Correlation between Normalized Difference Vegetation Index (NDVI) and in vitro organic matter digestibility (IVOMD) of reindeer pasture plants

Korrelation mellan Normalized Difference Vegetation Index (NDVI) och smältbarhet av renbetesväxter i vomvätska in vitro (VOS)

Jannica Helmersson

Master's thesis • 30 Credits
Swedish University of Agricultural Sciences, SLU
Department of Animal Nutrition and Management
Agriculture Programme - Animal Science
Uppsala 2023

Correlation between Normalized Difference Vegetation Index (NDVI) and in vitro organic matter digestibility (IVOMD) of reindeer pasture plants

Korrelation mellan Normalized Difference Vegetation Index (NDVI) och smältbarhet av renbetesväxter i vomvätska in vitro (VOS)

Jannica Helmersson

Supervisor:	**Anna Skarin, Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management**
Assistant supervisor:	Erik Cronvall, Swedish University of Agricultural Sciences, Department of Forest Resource Management
Assistant supervisor:	Horacio Gonda, Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management
Examiner:	Torsten Eriksson, Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management

Credits:	30 Credits
Level:	Second cycle, A2E
Course title:	Independent project in Animal Science, A2E
Course code:	EX0872
Programme/education:	Agriculture Programme - Animal Science
Course coordinating dept:	Department of Animal Nutrition and Management
Place of publication:	Uppsala
Year of publication:	2023
Cover picture:	Jannica Helmersson
Keywords:	Normalized Difference Vegetation Index, NDVI, in vitro organic matter digestibility, IVOMD, VOS, caribou, Rangifer tarandus, reindeer pasture plants, drone

Swedish University of Agricultural Sciences
Faculty of Veterinary Medicine and Animal Sciences
Department of Animal Nutrition and Management

Sammanfattning

Renen livnär sig på många olika betesväxter och den följer växtfenologins utveckling under barmarkssäsongen, vilket resulterar i högkvalitativt foderintag. Levande växtbiomassa kan uppskattas på landskapsnivå genom att använda vegetationsindex som värderar vegetation utifrån spektrala mätningar. Det finns indikationer på att dessa index även korrelerar med kvalitativa faktorer i växter. Denna studie syftade till att undersöka korrelationen mellan Normalized Difference Vegetation Index (NDVI) och smältbarhet av renbetesväxter i vomvätska in vitro (VOS). NDVI beräknades från multispektrala bilder tagna med en drönare. Växtprover för analysen klipptes för hand från totalt 18 provrutor (0,5 m x 0,5 m), insamlade på renbetesmark i Malå sameby, Sverige. Provtagningsplatserna placerades i försök att fånga vegetationen på fem olika områden: tre myrar, ett kalhygge och en vall. Resultatet av denna studie visar ingen korrelation (r =0,25; p =0,27) när alla växttyper inkluderas i en regressionsanalys. Det finns däremot en måttlig korrelation (r =0,41; p =0,13) mellan NDVI och VOS av renbetesväxter då endast provrutor med högst andel gräs, halvgräs och örter inkluderas. Detta kan vara en indikation på att det finns en variation i korrelationen beroende av växttyp. Vidare forskning behövs för en bättre förståelse av sambandet samt möjliga effekter av vegetationstyp, säsong eller fuktighetsgrad.

Keywords: Normalized Difference Vegetation Index, NDVI, in vitro organic matter digestibility, IVOMD, VOS, caribou, Rangifer tarandus, renbetesväxter, drönare

Abstract

Reindeer feed on a large variety of pasture plants and it follows the development of plant phenology during the bare ground season, which results in high quality forage intake. Live plant biomass can be estimated on a landscape-scale by using vegetation indices that value vegetation based on spectral measurements. There are indications that these indices also correlate with qualitative factors in plants. This study aimed to investigate the correlation between Normalized Difference Vegetation Index (NDVI) and in vitro organic matter digestibility (IVOMD) of reindeer pasture plants. NDVI was calculated from multispectral images taken with a drone. Plant samples for the analysis were cut by hand from a total of 18 sampling plots (0.5 m x 0.5 m), collected on reindeer pasture in Malå reindeer herding community, Sweden. The sampling plots were deployed to capture the vegetation at five different areas: three mires, a clear-cut forest area and a ley. The result of this study shows no correlation (r =0.25; p =0.27) when all plant types are included in a regression analysis. In contrast, there is a moderate correlation (r =0.41; p =0.13) between NDVI and IVOMD in reindeer pasture plants when only plots with the highest proportion of grasses, semi-grasses and herbs are included. This may be an indication that there is a variation in the correlation depending on plant type. Further research is needed for a better understanding of the relationship and possible effects of vegetation type, season or degree of soil moisture.

Keywords: Normalized Difference Vegetation Index, NDVI, in vitro organic matter digestibility, IVOMD, VOS, caribou, Rangifer tarandus, reindeer pasture plants, drone

Table of contents

List of tables

List of figures

Figures in Appendix

Abbreviations

ADF	Acid detergent fibre
CF	Crude fibre
CP	Crude protein
IVDMD	In vitro dry matter digestibility
IVOMD	In vitro organic matter digestibility
NDF	Neutral detergent fibre
NDVI	Normalized Difference Vegetation Index

Plant species

Latin name	Swedish name
Achillea millefolium	Röllika
Agrostis capillaris	Rödven
Andromeda polifolia	Rosling
Betula nana	Dvärgbjörk
Calluna vulgaris	Ljung
Carex	Starrsläktet
Carex bigelowii	Styvstarr
Carex livida	Vitstarr
Carex nigra ssp. juncella	Styltstarr
Carex pauciflora	Taggstarr
Carex rostrata	Flaskstarr
Carex rotundata	Rundstarr
Carex vaginata	Slidstarr
Cetraria islandica	Islandslav
Cladina arbuscula	Gulvit renlav
Cladina rangiferina	Grå renlav
Cladina stellaris	Fönsterlav
Cladonia uncialis	Pigglav
Deschampsia caespitosa	Tuvtåtel
Deschampsia flexuosa	Kruståtel
Empetrum nigrum	Kråkris
Equisetum fluviatile	Sjöfräken
Eriophorum angustifolium	Ängsull
Eriophorum scheuchzeri	Polarull

Eriophorum vaginatum	Tuvull
Euphrasia	Ögontröstsläktet
Festuca ovina	Fårsvingel
Juncus trifidus	Klynnetåg
Leontodon hispidus	Sommarfibbla
Menyanthes trifoliata	Vattenklöver
Molinia caerulea	Blåtåtel
Phragmites australis	Bladvass
Pinus sylvestris	Tall
Poa	Gröen
Potentilla erecta	Blodrot
Potentilla palustris	Kråkklöver
Ranunculus acris	Smörblomma
Rhinanthus minor	Ängsskallra
Rhododendron tomentosum	Skvattram
Rubus chamaemorus	Hjortron
Sagittaria sagittifolia	Pilblad
Sphagnum	Vitmossor
Stereocaulon pascale	Påskrislav
Trichophorum cespitosum	Tuvsäv
Trifolium repens	Vitklöver
Vaccinium myrtillus	Blåbär
Vaccinium oxycoccos	Tranbär
Vaccinium uliginosum	Odon
Vaccinium vitis-idaea	Lingon

1. Introduction

Reindeer husbandry is of great importance above all for the Sami culture and its livelihood. There are 51 reindeer herding communities in Sweden, 1000 professional reindeer herders and 4 600 reindeer owners (Sámediggi 2022a) with a total of 240 300 reindeer (*Rangifer tarandus*) in winter herd (Sámediggi 2023). According to reindeer husbandry law, which is based on ancient claims, the Sami population has the right to use land for themselves and their reindeer (SFS 1971). In Sweden, there is 33 forest reindeer herding communities, 10 mountain reindeer herding communities and 8 concession reindeer herding communities (Sámediggi 2022b). Reindeer husbandry areas constitutes 55% of the land base in Sweden (Sandström 2015). The reindeer husbandry is a pastoral system (Bjørklund 2013) and reindeer migrate through the landscape to exploit its grazing resources (Sandström 2015).

Rangifer tarandus (reindeer and caribou – hereafter generally referred to as "reindeer") seems to follow the phenological development of the plants (Kuropat 1984). This is also called to "surf the green wave" and is performed by herbivores to sustain the intake of high-quality forage (Merkle *et al.* 2016). Vegetation indices such as Normalized Difference Vegetation Index (NDVI) are used on a landscape-scale to estimate green biomass (Harrie *et al.* 2020). If NDVI also would correlate with qualitative factors on pastures, it would be easier to identify particularly valuable reindeer pastures and to understand migration patterns. Other attempts to map valuable reindeer pastures have been carried out, for example, by fecal pellet-group counting to assess reindeer habitat use (Skarin 2007; Skarin & Alam 2017) and by collecting data with GPS collars (Skarin 2006; Skarin *et al.* 2008).

The aim of this thesis was to investigate the relationship between the digestibility of reindeer pasture plants and NDVI. This was done correlating digestibility values for specific reindeer plants using in vitro organic matter digestibility (IVOMD) and NDVI calculated from multispectral images taken using drone remote sensing.

1.1 Background

1.1.1 Important reindeer pasture plants

Reindeer feed on grasses, semi-grasses, herbs, mushrooms, willows and dwarf shrubs and have a special ability to utilize lichens (Warenberg *et al.* 1997) (*Figure 1*). The nutritional content of plants varies depending on time of year, type of plant community, minerals in the ground and the plants´ ability to utilize these minerals and store nutrients (Warenberg 1982). For a reindeer pasture, both qualitative and quantitative production is important but plants with high nutritional value can compensate for a low quantity pasture (Warenberg 1982). In an overview based on 30 articles about reindeer's diet, Webber *et al.* (2022) found that reindeer, through their geographical distribution, consume at least 130 different plants species and that the consumption depend on seasonal and geographical availability.

Figure 1. Illustration of the reindeer year and the mainly important reindeer pasture plants over the seasons. Examples of species that are grazed all year round are centered around reindeer. The feed supply is large during the bare ground season, which supports reindeer's growth and build-up of body reserves. The body reserves are utilized during the winter season when the feed supply is small and of low quality.

Species that are grazed all year round

The dwarf shrub *Vaccinium myrtillus*, the semi-grass *Eriophorum angustifolium*, the herbs *Menyanthes trifoliata and Potentilla palustris* and several lichen species are grazed by reindeer throughout the year (Warenberg *et al.* 1997). Examples of lichen species are *Cladina arbuscula*, *Cladina rangiferina*, *Cladina stellaris*, *Cladonia uncialis*, *Stereocaulon pascale* and *Cetraria islandica* (Warenberg *et al.* 1997). *Menyanthes trifoliata* is singled out as a superior pasture plant due to its nutritional content (Warenberg 1982). In a comparison with *Vaccinium myrtillus*, *Eriophorum vaginatum*, *Juncus trifidus* and eight other species collected in the spring, *Menyanthes trifoliata* had the highest content of both crude protein, sugar, phosphorus, and calcium (Warenberg 1982). Reindeer graze the leaves and flower during the bare ground season and the rhizome during other parts of the year (Warenberg *et al.* 1997).

Lichens and mosses

Lichens have a high content of carbohydrates (Sundset *et al.* 2010) and provide reindeer high digestible energy (Parker *et al.* 2005). They have a low protein content of about 4-5% of dry matter which seems unchanged regardless of the season (Warenberg *et al.* 1997). Garmo (1986) investigated the chemical composition of eight ground lichens and found the mean dry matter content to be 4.2% for crude protein, 3.2% for ether extract and 16.6% for crude fibre. The mineral content was lower than in grasses, apart from the content of selenium and iron which were found to be much higher. However, the mineral content may vary depending on the lichen's geographical location (Åhman 1984). Lichen consumption tends to decrease as the amount of nutritious vascular plants increases (Webber *et al.* 2022).

