needs to be reassessed critically, as some vegetation trends could have been neglected. For each pixel, trends were calculated. By calculating the significance of vegetation trends with $p < 0.1$, vegetation trends might be excluded which did not show completely consistent trends over the whole time span. Also vegetation, which showed consistent negative or positive NDVI trends but were not sufficiently distinctive might have been excluded with this approach. Future work on the topic should include more time steps into the multi-scale analysis, to enhance representability of the prediction map and to reveal not only the state of lichen cover at one specific point according to the model, but also its changes over time.

Figure 8 shows the overlay of NDVI trends based on the described method and lichen vegetation structures based on the prediction for Vågå in specific. Figure 9 illustrates overlapping hotspots for the whole area of interest. Increasing vegetation trends occur parallel to > 40% predicted lichen cover in 19.4% of the area, majorly in higher elevations.

Quiet some studies examined the effects of reindeer herding on lichen vegetation (e.g. Falldorf et al. 2014, Bernes et al. 2015). Within most studies, lichen degradation and simultaneously increasing reindeer stock sizes could be observed (e.g. Johansen & Karlsen 2005). However, whilst state and condition of lichen cover in northern Norway has been an abundant research topic recently, little research has been done on lichen vegetation in southern Norway. Whereas the situation in northern Norway is characterized by heavily changed ecosystems due to overgrazing and overexploitation of the ranges (Löffler 2004), we find much less changes in southern Norway. For northern Norway exemplarily a decline of lichen-rich vegetation of 30% to less than 7% within winter districts and from more than 15% to less than 1% within spring and fall districts during 1973 and 2000 is reported (Johansen

& Karlsen 2005). According to our study, none of such findings could have been made for southern Norway. At Filefjell, only 0.6% significant negative vegetation trends could be observed, showing a situation being not remarkably different from the one on study site Vågå as non-grazed study area (0.2%). This represents the benefits of reindeer herding under stable conditions and with constant stock sizes as practiced at Filefjell. Due to specific challenges occurring in the North of Norway, the situations in both parts of the country are hard to scale with each other. Less herders as well as favorable institutional

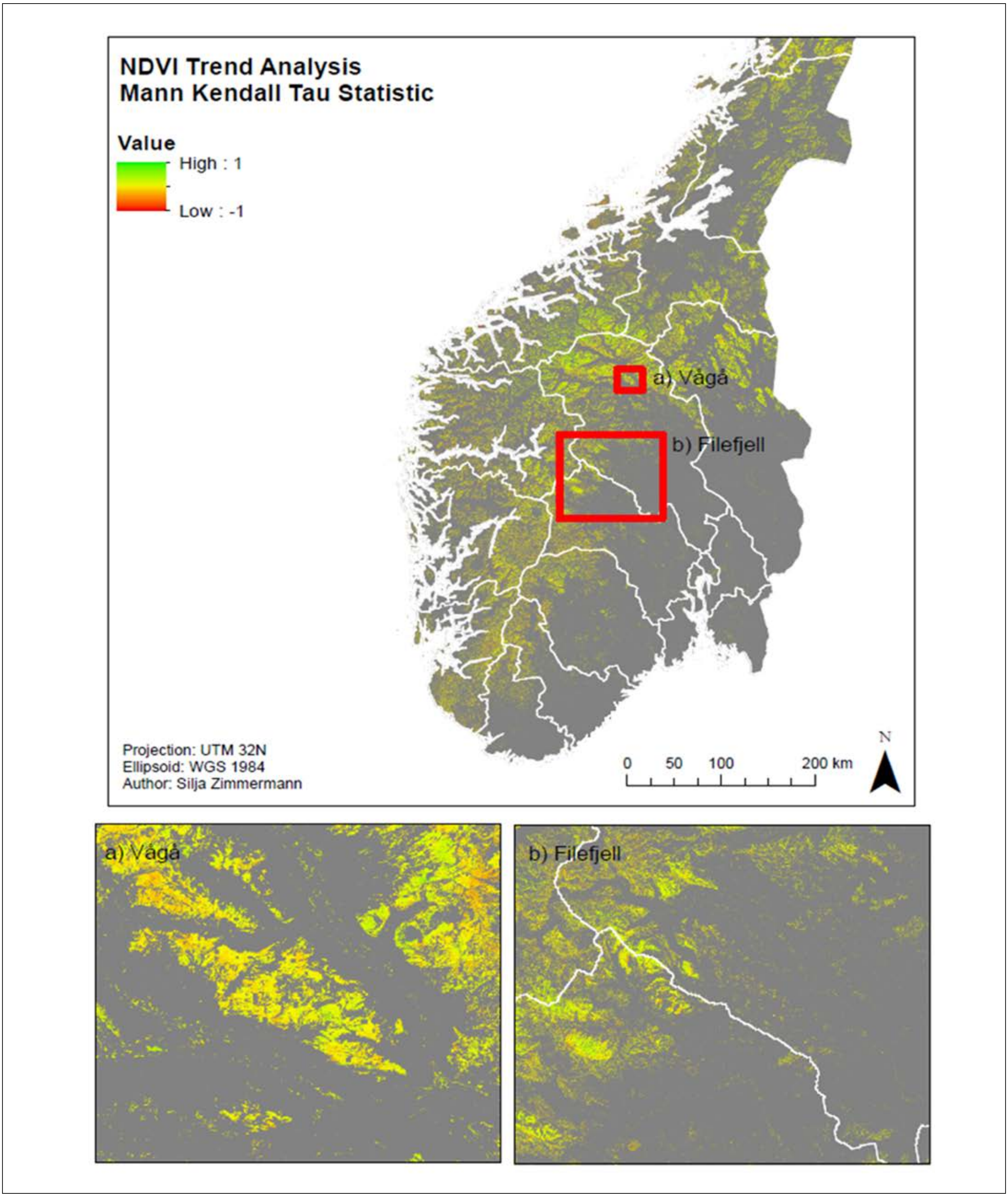

Figure 7: Lichen vegetation trend map based on 2000 – 2016 time-series of 250 m resolution MODIS vegetation indices. Mann-Kendall Tau ranges from –1 to +1, indicating the respective negative or positive vegetation trends. Pixels in which lichen vegetation is assumed to appear according to Johansen (2009) are shown.

Spatial Statistics of significant Mann-Kendall Vegetation Trends (p < 0.1)			
	Vegetation Trend Map	Vågå	Filefjell
Vegetation Index	NDVI	NDVI	NDVI
Significant Negative Trends			
Number of Pixels	524750	229	5471
Area in %	19.3%	0.2%	0.6%
Significant Positive Trends			
Number of Pixels	135663	1204	20074
Area in %	5.0%	1.1%	2.1%

Table 3: Spatial statistics of significant vegetation trends ($p < 0.1$) based on 250 m resolution MODIS vegetation indices

circumstances mitigate the situation in southern Norway, whereas North-Norwegian reindeer ranges are pressurized by a high number of herders, technological progress and resulting sedentarization processes (Riseth & Vatn 2009). Changes in vegetation associated with grazing and trampling may be spatially heterogeneous due to the high diversity of factors involved (Forbes & Kumpula 2009). Constantly increasing average annual grazing pressure in northern Norway explains the negative impact of reindeer grazing on lichen vegetation in northern Norway. Also, management strategies and institutional factors contribute to this. As several studies show, migrations between summer and winter pastures are inevitable to spare vulnerable lichen heaths during dry summer months (e.g. Käyhkö & Pellikka 1994). According to Bernes et al. (2015), damage on lichen heaths in northern Norway is caused not only by increased reindeer numbers, but on some ranges by a change in seasonal grazing from winter to summer, with lichens being more vulnerable to trampling and grazing during dry summer months (Bernes et al. 2015). History of reindeer herding, its productivity and underlying management systems as well as environmental factors of reindeer ranges, such as topography and elevation, vary considerably across Norway. *Rangifer* grazing systems are extremely variable, including a large number of different factors on a broad spatial scale and making it challenging to predict ecological consequences of single elements of the system.