Mosses seems not to be preferable by reindeer (Moore 1982; Danell *et al.* 1994) and the consumption probably consists of accidental intake when eating other plant material (White 1983). Generally, mosses have a high fiber content with poor digestibility, but they may still form an important part of the diet as they provide calcium and phosphorus for example (White 1983).

Refill of energy reserves

In the spring, reindeer migrates from the winter grazing area to the summer grazing area before calving in May. After the winter season, reindeer can be in poor condition and have been started to utilize its body reserves (Warenberg 1982). Reindeer lose 20% of its weight during a normal winter with good grazing conditions, but may lose up to 40% if the grazing conditions are difficult (Warenberg *et al.* 1997). The content of protein, calcium and phosphorus are the most important in plants that are grazed in the spring (Warenberg 1982). Phosphorus is important during maternity and calcium is needed for growth and the females milk production (Steen 1966).

The species *Potentilla palustris, Deschampsia caespitosa, Deschampsia flexuosa* and *Juncus trifidus* are important in the spring because of a high protein content (Warenberg 1982). *Carex bigelowii* and *Juncus trifidus* are particularly important for reindeer during May due to a rapid increase in biomass early in the season (Warenberg 1982). *Eriophorum vaginatum* has a high nutritive value and is extensive and easy to find during calving (Kuropat 1984). Additionally, *Eriophorum vaginatum* contains the important minerals calcium and phosphorus (Warenberg *et al.* 1997). Reindeer select for *Eriphorum vaginatum* regardless of its availability (Moore 1982). In addition to these species, *Festuca ovina*, *Eriophorum angustifolium*, various semi-grasses such as many sedge species (*Carex*), dwarf shrubs, lichens and leaf buds are also important in spring (Warenberg *et al.* 1997). Species that develop green shoots early and species that form nutritious rootstocks form a very important part of the spring grazing (Warenberg *et al.* 1997).

During the summer, reindeer need to build up their body reserves for the winter with intake of both protein and fat (Warenberg *et al.* 1997; Johnson *et al.* 2021). In early summer, there is the best quality pasture compared to other parts of the year (Warenberg *et al.* 1997). Reindeer then graze wetland plants, rhizomes of *Menyanthes trifoliata* and *Potentilla palustris* and leaves of dwarf shrubs and deciduous tree (Warenberg *et al.* 1997). A smaller proportion of lichens is grazed during the summer (Warenberg *et al.* 1997). The review of Webber *et al.* (2022) indicate that vascular plants such as shrubs, forbs and trees represent the highest proportion in the diet during calving and summer compared to spring, autumn and winter. The proportion of lichens in the diet is the lowest during calving and summer and increase in autumn, winter and spring (Webber *et al.* 2022). Graminoids (e.g. grasses and sedges) have the largest proportion in the diet during calving, summer and autumn and are the lowest in winter and spring (Webber *et al.* 2022). The pasture deteriorates nutritionally during the late summer (Warenberg *et al.* 1997). This makes it difficult for reindeer to meet its protein needs for growth and it begins to store fat for the winter (Warenberg *et al.* 1997).

Autumn and winter seasons

Reindeer need to adapt to a new diet in the autumn. Mushrooms become part of the diet from late summer and during autumn, and the importance of dwarf shrubs and lichens increases (Warenberg *et al.* 1997). The females have their oestrous period in autumn. Reindeer migrate from summer pastures to winter pastures during the latter part of autumn. The diet in the winter is dominated by lichens (Parker *et al.* 2005), but is also constituted of dwarf shrubs, rootstocks, green parts of grasses and forbs, as well as buds and shoots from shrubs and deciduous trees (Warenberg *et al.* 1997). Leaves, stems and graminoids have a higher protein content than lichens (Parker *et al.* 2005) and form an important part of the diet. *Eriophorum vaginatum*, *Deschampsia flexuosa*, *Deschampsia cespitosa* and *Empetrum nigrum* are good additions to the lichen diet if reindeer can access them (Warenberg *et al.* 1997).

1.1.2 Plant maturity and digestibility

Plant maturity

The plant cell walls mainly consist of cellulose, hemicellulose and lignin and the content of all these three components increases with the plant's degree of maturity (McDonald *et al.* 2010). Meanwhile, the cell content decreases, where most of the crude protein (CP) and digestible nutrients are found (McDonald *et al.* 2010). By using a neutral detergent solution to the plant sample, cell content can be dissolved, and the neutral detergent fibre (NDF) can be quantified (McDonald *et al.* 2010). Natural pastures intended for cows have a higher content of metabolisable energy in early summer than late summer (Andrée *et al.* 2011). The content of NDF, on the other hand, is lower in early summer than late summer (Andrée *et al.* 2011). The natural pasture's change in CP content during the summer varies depending on the type of vegetation (Andrée *et al.* 2011).

Digestibility

The digestibility of plants and feeds in the rumen can be analysed with rumen in vitro techniques such as in vitro organic matter digestibility (IVOMD) (Lindgren 1979) or in vitro dry matter digestibility (IVDMD) (Tilley & Terry 1963). The result indicates the percentage of the ingested biomass that is digested (Danell *et al.* 1994; Mahyuddin 2008; McDonald *et al.* 2010). The result of an increasing proportion of cell wall according to maturity is a reduced digestibility, since digestibility has a negative relationship to cell wall components (Mahyuddin 2008; McDonald *et al.* 2010). Anti-nutritional constituents are secondary plant compounds in the plant that may also reduce the digestibility, such as condensed tannins (Gerlach *et al.* 2018) and saponins (Makkar *et al.* 1995; McDonald *et al.* 2010). The digestibility is also affected by weather, as green plants are more easily digested in cold and dry weather because the cell walls become thinner (Warenberg *et al.* 1997). Leaf buds are more digestible than leaves, and leaf material is more digestible than stem material (Moore 1982). Green leaves can be harder than deciduous and evergreen shrubs to digest (Moore 1982).

1.1.3 Morphophysiology and foraging patterns of reindeer

Ruminants can be divided into three morphophysiological feeding types: concentrate selectors, grass and roughage eaters and lastly the intermediate type which is a mixed version of the previous two (Hofmann 1989). Within this framework, reindeer are classified as the intermediate feeding type, but more towards concentrate selectors. Concentrate selectors are adapted to digest forage low in fibre, with high plant cell content and low cell wall content due to that their feeding rhythm is high and the digesta has a low retention time in the digestive tract (Hofmann 1989). On the contrary, grass and roughage eaters easily digest high fibrous forage low in plant cell content and high in cell wall content and their feeding rhythm is low while the retention time is high, and rumination is of greater importance (Hofmann 1989). The intermediate feeding type prefer not to eat fibrous feed but is adapted to both browsing and grazing (Hofmann 1989). It seems to be the balance of qualitative and quantitative characteristics that determines which strategy to use (Moore 1982).

The diet of reindeer seems to be more varied when forage biomass is high, which can reduce the effects of secondary plant compounds (Moore 1982). Hofmann (1989) describes the intermediate feeders as selective opportunists. They can anatomically adapt to forage quality changes in a short time and increase the feed intake two or threefold when feed is plentiful (Hofmann 1989). Selective grazing increases the dry matter intake (DMI), and make reindeer maintain a high quality diet, which also increases the dry matter digestibility (DMD) and metabolizable energy intake (MEI) (Moore 1982). White and Trudell (1980) gives an example of this in their review about such multiplier effects on productivity that foraging patterns have on reindeer. They compare the effect on feed intake and energy retention that selective grazing brings. When DMD increases by 14% DMI increases by 27%, and therefore the digestible DMI could increase with 45%. This results in an increase in net energy production of as much as 267%.

Moore (1982) studied grazing patterns of reindeer in summer and found that reindeer graze about 53% of the time. The searching activity increases with an increasing live biomass, which is an indicator of selective grazing (Moore 1982). Moore (1982) concluded that reindeer select for vegetation with high biomass and for diversity of pasture species. White and Trudell (1980) found that reindeer avoid plant communities with a high biomass of dead plant material to obtain efficient grazing. Reindeer have a unique grazing pattern walking as they are foraging, thereby they efficiently graze nutritious and easily digestible feed (Warenberg *et al.* 1997). This movement is particularly beneficial during calving and lactation as it provides an abundant supply of fresh, high-quality forage (Kuropat 1984).

External factors that prevent reindeer from following their foraging patterns

Predators on reindeer in Sweden is wolf (*Canis lupus*), wolverine (*Gulo gulo*), lynx (*Lynx lynx*), brown bear (*Ursus arctos*) and golden eagle (*Aquila chrysaetos*) (Åhman 2013; Sámediggi 2021). A study by Rivrud *et al.* (2018) showed an increased movement speed of reindeer in areas where the density of brown bear was high. Reindeer are also forced to move in areas with poorer pasture quality instead of following the phenological plant development when predators are present (Rivrud *et al.* 2018).

Insects' harassment strongly affects the grazing possibilities (Kuropat 1984; Skarin *et al.* 2010; Johnson *et al.* 2021; Johnson *et al.* 2022). It leads to increased physical activity and reduced forage intake (Johnson *et al.* 2021). Reindeer do not compensate for lost grazing time during the day by grazing at night instead, resulting in reduced physical condition with lower carcass weights in turn (Colman *et al.* 2003). A high mosquito activity is also shown to reduce the reproducibility and survival of adult females' reindeer (Johnson *et al.* 2022). It seems that insect activity is higher in higher temperatures and lower when cloudy (Colman *et al.* 2003).

Forestry, wind power, hydropower and mining operations, as well as the increased need for functioning infrastructure in the form of roads and power lines that these developments entail, make migration difficult (Larsen *et al.* 2016). It also reduces grazing resources and interferes with grazing (Larsen *et al.* 2016). The cumulative effects of disruption of infrastructure and human activities (including tourism and activities in the mountains) on reindeer husbandry within Vilhelmina North reindeer herding community have been mapped by Larsen *et al.* (2016). The calculations on the total disturbance area amounted to 30% of the reindeer herding community's total area and 54% of the winter grazing land.

1.1.4 Normalized Difference Vegetation Index

Remote sensing is performed to observe the environment from long distances and collect data by using satellites, airplanes, helicopters and drones. Multispectral cameras that measure specific intervals within the electromagnetic spectrum, so-called wavelength bands, can be used in remote sensing (Harrie *et al.* 2020). A standard color camera has the three wavelength bands red, green, and blue, while most aerial cameras also measure in the near infrared (NIR) wavelength band (Harrie *et al.* 2020). To interpret vegetation, NIR can be combined with other wavelength bands to create a so-called false color image (Harrie *et al.* 2020). The red (R) band is then controlled by the NIR band and areas with growth will glow bright red because healthy vegetation reflects a lot in the NIR (Harrie *et al.* 2020).

Vegetation indices can be used to estimate quantitative properties by combining different wavelength bands and exploiting the difference in reflectance between different wavelength ranges (Harrie *et al.* 2020). The most used vegetation index is NDVI, which can be calculated using the formula (NIR-R) / (NIR+R) (Harrie *et al.* 2020; Jennewein *et al.* 2020; Myers-Smith *et al.* 2020). This index normalizes the difference between the reflectance in NIR and R against the sum of the two bands and can vary between -1 and +1 (Harrie *et al.* 2020). NDVI increases with the amount of green biomass and is related to the amount of light absorbed by vegetation during photosynthesis (Harrie *et al.* 2020). Water gives negative values up to zero, while rocks, sand and snow gives values close to zero (Ya'acob *et al.* 2014). Vegetation and greenery have values between 0.1-1.0 and values between 0.4-1.0 is commonly associated with tropical rainforest (Ya'acob *et al.* 2014).

NDVI as a predictor of quantitative and qualitative factors

NDVI is commonly used as a tool to predict ungulate forage condition at landscape-scale even though the knowledge about the correlation between NDVI and the forage quality and quantity is limited (Johnson *et al.* 2018). Johnson *et al.* (2018) investigated correlations between satellite-derived NDVI and biomass, nitrogen, digestible nitrogen and digestible energy in six reindeer forage species. Their results showed weak relationships at the beginning of the growing season. Later, when the biomass continuously increased while forage quality decreased, the relationships between forage components and NDVI became even weaker. Biomass and digestible energy showed stronger relationships over the summer than nitrogen and digestible nitrogen. They concluded that NDVI should be used with caution in these contexts and not as a proxy because of differences in what forage component it represents over the season. Results from a study by Garroutte *et al.* (2016) also indicate that NDVI should be used with caution when predicting forage quality, but that NDVI, on the other hand, explains the variation in quantity adequately.

The relationship between NDVI and IVOMD (48h of fermentation in buffered rumen fluid) of tropical grasses have been investigated by Hughes *et al.* (2014; 2017) with the hand-held optical chlorophyll gun FieldScout CM 1000 NDVI Meter (Spectrum Technologies, Inc. of Plainfield, Illinois, USA). This is a "point and shoot" measurement that calculates NDVI by using red and near infrared reflectance. In the first study (Hughes *et al.* 2014), a pasture sample was taken four times during the growing season and the correlations between NDVI and the IVOMD of the grasses were significant strong (r =0.67-0.85). In the second study (Hughes *et al.* 2017), there were pots of three different tropical grasses that were used in the survey. The correlations between NDVI and the IVOMD of two of the grass species were significant strong (r =0.75 and r =0.83), while the correlation for the third grass species was non-significant weak (r =-0.23). Hughes *et al.* (2014) concluded that there is a potential to predict both CP and IVOMD content of the tropical grass species with the hand-held optical chlorophyll gun. In the latter study (Hughes *et al.* 2017), they concluded that there is potential for useful estimates of NDF and IVOMD in some of the species that were tested.

Gao *et al.* (2019) used images taken by a drone to calculate NDVI and eight other indices and examined how well they correlated with IVDMD (48h of fermentation in buffered rumen fluid) of grass species. A total of 100 plots (1 x 1 m) were deployed on two natural grasslands in China and were harvested at one point. The correlation between NDVI and IVDMD of the grasses were non-significant weak (r =0.196). Gao *et al.* (2019) performed prediction models to confirm the relationships between IVDMD and remote sensing variables, but the authors concluded that the models need to be improved. Gao *et al.* (2019) discusses that more sensitive wavelengths might improve the models, together with an improved mathematical model.

2. Material and methods

2.1.1 Literature review

The review of literature for this study has been carried out by obtaining material from books and from various databases such as Web of Science, Google Scholar, PubMed and Scopus. Keywords that have been used in the databases are for example: reindeer, Rangifer tarandus, caribou, ungulates, multispectral, in vitro, digestibility, NDVI, IVOMD, IVDMD.

2.1.2 Plant sampling, assessment and analysis

Sampling

The plant samples for the analyses in this study were collected June 28-30, 2022, during the summer grazing season. Five areas with different vegetation types were selected in Malå reindeer herding community, a forest reindeer herding community in the county of Västerbotten (*Figure 2*). In total, 18 sampling plots 0.5 m x 0.5 m in size were placed in the five areas, that consisted of a clear-cut forest area from 2015, a ley and three mires (*Appendix 1*). It was one larger mire with great vegetation variation, one smaller, wetter mire and one mire with elements of reeds. The sampling plots were placed by stratified sampling to capture the variation of vegetation types also within the five areas (*Appendix 2*). Blue marker sticks, 4.8 cm x 60 cm, were placed in northerly direction at the sampling sites (*Figure 3*) to make them detectable in the images taken by the drone. A wooden frame of 0.5 m x 0.5 m was placed 5 cm to the right of the marker stick (*Figure 4*).

The plants in each plot were cut down to the height of 1 cm from ground with scissor and placed in a sample bag. Dead biomass was sorted out. At least 100 g of plant material was needed for the analysis. In cases where the plant material in the plot was not sufficient to achieve that weight, the same type of plant material outside the plot was also cut down and collected in the same bag. The weight of the plant material in the plot and the final total weight were documented. The sample bags (*Figure 5*) were stored in a bag with ice pack to minimize dry matter changes and then frozen within five hours. One sample bag per plot was collected. In plots with moss in, moss was collected for analyses in a separate sample bag.

Photos of the sampling plots with the wooden frame were taken with an RGB camera at a height of 1.5 meters. Overview photos in the four cardinal directions of the compass were taken in each area. Finally, the sampling sites were photographed when they had been cut (*Figure 6*).

Figure 2. Malå reindeer herding community is in the county of Västerbotten. This study has taken place within the circled area. Map created from Karta © Lantmäteriet (2023).

Figure 3. Marker stick laid out at the sampling site.

Figure 4. A wooden frame formed the sampling plot and was laid out 5 cm to the right of the marker stick.

Figure 5. Sample bags with collected plant material from three of the sampling plots.

Figure 6. Cut sampling site.

Species identification and assessment of plant coverage

The different plant species in the sampling plots were documented. Species identification took place either on site or afterwards using a Nordic flora by Mossberg and Stenberg (2018). An assessment of plant coverage according to Esseen *et al.* (2003) was performed for each detected plant species as well as for the total living vegetation in the sampling plot, the so-called greenness. Strict assessment of plant coverage with no allowance for over-coverage was applied. The total sum for the species and greenness respectively in the sampling plots could therefore not exceed 100%. The plants did not have to have their roots in the sampling plots to be included. The proportion of each plant surface visible in the RGB images was counted. Based on the result of the assessment of plant coverage, the ratio for the whole sampling plot between semi-grasses/grasses/herbs and dwarf shrubs was calculated. The images of each sampling plot were cropped and edited with grids in a gridmaker application (The AppGuru 2019) to facilitate the assessments (*Figure 7*).

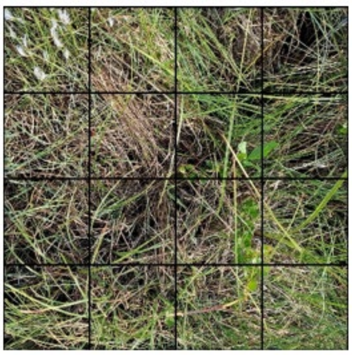


Figure 7. Grids were applied to the sampling plot images to facilitate the assessments of plant coverage.

Soil moisture classification

The soil moisture in the sampling plots was classified either as a dry, semi-wet or wet vegetation patch. The assessment was carried out visually by being on site. Ten sampling plots were classified as dry, six sampling plots classified as semi-wet and two sampling plots classified as wet.

Plant analysis

The samples from each of the 18 sampling plots and moss samples from four of the sampling plots (6, 8, 13 and 14) were analysed to determine ash content, dry matter (DM) content and in vitro organic matter digestibility (IVOMD). Determination of DM and ash content were carried out in accordance with AOAC (1990). Each sample was first weighed and dried overnight in 60ºC, then weighed again and thereafter grinded. A proportion of each of the grinded sample was weighed out and was then left in a drying oven at 103ºC overnight so that water and other volatiles would evaporate. The dry samples were then weighed again so that the DM content could be calculated. For ash determination, the same samples were also left to dry in an ash oven at 550ºC for three hours so that the organic matter would burn up. Then the samples were weighed again for the calculations of ash content.

The IVOMD was determined as ”vomvätskelöslig organisk substans” (VOS) according to Lindgren (1979). Three analysis per sample were made. Dried and grounded samples were incubated in glass filter crucibles with a mixture of rumen fluid (2%) and buffer for 96 hours in 38ºC under anaerobic conditions. The rumen fluid came from a non-lactating fistulated cow fed a standardized diet at maintenance level. For vascular plants it has been shown that both rumen fluid from reindeer and cattle can be used (Wallsten 2003). For analysis of lichens, on the other hand, the use of rumen fluid from reindeer eating lichens is required (Wallsten 2003). The buffer was intended to act as synthetic saliva. After the incubation, the samples were filtered to remove the digested material, first with hot deionized water several times and finally with acetone. Thereafter, the samples were dried in an oven at 103ºC overnight and weighed when cooled. Lastly, they were ashed at 500ºC so that the remaining organic matter would disappear. The ash residues were weighed when cooled so that all the information for the calculations was available. The IVOMD is the proportion of the organic matter weight that disappear during the incubation.

2.1.3 Multispectral images and NDVI

Multispectral images

The five areas were photographed using DJI Phantom 4 Multispectral (DJI, Frankfurt am Main, Germany), with marker sticks placed at the sampling sites. DJI Phantom 4 Multispectral is a drone that has an RGB camera and five multispectral cameras that measure the wavelength bands blue, green, red, red edge and NIR. An RGB image (*Figure 8*) and a multispectral image (*Figure 9*) were taken over each area. Photos were taken at 50 and 100 meters above the ground, giving a resolution of 2.5 and 5.0 cm per pixel, respectively. The photos at a height of 50 meters were taken to be able to identify the sampling sites more easily in the orthophoto. The flight was performed in overcast weather to reduce shadows in the images. The plant sample collection was subsequently carried out within three days. An orthophoto was created from the drone images. A polygon layer with sampling plots was created in the geographic information system QGIS 3.18 Zürich (QGIS Development Team 2020) based on the blue markings in the orthophoto (*Figure 10*).

NDVI

The NDVI-values for all pixels in each of the five areas were counted in new raster layers in QGIS 3.18 Zürich using the raster calculator and the formula (NIR - R) / (NIR + R) (*Figure 11*). A sampling plot consisted of 100 pixels which each had an NDVI-value. The NDVI for a sampling plot was calculated as the mean of the pixels with the highest NDVI-values, at the same extend as the proportion of greenness. For instance, the NDVI for sampling plot 13 is calculated as the mean of the 65 pixels with the highest NDVI-values as the greenness is assessed to 65%. This was done because it is the greenery that has been analysed and according to the images it is this greenery that has the highest NDVI-values.

Figure 8. An RGB image of one of the five areas.

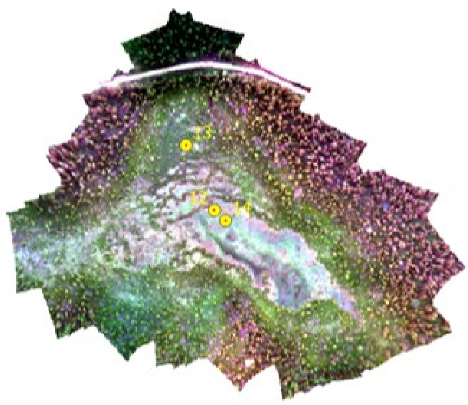


Figure 9. A multispectral image of one of the five areas.

Figure 10. The sampling plots were pointed out using the blue marker sticks, and a polygon layer in QGIS 3.18 Zürich was created.

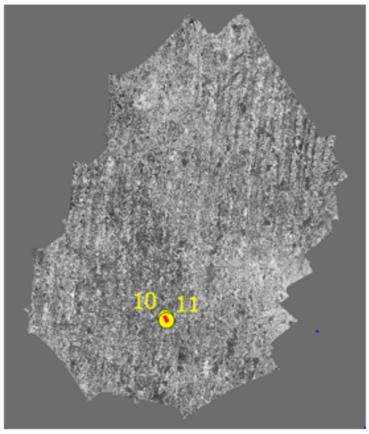


Figure 11. An NDVI raster layer was created for each area.

2.1.4 Data processing and statistical analyses

Simple linear regression analyses, Pearson´s correlation coefficients, scatter plots, boxplots and calculations were computed in Microsoft Excel (Version 2208). NDVI was set as the independent variable in the analyses. The strength of the correlation coefficients (r) was considered accordingly Dancey and Reidy (2007). The value 0 was thereby considered as no correlation, +/- 0.1 – +/- 0.3 as weak, +/- 0.4 – +/- 0.6 as moderate, +/- 0.7 – +/- 0.9 as strong and +/- 1 as perfect. No limit was set on significance as the study contained only a small number of analyses.

3. Results

The results of the soil moisture classification, NDVI, IVOMD, DM, ash, weight from plot, ratio of plant types, assessment of plant coverage of both greenness and species and RGB and NDVI images on the sampling plots are presented in *Table A1* in *Appendix 3*.