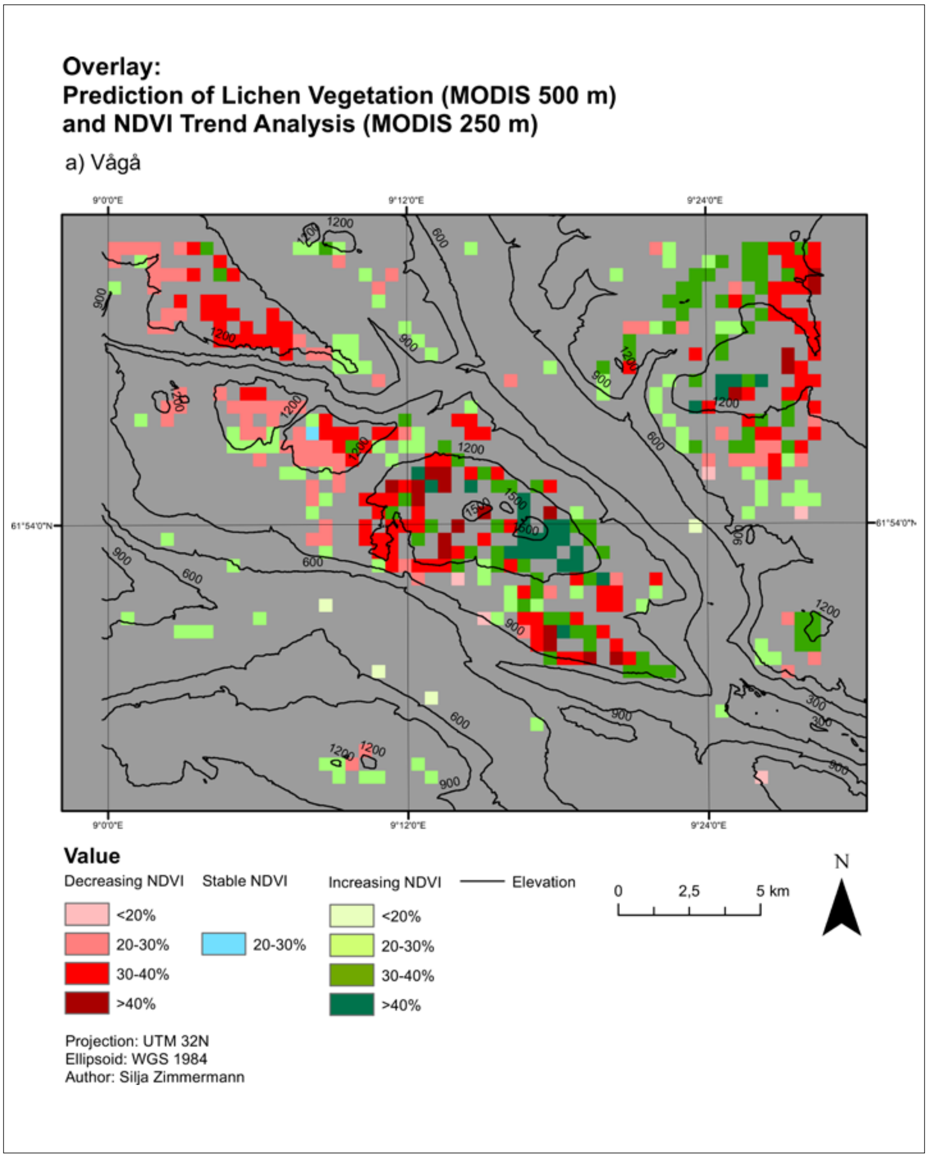

Figure 8: Overlay of predicted lichen vegetation (2010) and NDVI trends (2000 – 2016) for a) Vågå. Color saturation of the respective class indicates the amount of lichen cover per pixel. Decreasing NDVI trends were reclassified ranging from –1 to –0.01, stable NDVI cover the data range from –0.01 to 0.01 and increasing NDVI trends include all data between 0.01 and 1.

Summarizing, stable conditions within southern Norwegian reindeer husbandry are assumed of having prevented excessive lichen degradation from happening according to the underlying study. On the contrary, modernized and mechanized management strategies in northern Norway and consequently large number of reindeer, lead onto diminished lichen vegetation, poor pastures and suffering nature. Reindeer herding which was once a source of living and essential for the Sàmi culture has lost its rating as genuine tradition in vast parts of Fennoscandia.

5 CONCLUSION

Dynamics in land cover are one of the most important visual indicators for environmental change and remote sensing techniques are especially suitable for monitoring these (Tüshaus et al. 2014). Lichens are distinctive plants within arctic-alpine ecosystems and above else they play an important role in the context of reindeer herding. Reindeer, as being migrating herd animals, affect vegetation cover in structure and diversity over space and time. Using satellite imageries for mapping habitats and monitoring their condition and state helps gaining knowledge regarding the animals influence on their surrounding environments and allows deducing management strategies from these observations (Théau & Duguay 2004). In this study, lichen cover was analysed for two study areas in southern Norway and further up-scaled using Random Forest regressions, programmed in R. The analysis was based on a multi-resolution approach, using several kinds of data as a basis. Field data, as well as remote sensing data of different spatial resolutions (0.3 m, 0.5 m, 30 m, 250 m; 500 m) were taken into account. Referring to this study's research questions, the utilized multi-scale approach can be named as being generally suitable not only for arctic-alpine ecosystem landscapes within southern Norway, but also for other regions for which optical remote sensing data as well as ground-truth data for validation are available. The multi-scale approach, as applied in this study, allowed mapping lichen cover at multiple spatial scales. Additionally, lichen vegetation in southern Norway, as one element of arctic-alpine ecosystems, is by far not as threatened as lichen vegetation in northern Norway. Stable reindeer stock sizes over the last decades lead to the assumption that more balanced reindeer-lichen interactions can be named as a main reason. The results of our study indicate reindeer herding under sustainable conditions (e. g. with stable population sizes), as being inevitable to prevent excessive degradation of lichen cover and ecosystem degradation. The approach turned out to be well suited to detect and monitor lichen cover in arctic-alpine landscapes. Future studies would make usage of this approach not only for lichen vegetation, but also for other elements of arctic-alpine vegetation, aiming at fully understanding grazing effects over space and time. To enhance accuracy and allow change detection within future research, it is highly recommended to include more time steps in the analysis. This approach has a potential also to monitor vegetation cover not only in arctic-alpine regions but also in other landscapes globally.