Assessment of plant coverage

The proportion of grasses, semi-grasses and herbs was higher than the proportion of dwarf shrubs in 15 of the 18 sampling plots, and in the three remaining the proportion of dwarf shrubs was higher. Of these 15 sampling plots, only two contained a lower proportion of dwarf shrubs, while the other 13 consisted only of grasses, semi-grasses and herbs. The greenness in the sampling plots varied between 19.5-100.0%.

IVOMD analysis

The mean IVOMD were higher for grasses, semi-grasses and herbs (66.4%) than for dwarf shrubs (46.7%), that in turn was higher than the mean IVOMD for mosses (19.6%) (*Figure 12*). Grasses, semi-grasses and herbs varied between 44.1-87.0%. Dwarf shrubs varied between 36.4-56.4%. Mosses varied between 16.0-25.6%.

Relationship between IVOMD and NDVI

A scatterplot with IVOMD and NDVI for all sampling plots and moss samples is shown in *Figure 13*. With all samples included in a regression analysis, there is no correlation ($r = 0.25$; $p = 0.27$) between IVOMD and NDVI. The correlation coefficient (r) between IVOMD and NDVI for sampling plots with highest proportion of grasses, semi-grasses and herbs is 0.41 ($p = 0.13$) (*Figure 14*).

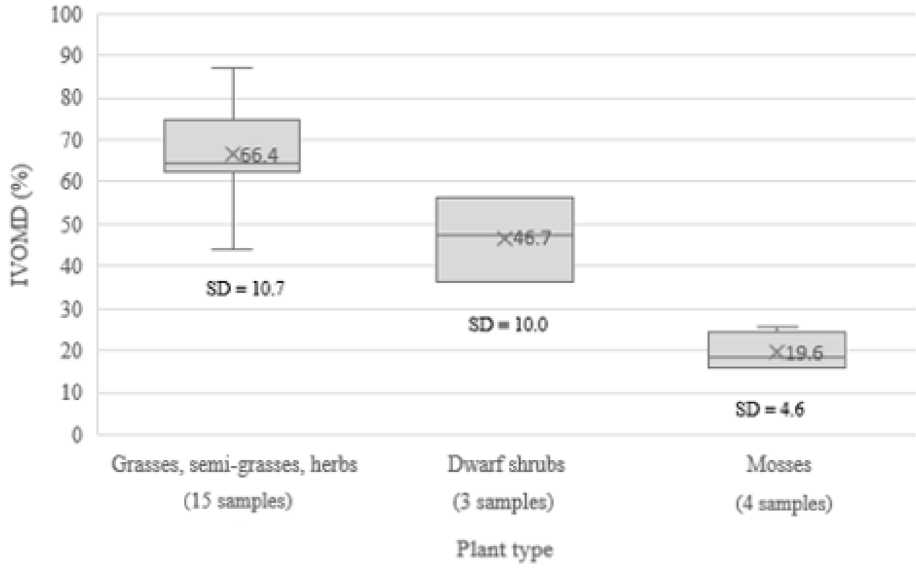


Figure 12. Boxplot and standard deviation (SD) for in vitro organic matter digestibility (IVOMD) per plant type.

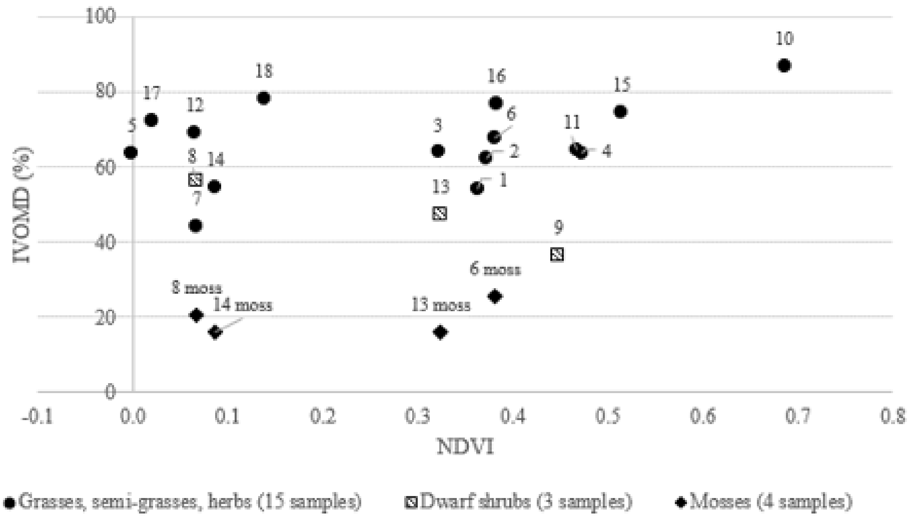


Figure 13. In vitro organic matter digestibility (IVOMD) plotted against Normalized Difference Vegetation Index (NDVI) for all sampling plots (numbered 1-18) and moss samples (4 numbered samples) from the plots where they occurred.

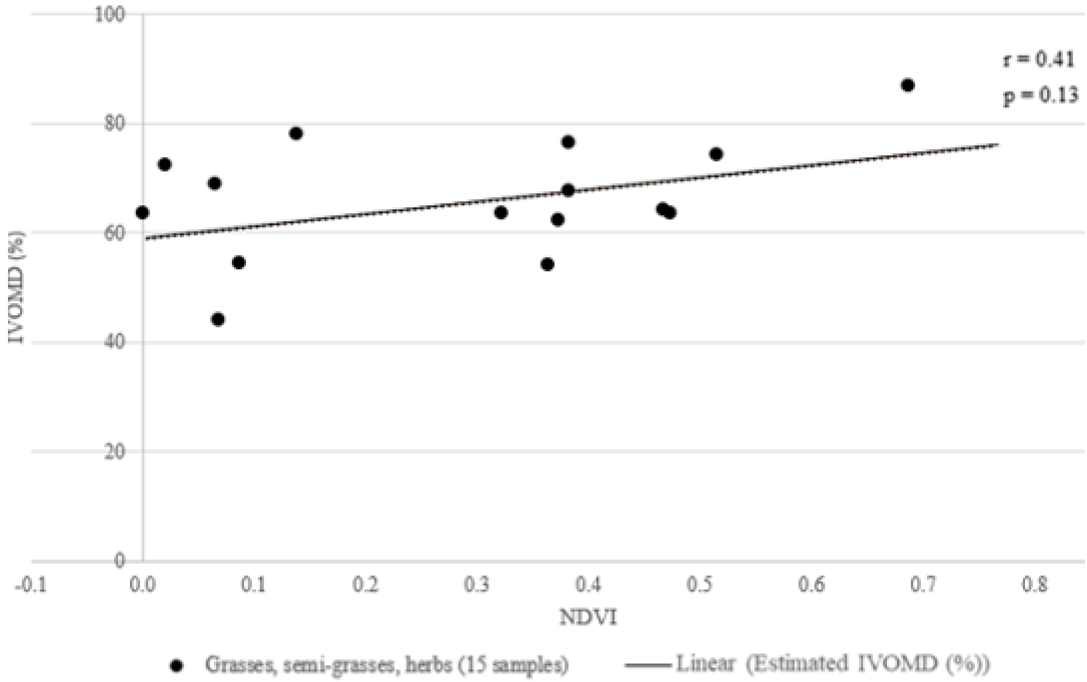


Figure 14. In vitro organic matter digestibility (IVOMD) for grasses, semi-grasses and herbs regressed against Normalized Difference Vegetation Index (NDVI).

Relationship between green biomass and NDVI

The correlation coefficient (r) between the weight of the green biomass that were cut in the sampling plots and NDVI is 0.60 (p = 0.01) (*Figure 15*).

al. (2019) could demonstrate when they investigated grasslands. More samples are

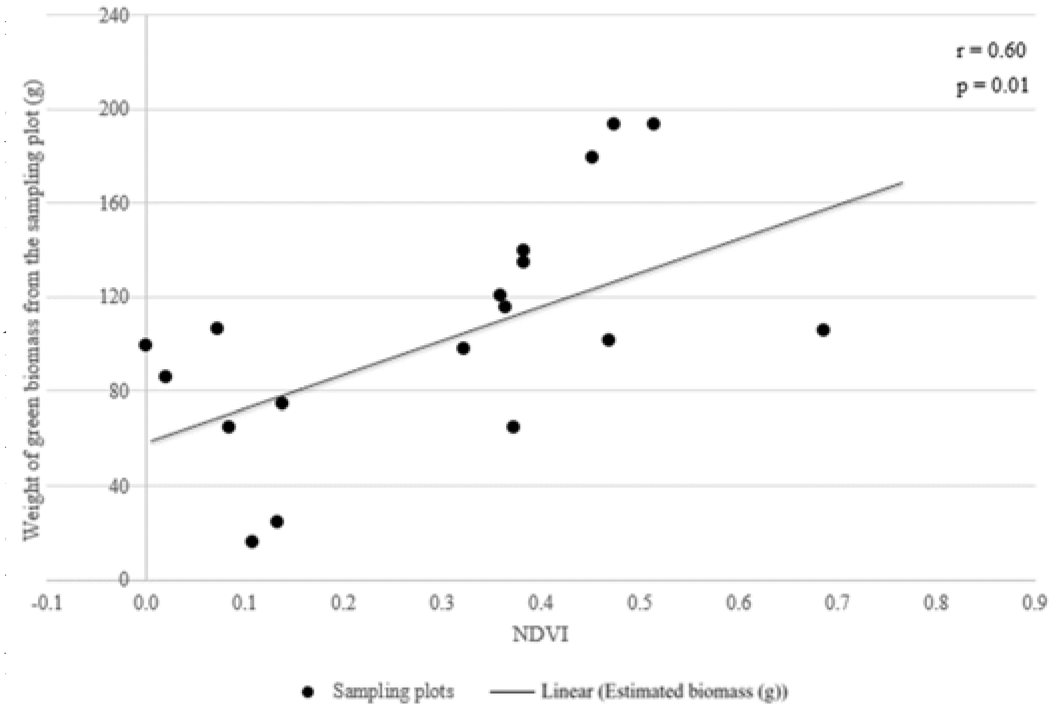


Figure 15. Weight of green biomass from the sampling plot (g) regressed against Normal Difference Vegetation Index (NDVI).

This because cell wall components show a strong negative correlation with digestibility and may be another, more indirect, way to reach a prediction of digestibility of the reindeer pastures. Ileri and Koc (2022) investigated the relationship between satellite derived NDVI and both NDF and ADF. There was a poor correlation between NDVI and NDF, but a moderate correlation between NDVI and ADF. When these relationships have been investigated using portable spectroradiometers, the results have varied. Starks *et al.* (2006) have shown low correlations while Albayrak (2008) has shown strong ones.

One thing to consider is that the conditions for the ability to predict digestibility of reindeer pastures may differ from the prediction on a ley since there is also dead biomass on reindeer pastures. The dead biomass risks covering living vegetation, which is then not captured on multispectral images and risk to underestimate the digestibility.

IVOMD analysis

The low digestibility of the mosses is expected because moss is rich in fibre and therefore difficult to digest. The digestibility values for mosses in this study are similar to earlier findings (Thomas & Kroeger 1981; Danell *et al.* 1994).

It is difficult to compare the digestibility results in the present analysis with results from the literature because the samples contain a large variety of species. In addition, in the plant group grasses, semi-grasses and herbs there may also be species that belong to the plant group dwarf shrubs, and vice versa. They are classified according to the plant type that had the largest proportion. Moreover, it seems generally that herbs are more digestible than dwarf shrubs, which in turn are more digestible than grasses and semi-grasses (Moore 1982). The most easily digestible plant type, herbs, is thus in this study grouped together with the most difficult to digest, grasses and semi-grasses. This makes the comparison even more difficult.

Sampling plot 10, on the other hand, contained only *Deschampsia flexuosa*. The analysis of this can be compared with the analysis of the same species conducted by Danell *et al.* (1994). Their IVOMD analysis (96h of fermentation in buffered rumen fluid) resulted in 82.5%, while the IVOMD in this study is 87.0%. Likewise, the species of *Carex* in sampling plot 5 can be compared with the analysis of *Carex rostrata* conducted by Thomas and Kroeger (1981). After 90h of fermentation in buffered rumen fluid, their IVDMD analysis resulted in 64.0%. For comparison, the IVDMD can be calculated to 61.4% in the present study.

The reindeer pasture plants used in this study were collected to capture the different vegetation types on the reindeer pastures. Regarding IVOMD, this can be considered very interesting. However, regarding the investigation of the correlation between IVOMD and NDVI, which was the main purpose of the study, it might have been better to focus on one plant type in this minor study. With only a small number of analyses as in this study, it could have given a clearer result.

Relationship between green biomass and NDVI

NDVI aims to capture the amount of living vegetation and in this study, there is a moderate correlation (r =0.60; p =0.01) between green biomass and NDVI. When comparing the visually assessed greenness of the sampling plots with its NDVI, the NDVI fails to capture the higher greenness assessed in sampling plot 8 than sampling plot 7 as both receives an equally low NDVI. The low NDVI for sampling plot 7 can be explained due to the wet soil moisture. Meanwhile, the low NDVI in sampling plot 8 may be due to its dry parts, as drought also gives a low NDVI (Dutta *et al.* 2013). Another reason could be that the *Calluna vulgaris* that dominates in the sampling plot 8 has small leaves. Thereby there is not as much chlorophyll that can absorb the light for photosynthesis which affects the NDVI (Dutta *et al.* 2013). Sampling plot 5 as well, has a lower NDVI value than sampling plot 2, even though the greenness was rated higher in sampling plot 5, and it also generated a higher amount of living plant material. It seems that the camera was not able to capture the narrow leaves of grass in sampling plot 5 as well as it managed to capture the broad leaves of the *Menyanthes trifoliata* in sampling plot 2. This can be seen as a shortcoming in the method of measuring the amount of living vegetation using NDVI calculated from images taken by drones. The correlation between green biomass and NDVI could have been stronger with another method to measure NDVI. An NDVI meter with "point-and-shoot" technology could possibly give a higher correlation, but we must not forget that it is an effective measurement at landscape level that we want to achieve.

Since reindeer feed on a large variety of plants and in several vegetation types, the NDVI as a measurement of representativeness of how much forage reindeer has available on a reindeer pasture can vary among different vegetation types and among the plant species. There may be many plant parts and species favorable for reindeer that don't correlate so well with greenness, flowers for example (Creech 2016), which will get the result that NDVI becomes underestimated. Even in this minor study this can be seen in the sampling plots 15 and 16, located at the ley. Both sampling plots are assessed to the same degree of greenness, but the NDVI is lower in sampling plot 16, probably because of the red sedges on *Agrostis capillaris*. The high greenness in the sampling plots 17 and 18, located at the mire with elements of reeds does not shine through in their values of NDVI which are very low. In sampling plot 17 there are many narrow leaves of grass among a lot of dead biomasses, which also do not seem to have been captured well by the camera. For sampling plot 18, the low NDVI value may be due to the semi-wet soil moisture.

The importance of reindeer getting the opportunity to graze selectively

If reindeer are given the opportunity to use its opportunistically selective foraging pattern, the feed intake increases. This also increases production capacity in terms of both the animal's own muscle growth and milk production for the calf's growth. High quality feed is ingested, and the plants' essential nutrients and biomass are balanced with the avoidance of secondary plant compounds. Pasture studies on cattle also show that the animals become less selective when there is a shortage of pasture and that if they are given the opportunity to select freely, they usually choose pasture with the highest content of metabolisable energy (Andrée *et al.* 2011). An increase in metabolisable energy intake would help build viable reindeer herds. The females get increased chances to be kept in good condition and produce a lot of milk for the calf's, which in turn get a good start in life. With a continued nutritious feed intake over the summer, the animals get excellent conditions for growth and to build up their body reserves for the winter and thus increase the possibilities of coping with the more difficult seasonal challenges.

Direction of reindeer husbandry

The interest in land areas is great, and knowledge is then particularly important in decision-making about land use. Decisions must also be based on long-term sustainability, where the question of the direction in which reindeer husbandry is heading becomes important. Pasture is the basic resource in reindeer husbandry and supplemental feeding should be considered a short-term emergency solution. When supplementary feeding becomes more common (Sámediggi 2020), there is a risk that the extensive animal husbandry that reindeer husbandry entails will more turn into intensive husbandry. Supplemental feeding also means an increased cost that does not necessarily lead to an increased slaughter yield, so it can be difficult for reindeer herders from a financial point of view. Reindeer's physiological development should also be considered. Even though reindeer have a good ability to adapt their digestion to new conditions in the environment (Hofmann 1989), it is the ability to convert feed undigestible to humans into valuable protein that distinguishes ruminants as a valuable and sustainable resource. Ringo *et al.* (2005) studied small intestines of slaughtered reindeer either fed pellets or grazed naturally on winter pasture. Small intestines from the pellet-fed animals showed abnormal changes, including deterioration or loss of microvilli. Continued feeding with pellets risks partly ill health in the individual, partly loss of important physiological functions, even in the long term. Furthermore, migration is a learning and cultural transmission that provides important knowledge about where high-quality forage is available and how habitat use can be optimized (Jesmer *et al.* 2018). Another consequence of the reduction in grazing area and migration possibilities is that this knowledge risks being lost.

What studies like this can contribute

Being able to predict the digestibility and chemical components of reindeer pastures on a landscape-scale using drone remote sensing would be fast and efficient, in comparison with the measurement of portable spectroradiometers. It would also be possible to take measurements in places that may be difficult to get to. This method could increase the understanding of reindeer's natural migration patterns and help promote green wave surfing. This could be used to identify valuable pastures and suitable stopover sites (Sawyer & Kauffman 2011), which can add valuable energy along migration. It could also be used to influence the construction of infrastructure and be a factor to measure when studying the impact of infrastructure.

Future research areas

Strong conclusions should not be drawn as this was a minor study with a limited amount of data. Further research with greater resources and more collected data could examine the relationship between NDVI and the digestibility of reindeer pasture plants more closely. It could also be investigated whether area, vegetation type and soil moisture have any effect on the result. As resources were limited in this study, the investigations were limited to digestibility only. This because it characterizes how much reindeer could assimilate from the pasture. Other qualitative factors could also be investigated such as CP, NDF and ADF. Future improvements in camera and drone technology may also increase the possibilities for a better reflection of the landscape and its detail and thereby contribute to being able to investigate the relationship further.

5. Conclusions

To give reindeer the opportunity to use its well-developed foraging pattern and follow the phenological development of the plants is of immense importance in obtaining viable reindeer herds. The aim of this study was to investigate the relationship between NDVI and the digestibility of reindeer pasture plants. The result of this study shows no correlation ($r = 0.25$; $p = 0.27$) between NDVI and IVOMD when all plant types are included in a regression analysis, but that there is a moderate correlation ($r = 0.41$; $p = 0.13$) between NDVI and IVOMD of the plant type grasses, semi-grasses and herbs. The multispectral camera did not capture the greenness from narrow leaves very well, which seems to be a weakness of calculating NDVI from multispectral images taken from a drone. This study is a small step forward in trying to understand the relationship between NDVI and digestibility of reindeer pasture plants. The strength of the relationship could vary among vegetation type, plant type or season. Reindeer graze in several different vegetation types and estimating the digestibility of pastures in this way may not be suitable in all areas or seasons. Further research could more clearly explain the relationship.

References

AOAC (1990). *AOAC: Official Methods of Analysis (Volume 1)*. 15th edition. Virginia, USA: Association of Official Analytical Chemists, Inc. https://law.resource.org/pub/us/cfr/ibr/002/aoac.methods.1.1990.pdf

Albayrak, S. (2008). Use of Reflectance Measurements for the Detection of N, P, K, ADF and NDF Contents in Sainfoin Pasture. *Sensors,* 8(11), 7275-7286. https://doi.org/10.3390/s8117275

Andrée, L., Pelve, M., Back, J., Wahlstedt, E., Glimskär, A. & Spörndly, E. (2011). *Naturbetets näringsinnehåll och avkastning i relation till nötkreaturens val av plats vid bete, vila, gödsling och urinering*. (Report 278). https://pub.epsilon.slu.se/8421/1/andree_l_etal_111208.pdf

Bjørklund, I. (2013). Domestication, Reindeer Husbandry and the Development of Sámi Pastoralism. *Acta Borealia,* 30(2), 174-189. https://doi.org/10.1080/08003831.2013.847676

Colman, J.E., Pedersen, C., Hjermann, D.Ø., Holand, Ø., Moe, S.R. & Reimers, E. (2003). Do Wild Reindeer Exhibit Grazing Compensation during Insect Harassment? *The Journal of Wildlife Management,* 67, No 1, 11-19. https://doi.org/10.2307/3803056

Creech, T.G., Epps, C.W., Monello, R.J., Wehausen, J.D. (2016). Predicting diet quality and genetic diversity of a desert-adapted ungulate with NDVI. *Journal of Arid Environments,* 127, 160-170. https://doi.org/10.1016/j.jaridenv.2015.11.011

Dancey, C.P. & Reidy, J. (2007). Statistics without Maths for Psychology. Pearson Education.

Danell, K., Utsi, P.M., Palo, T. & Eriksson, O. (1994). Food plant selection by reindeer during winter in relation to plant quality. *Ecography,* 17, 153-158. https://doi.org/10.1111/j.1600-0587.1994.tb00088.x

Dutta, D., Kundu, A. & Patel, N.R. (2013). Predicting agricultural drought in eastern Rajasthan of India using NDVI and standardized precipitation index. *Geocarto International,* 28(3), 192-209. https://doi.org/10.1080/10106049.2012.679975

Engine, G.E. (2022). *MOD13Q1.006 Terra Vegetation Indices 16-Day Global 250m [deprecated]*. https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD13Q1#bands

Esseen, P.-A., Glimskär, A., Ståhl, G. & Sundquist, S. (2003). Fältinstruktion för nationell inventering av landskapet i Sverige, NILS. Institutionen för skoglig resurshushållning och geomatik. Umeå: Sveriges lantbruksuniversitet.

Gao, R., Kong, Q., Wang, H. & Su, Z. (2019). Diagnostic Feed Values of Natural Grasslands Based on Multispectral Images Acquired by Small Unmanned Aerial Vehicle. *Rangeland Ecology & Management,* 72, 916-922. https://doi.org/10.1016/j.rama.2019.06.005

Garmo, T.H. (1986). Chemical composition and in vitro dry matter digestibility of lichens. *Rangifer,* 6, 8-13. https://doi.org/10.7557/2.6.1.569

Garroutte, E.L., Hansen, A.J. & Lawrence, R.L. (2016). Using NDVI and EVI to Map Spatiotemporal Variation in the Biomass and Quality of Forage for Migratory Elk in the Greater Yellowstone Ecosystem. *Remote Sensing,* 8(5). https://doi.org/10.3390/rs8050404

Gerlach, K., Pries, M. & Südekum, K.H. (2018). Effect of condensed tannin supplementation on in vivo nutrient digestibilities and energy values of concentrates in sheep. *Small Ruminant Research,* 161, 57-62. https://doi.org/10.1016/j.smallrumres.2018.01.017

Harrie, L., Eklundh, L., Ågren, J., Olsson, H. & Klang, D. (2020). *Geografisk informationsbehandling - Teori, metoder och tillämpningar*. (Upplaga 7:1). Lund: Författarna och Studentlitteratur.