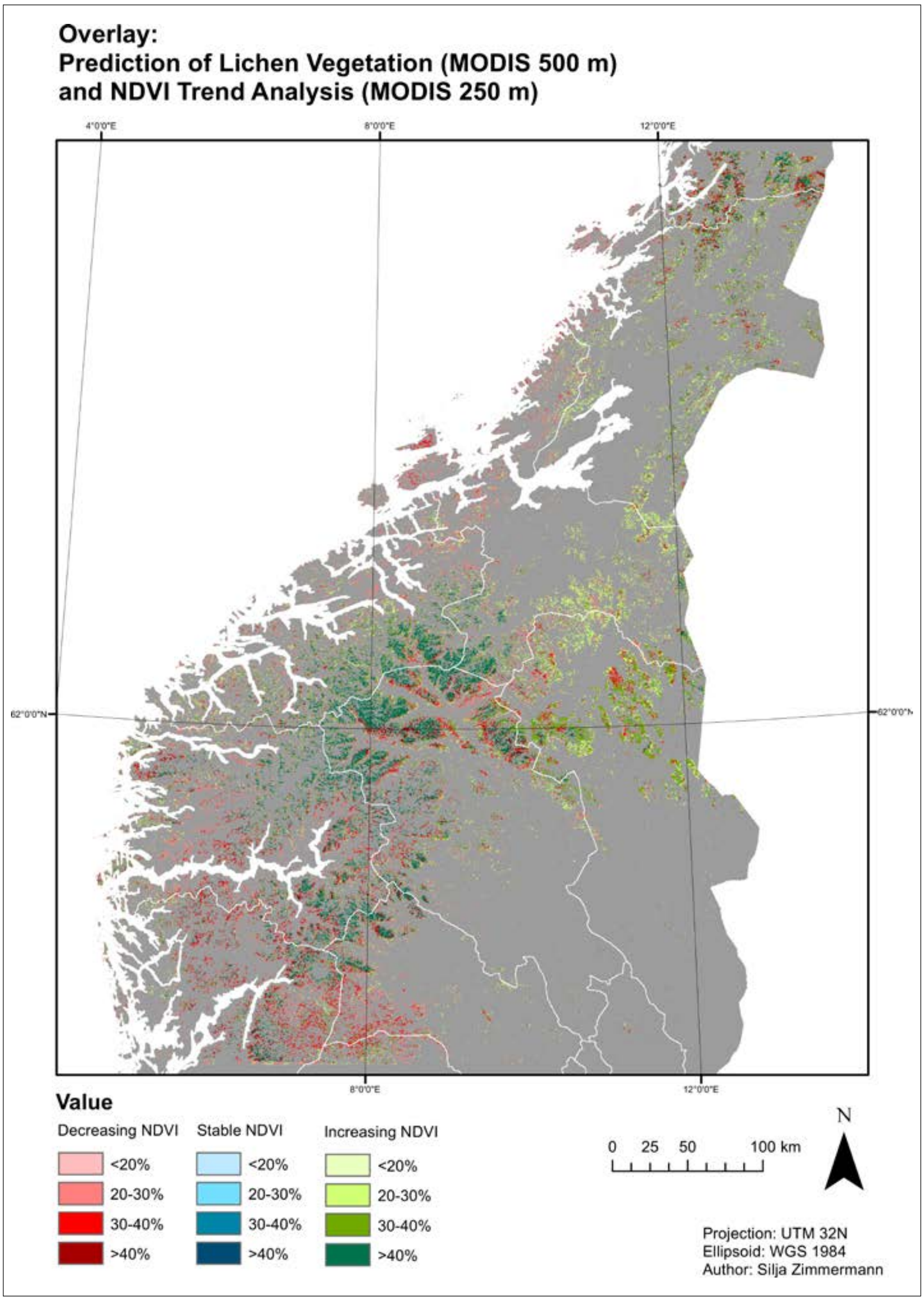

Figure 9: *Overlay of predicted lichen vegetation (2010) and NDVI trends (2000 – 2016). Color saturation of the respective class indicates the amount of lichen cover per pixel. Decreasing NDVI trends were reclassified ranging from –1 to –0.01, stable NDVI cover the data range from –0.01 to 0.01 and increasing NDVI trends include all data between 0.01 and 1.*

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