Hofmann, R.R. (1989). Evolutionary steps of ecophysiological adaptation and diversification of ruminants: A comparative view of their digestive system. *Oecologia,* 78, 443-457. https://www.jstor.org/stable/4218890

Hughes, M.P., Mlambo, V., Jennings, P.G.A., Lallo, C.H.O., Basha, N.A.D. & Nsahlai, I.V. (2017). Accuracy of two optical chlorophyll meters in predicting chemical composition and in vitro ruminal organic matter degradability of Brachiaria hybrid, Megathyrsus maximus, and Paspalum atratum. *Animal Nutrition,* 3(1), 67-76. https://doi.org/10.1016/j.aninu.2016.10.002

Hughes, M.P., Wuddira, M.N., Mlambo, V., Jennings, P.G.A. & Lallo, C.H.O. (2014). Non-destructive foliar chlorophyll measurement has the potential to predict crude protein concentration and in vitro ruminal organic matter digestibility in Bracharia decumbens herbage. *Animal Feed Science and Technology,* 195, 14-27. https://doi.org/10.1016/j.anifeedsci.2014.06.011

Ileri, O. & Koc, A. (2022). Monitoring the available forage using Sentinel 2-derived NDVI data for sustainable rangeland management. *Journal of Arid Environments,* 200. https://doi.org/10.1016/j.jaridenv.2022.104727

Jennewein, J.S., Eitel, J.U.H., Pinto, J.R. & Vierling, L.A. (2020). Toward Mapping Dietary Fibers in Northern Ecosystems Using Hyperspectral and Multispectral Data. *Remote Sensing,* 12(16). https://doi.org/10.3390/rs12162579

Jesmer, B.R., Merkle, J.A., Goheen, J.R., Aikens, E.O., Beck, J.L., Courtemanch, A.B., Hurley, M.A., MeWhicter, D.E., Miyasaki, H.M., Monteith, K.L. & Kauffman, M.J. (2018). Is ungulate migration culturally transmitted? Evidence of social learning from translocated animals. *Science,* 361(6406), 1023-1025. https://doi.org/10.1126/science.aat0985

Johnson, H.E., Golden, T.S., Adams, L.G., Gustine, D.D., Lenart, E.A. & Barboza, P.S. (2021). Dynamic selection for forage quality and quantity in response to phenology and insects in an Arctic ungulate. *Ecology and Evolution,* 11(17), 11551-12231. https://doi.org/10.1002/ece3.7852

Johnson, H.E., Gustine, D.D., Golden, T.S., Adams, L.G., Parrett, L.S., Lenart, E.A. & Barboza.P.S. (2018). NDVI exhibits mixed success in predicting spatiotemporal variation in caribou summer forage quality and quantity. *Ecosphere 9(10)*. https://doi.org/10.1002/ecs2.2461

Johnson, H.E., Lenart, E.A., Gustine, D.D., Adams, L.G. & Barboza, P.S. (2022). Survival and reproduction in Arctic caribou are associated with summer forage and insect harassment. *Front. Ecol. Evol.,* 10. https://doi.org/10.3389/fevo.2022.899585

Kuropat, B.S.P.J. (1984). *Foraging Behaviour of Caribou on a Calving Ground in Northwestern Alaska.* Fairbanks, Alaska: University of Alaska. http://hdl.handle.net/11122/7423

Larsen, R.K., Raitio, K., Sandström, P., Skarin, A., Stinnerbom, M., Wik-Karlsson, J., Sandström, S., Österlin, C. & Buhot, Y. (2016). *Kumulativa effekter av exploateringar på renskötseln -vad behöver göras inom tillståndsprocesser*. Bromma: Naturvårdsverket.

Lindgren, E. (1979). *Vallfodrets näringsvärde bestämt in vivo och med olika laboratoriemetoder.* (45). Animal Nutrition and Management. Swedish University Agricultural Science, SLU. Uppsala, Sweden (in Swedish with English summary).

Mahyuddin, P. (2008). Relationship Between Chemical Component and In Vitro Digestibility of Tropical Grasses. *Journal of Biosciences,* 15. https://doi.org/10.4308/hjb.15.2.85

Makkar, H.P.S., Blümmel, M. & Becker, K. (1995). In vitro effects of and interactions between tannins and saponins and fate of tannins in the rumen. *Journal of the Science of Food and Agriculture,* 69(4), 481-493. https://doi.org/10.1002/jsfa.2740690413

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A. & Wilkinson, R.G. (2010). *Animal Nutrition*. (Sevent Edition). Pearson.

Merkle, J.A., Monteith, K.L., Aikens, E.O., Hayes, M.M., Hersey, K.R., Middleton, A.D., Oates, B.A., Sawyer, H., Scurlock, B.M. & Kauffman, M.J. (2016). Large herbivores surf waves of green-up during spring. *Proceedings of the Royal Society B-Biological Sciences,* 283(1833). https://doi.org/10.1098/rspb.2016.0456

Moore, J.T. (1982). *Factors Affecting Grazing Patterns Of Reindeer On Summer Tundra Ranges*. University of Alaska. http://hdl.handle.net/11122/8388

Mossberg, B. & Stenberg, L. (2018). *Nordens Flora*. New edition. Stockholm: Bonnier Fakta.

Myers-Smith, I.H., Kerby, J.T., Phoenix, G.K., Bjerke, J.W., Epstein, H.E., Assmann, J.J., John, C., Andreu-Hayles, L., Angers-Blondin, S., Beck, P.S.A., Berner, L.T., Bhatt, U.S., Bjorkman, A.D., Blok, D., Bryn, A., Christiansen, C.T., Cornelissen, J.H.C., Cunliffe, A.M., Elmendorf, S.C., Forbes, B.C., Goetz, S.J., Hollister, R.D., de Jong, R., Loranty, M.M., Macias-Fauria, M., Maseyk, K., Normand, S., Olofsson, J., Parker, T.C., Parmentier, F.J.W., Post, E., Schaepman-Strub, G., Stordal, F., Sullivan, P.F., Thomas, H.J.D., Tommervik, H., Treharne, R., Tweedie, C.E., Walker, D.A., Wilmking, M. & Wipf, S. (2020). Complexity revealed in the greening of the Arctic. *Nature Climate Change,* 10(2), 106-117. https://doi.org/10.1038/s41558-019-0688-1

Parker, K.L., Barboza, P.S. & Stephenson, T.R. (2005). Protein conservation in female caribou (Rangifer tarandus): Effects of decreasing diet quality during winter. *Journal of Mammalogy,* 86(3), 610-622. https://doi.org/10.1644/1545-1542(2005)86[610:Pcifcr]2.0.Co;2

QGIS Development Team (2020). *QGIS 3.18 Zürich*. (3.18.3-Zürich) [Soft ware].

Ringø, E., Mathiesen, S.D., Storeheier, P.V., Mayhew, T.M., Myklebust, R. (2005). Effects of natural winter pasture and commercial pellet on the ultrastructure of small intestinal epithelium in reindeer. *Cell Tissues Res,* 320, 355-359. https://doi.org/10.1007/s00441-004-1074-4

Rivrud, I.M., Sivertsen, T.R., Mysterud, A., Åhman, B., Støen, O.-G. & Skarin, A. (2018). Reindeer green-wave surfing constrained by predators. *Ecosphere,* 9. https://doi.org/10.1002/ecs2.2210

Sámediggi (2020). Rennäringens tillstånd 2020. Giron/Kiruna: Sametinget 20201.

Sámediggi (2021). *Rovdjursersättning*. https://www.sametinget.se/rovdjur [2023-03-17]

Sámediggi (2022a). *Rennäringen i Sverige*. https://www.sametinget.se/rennaring_sverige [2023-03-17]

Sámediggi (2022b). *Rennäring*. https://sametinget.se/samebyar [2023-03-17]

Sámediggi (2023). *Renhjorden*. https://www.sametinget.se/statistik/renhjorden [2023-01-04]

Sandström, P. (2015). *A toolbox for Co-production of Knowledge and Improved Land Use Dialogues. The Perspective of Reindeer Husbandry.* Faculty of Forestry, Department of Forest Resource Management. Umeå: Swedish University of Agricultural Sciences. https://publications.slu.se/?file=publ/show&id=64872

Sawyer, H. & Kauffman, M.J. (2011). Stopover ecology of a migratory ungulate. *Journal of Animal Ecology,* 80(5), 1078-1087. https://doi.org/10.1111/j.1365-2656.2011.01845.x

SFS. *Rennäringslag (1971:437)*. Näringsdepartementet RSL. https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/rennaringslag-1971437_sfs-1971-437 [2022-09-07]

Skarin, A. (2006). *Reindeer Use of Alpine Summer Habitats.* Faculty of Veterinary Medicine and Animal Science Reindeer Husbandry. Uppsala: Swedish University of Agricultural Sciences. https://pub.epsilon.slu.se/1196/1/AS_thesis.pdf

Skarin, A. (2007). Habitat use by semi-domesticated reindeer, estimated with pellet-group counts. *Rangifer,* 27(2), 121-132. https://doi.org/10.7557/2.27.2.167

Skarin, A. & Alam, M. (2017). Reindeer habitat use in relation to two small wind farms, during preconstruction, construction, and operation. *Ecology and Evolution,* 7(11), 3870-3882. https://doi.org/10.1002/ece3.2941

Skarin, A., Danell, Ö., Bergström, R. & Moen, J. (2008). Summer habitat preferences of GPS-collared reindeer Rangifer tarandus tarandus. *Wildlife Biology,* 14(1), 1-15. https://doi.org/10.2981/0909-6396(2008)14[1:SHPOGR]2.0.CO;2

Skarin, A., Danell, Ö., Bergström, R. & Moen, J. (2010). Reindeer movement patterns in alpine summer ranges. *Polar Biol,* 33, 1263-1275. https://doi.org/10.1007/s00300-010-0815-y

Starks, P.J., Zhao, D., Phillips, W.A. & Coleman, S.W. (2006). Herbage mass, nutritive value and canopy spectral reflectance of bermudagrass pastures. *Grass and Forage Science,* 61(2), 101-111. https://doi.org/10.1111/j.1365-2494.2006.00514.x

Steen, E. (1966). I renbetesmarkerna. *SOU 1966:12*. https://lagen.nu/sou/1966:12

Sundset, M.A., Barboza, P.S., Green, T.K., Folkow, L.P., Blix, A.S. & Mathiesen, S.D. (2010). Microbial degradation of usnic acid in the reindeer rumen. *Naturwissenschaften,* 97(3), 273-278. https://doi.org/10.1007/s00114-009-0639-1

The AppGuru (2019). *Grid Drawing* (2.5) [Soft ware].

Thomas, D.C. & Kroeger, P. (1981). Digestibility of Plants in Ruminai Fluids of Barren-Ground Caribou. *Arctic Institute of North America,* 34, 321-324. https://www.jstor.org/stable/40509207

Tilley, J.M.A. & Terry, R.A. (1963). A two-stage technique for the in vitro digestion of forage crops. *J Brit Grassland Soc,* 18:104. https://doi.org/10.1111/j.1365-2494.1963.tb00335.x

Wallsten, J. (2003). *In vivo and in vitro digestibility of lichens and silage for reindeer.* Institutionen för husdjursgenetik. Swedish University of Agricultural Science, SLU.

Warenberg, K. (1982). *Reindeer forage plants in the early grazing season. Growth and nutritional content in relation to climatic conditions.* Acta Phytogeogr. Suec. 70. Uppsala: Uppsala Universitet. http://uu.diva-portal.org/smash/get/diva2:565354/FULLTEXT02.pdf

Warenberg, K., Danell, Ö., Gaare, E. & Nieminen, M. (1997). *Flora i renbetesland*. Nordiskt organ för renforskning (NOR) och A/S Landbruksforlaget.

Webber, Q.M.R., Ferraro, K.M., Hendrix, J.G. & Vander Wal, E. (2022). What do caribou eat? A review of the literature on caribou diet. *Canadian Journal of Zoology,* 100(3), 197-207. https://doi.org/10.1139/cjz-2021-0162

White, R.G. (1983). Foraging Patterns and Their Multiplier Effects on Productivity of Northern Ungulates. *Oikos,* 40, 377-384. https://doi.org/10.2307/3544310

White, R.G. & Trudell, J. (1980). Habitat Preference and Forage Consumption by Reindeer and Caribou near Atkasook, Alaska. *Arctic and Alpine Research,* 12, 511-529. https://doi.org/10.2307/1550498

Ya'acob, N., Azize, A.B.M., Mahmon, N.A., Yusof, A.L., Azmi, N.F. & Mustafa, N. (2014). Temporal Forest Change Detection and Forest Health Assessment using Remote Sensing. *IOP Conf. Series: Earth and Environmental Science,* 19. https://doi.org/10.1088/1755-1315/19/1/012017

Åhman, B. (1984). Renbeteslavarnas mineralinnehåll — en litteraturöversikt. *Rangifer, 4(2-App)*, 44-63. https://doi.org/10.7557/2.4.2-App.515

Åhman, B. (2013). *Renhjord i kollaps - Produktivitet, kondition och renförluster i Njaarke sameby*. (285). Uppsala. https://pub.epsilon.slu.se/10210/11/ahman_b_1304024.pdf

Popular science summary

Kan värdefulla renbetesmarker identifieras med hjälp av drönarteknik?

Renen är ett tåligt hjortdjur som genom tiderna har lyckats anpassa sig väl till sina förutsättningar i omgivningen. Den har en förmåga att kunna följa grönskans utveckling på våren för att maximera intaget av späda och näringsrika växter under sin vandring till sommarbetet. I den här studien har sambandet mellan renbetesväxters kvalitet och ett vegetationsindex från drönarfoton undersökts.

Renen utnyttjar sina kroppsreserver vintertid och kan tappa 20-40 % av sin kroppsvikt till följd av den magrare betessäsongen. Sommarbetet är mycket viktigt för återuppbyggnaden av kroppsreserverna. Det kan erbjuda gott om näringsrika växter för renen men där lurar även rovdjur som varg, lo, björn, järv och örn som kan störa betesron. Angrepp av insekter kan också vara mycket besvärligt och störa betesron. Infrastruktur och övrig mänsklig påverkan försvårar tillgängligheten av betesmarkerna och vilka flyttleder renen kan ta. Med dessa störningar blir det svårare för renen att följa grönskans utveckling.

Drönartekniken har utvecklats mycket på senare år och drönarens användningsområden har expanderat. Även inom rennäringen används drönare som ett effektivt hjälpmedel vid övervakning och förflyttning av renhjorden. Drönare kan utrustas med multispektrala kameror för att fotografera landskapet även i det nära-infraröda (NIR) våglängdsbandet. Med hjälp av sådana fotografier kan vegetationsindexet Normalized Difference Vegetation Index (NDVI) beräknas. Detta index kan mäta hur mycket levande vegetation det finns i det fotograferade området. Den här studien syftade till att undersöka om detta index även kan avslöja smältbarheten av renbetesväxter, d.v.s. hur mycket renen kan tillgodogöra sig av de växter den äter. Renbetesmark i Malå sameby fotograferades med hjälp av en drönare. Växtprover samlades därefter in från området för att göra en analys av smältbarheten.

Resultatet kunde inte visa på ett samband mellan indexet och smältbarheten av renbetesväxter när alla växttyper studerades. Ett måttligt samband kunde däremot urskiljas på de platser där andelen gräs och örter var större än andelen blåbärsris och andra småbuskar. Det fanns alltså en tendens till ett samband mellan indexet och smältbarheten av gräs och örter. Tidigare forskning har visat ett relativt starkt samband mellan indexet och smältbarheten av gräs då indexet i stället beräknats med hjälp av handhållna NDVI-mätare på mycket nära avstånd. Framtidens teknik kanske effektivt kommer kunna ge svaret på i vilka markområden renen bäst kan tillgodogöra sig näring. Med en sådan information blir det lättare att förstå renens naturliga vandringsmönster och hur vi kan arbeta för att främja dessa, bland annat genom anpassningar i uppbyggandet av infrastruktur.

Acknowledgements

I would like to thank my supervisors Anna Skarin, Erik Cronwall and Horacio Gonda for all their commitment and support. I would also like to thank MINEDEER, reference number 2019-05191, who gave me this study opportunity. Finally, I would like to thank my husband for all his love and support.

Appendix 1

Overview of the five areas and the 18 sampling plots.

1-9: The large mire
10-11: The clear-cut forest area
12-14: The small mire
15-16: The ley
17-18: The mire with elements of reeds

Figure A1. Overview of the five areas and the 18 sampling plots.

Appendix 2

The five different areas and the 18 vegetation types sampled.

The large mire

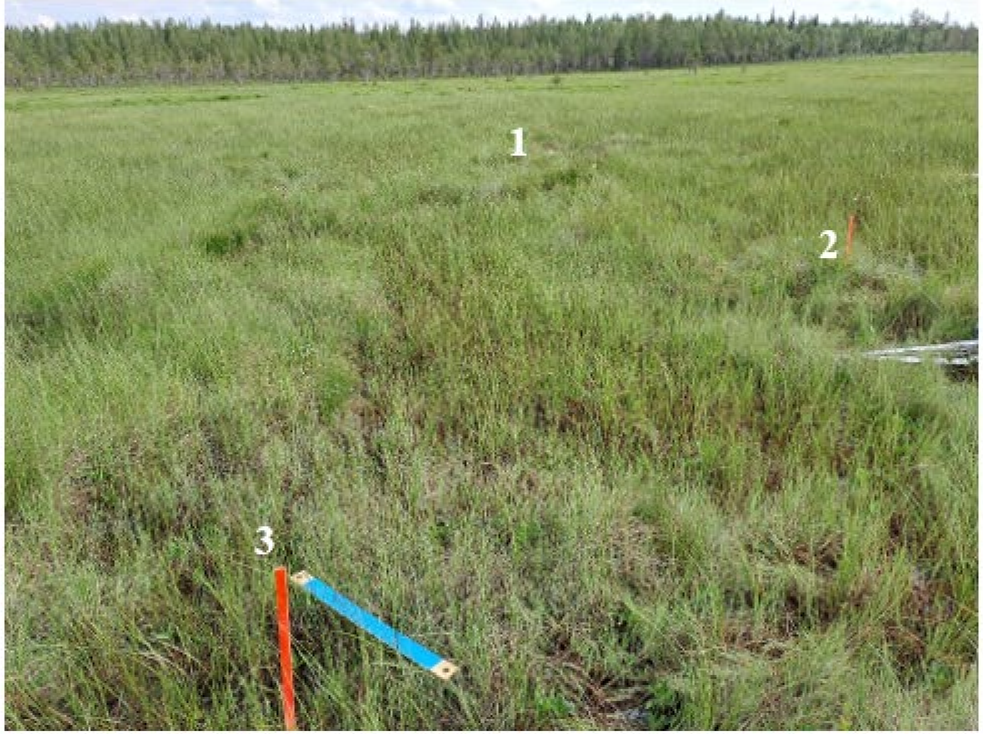


Figure A2. The large mire – Sample 1-3. Sample 1 was collected from a drier part in this area and contained mainly Trichophorum cespitosum and Carex rostrata (1). Sample 2 contained mainly Menyanthes trifoliata and Carex rostrata and was collected from a wetter part (2). Sample 3 was collected from a semi-wet part and contained mainly Carex livida and Menyanthes trifoliata (3).

Figure A3. The large mire – Sample 4 & 5. Sample 4 was collected from the tufted Molinia caerulea on the right in the image, which also grew with some Carex nigra ssp. juncella (4). Sample 5 contained Carex rostrata and was collected from a wetter part, more to the left in the image (5).

Figure A4. The large mire – Sample 6 & 7 no.1. Sample 6 was intended to capture the strands of grass, which consisted mainly of Molinia caerulea (6). The less greener vegetation type in this image is captured in sample 7 (7 e.g.). The moss in the sixth plot was collected in a separate sample bag.

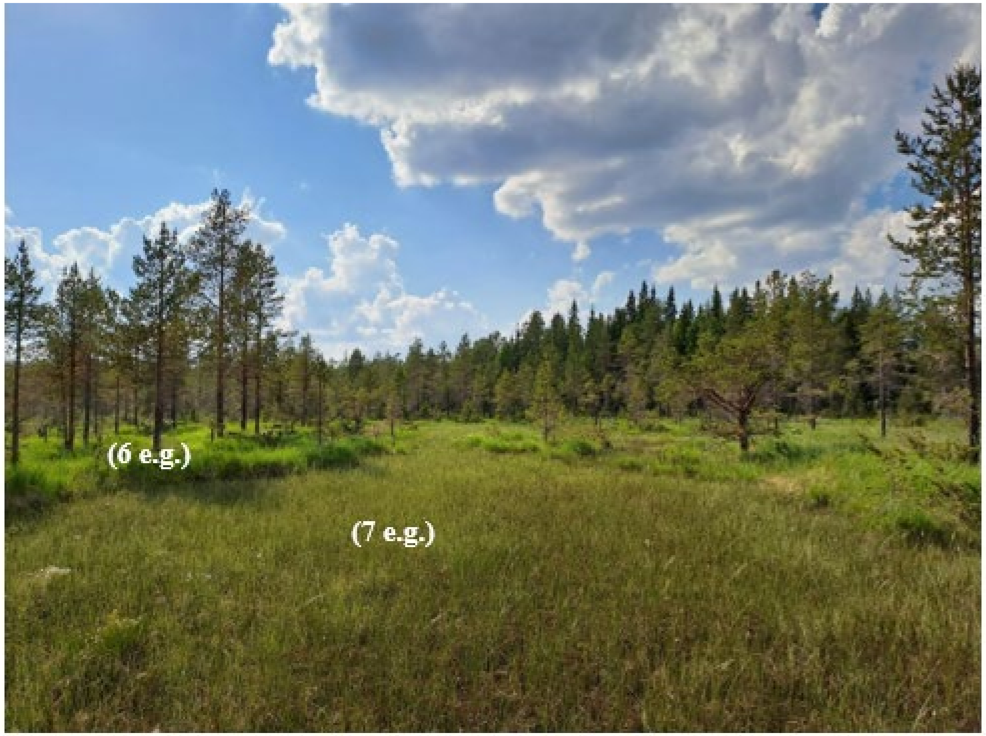


Figure A5. The large mire – Sample 6 & 7 no.2. Sample 7 was collected in this wetter type of vegetation, which consisted of several Carex species and Eriophorum angustifolium (7 e.g.). The strands of grass which constituted sample 6 is also visible in the image (6 e.g.).

Figure A6. The large mire – Sample 8. Sample 8 contained mainly Calluna vulgaris, but also some Betula nana, Molinia caerulea and Carex vaginata (8). Moss was collected in a separate sample bag.

Figure A7. The large mire – Sample 9. Sample 9 contained several species of dwarf shrubs but also Eriophorum vaginatum among other species (9).

The clear-cut forest area

Figure A8. The clear-cut forest area – Sample 10. Sample 10 contained Deschampsia flexuosa (10).

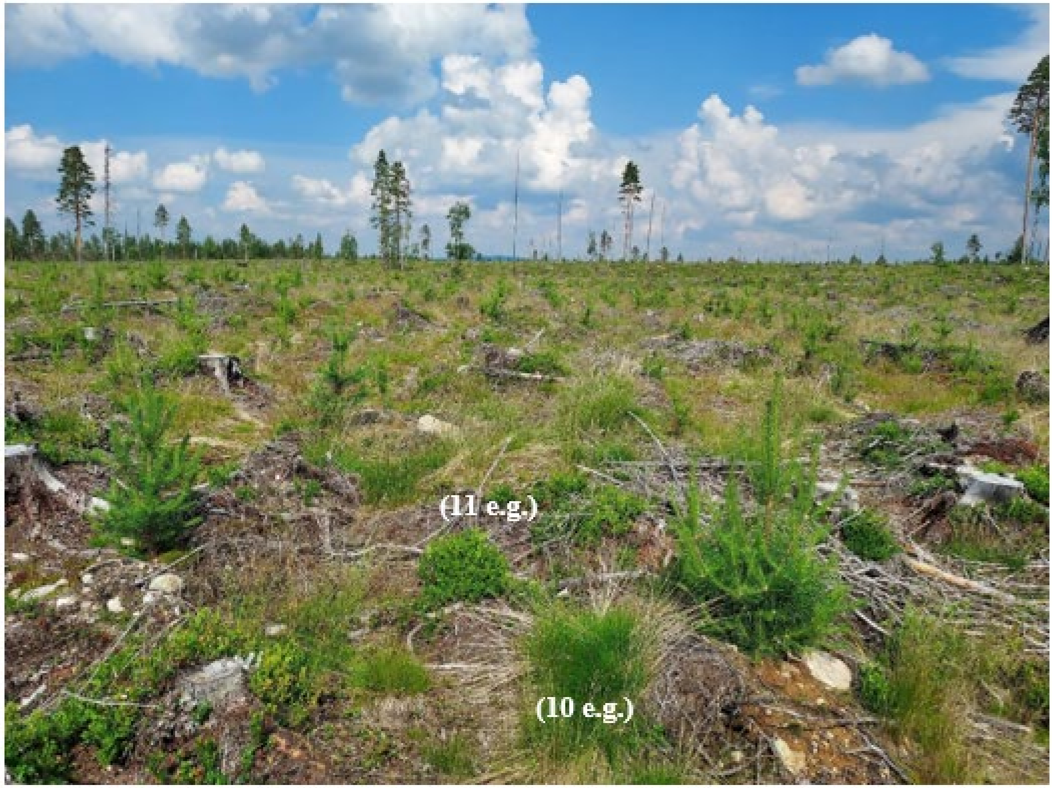


Figure A9. The clear-cut forest area – Sample 10 & 11. Sample 10 was collected from a plot with tufts of Deschampsia flexuosa on this clear-cut (10 e.g.). Sample 11 was collected from another vegetation type in the area, which consisted of Vaccinium myrtillus and Deschampsia flexuosa (11 e.g.).

The small mire

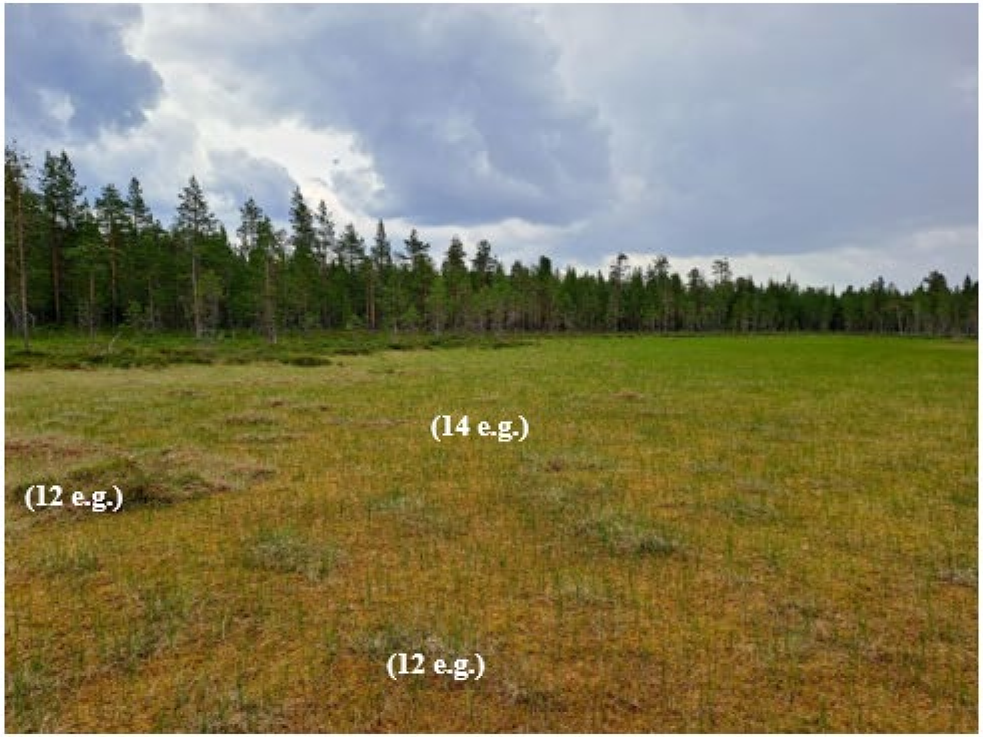


Figure A10. The small mire – Sample 12 & 14. Sample 12 was collected from parts in this area corresponding to the drier patches in this image, which consisted mainly of Trichophorum cespitosum, Carex pauciflora and Spaghnum (12 e.g.). Sample 14 was collected from the wetter parts, which consisted mainly of Eriophorum scheuchzeri on a bed of spaghnum (14 e.g.). The spaghnum was collected in a separate sample bag.

Figure A11. The small mire – Sample 13. Sample 13 was collected from this type of vegetation, near the forest edge, which consisted of Empetrum nigrum and Rubus chamaemorus, among other species (13 e.g.). The spaghnum was collected in a separate sample bag.

The ley

Figure A12. The ley – Sample 15 & 16. Sample 15 and 16 was collected from plots close together on this ley and consisted of Agrostis capillaris and several other ley species (15 & 16 e.g.).

The mire with elements of reeds

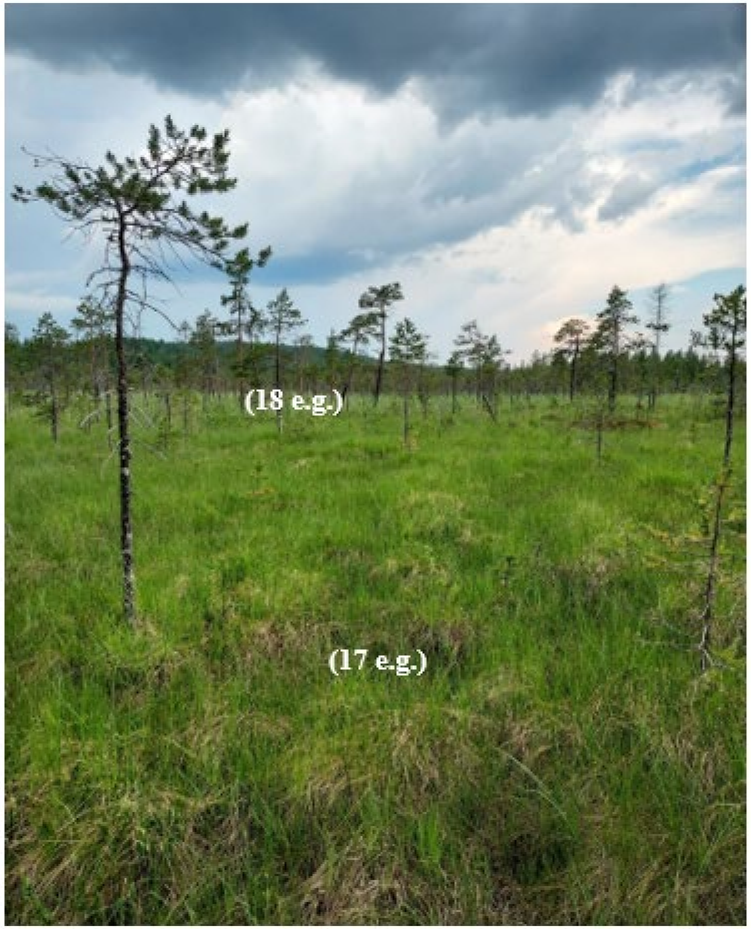
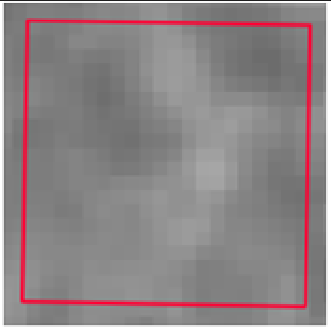
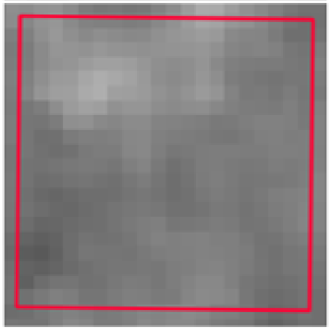
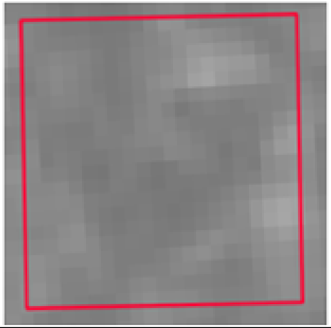


Figure A13. The mire with elements of reeds – Sample 17 & 18 no.1. Sample 17, which consisted mainly of Molinia caerulea, was collected from this part of the mire (17 e.g.). Further in the image, the part with reed for sample 18 can be glimpsed (18 e.g.).

Figure A14. The mire with elements of reeds – Sample 17 & 18 no.2. Sample 18 was collected from this part of the mire with mainly Trichophorum cespitosum and Molinia caerulea and with elements of reeds (18 e.g.). Further in the image, the part for sample 17 can be glimpsed (17 e.g.).

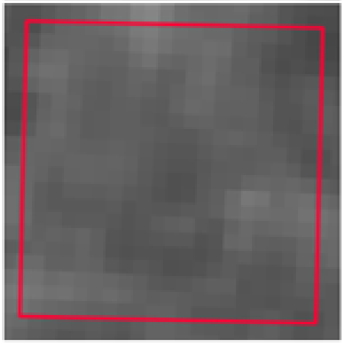
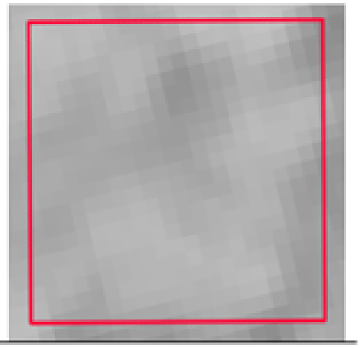
Appendix 3

Table A1. Results of soil moisture classification, NDVI, IVOMD, DM, ash, weight from plot, ratio of plant types, assessment of plant coverage of both greenness and species and RGB and NDVI images on the sampling plots.

Sampling plot	Area	Soil moisture classification	Mean NDVI-value	Mean IVOMD (%)	Mean IVOMD (%) of moss	DM (g/kg)	Ash (g/kg)	Weight from plot (g)	Ratio grasses/semi-grasses/herbs : dwarf shrubs	Greenness (%)	Species[1]	RGB-image	NDVI-image
1	Large mire	Dry	0.4	54.13		930.5	34.0	116.0	11.5 : 1.0	46.9	*Trichophorum cespitosum* (34.0%), *Carex rostrata* (8.1%), *Betula nana* (2.9%), *Menyanthes trifoliata* (0.9%), *Andromeda polifolia* (0.9%), *Equisetum fluviatile* (0.1%)		
2	Large mire	Wet	0.4	62.4		929.7	37.9	65.0	1 : 0	19.5	*Carex rostrata* (14.8%), *Menyanthes trifoliata* (4.0%), *Equisetum fluviatile* (0.7%)		
3	Large mire	Semi-wet	0.3	63.9		925.8	39.5	98.0	1 : 0	23.8	*Carex livida* and an unspecified low *Carex* species (19.1%), *Menyanthes trifoliata* (4.7%), *Equisetum fluviatile* (0.0%)		

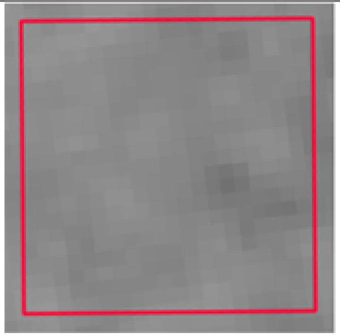
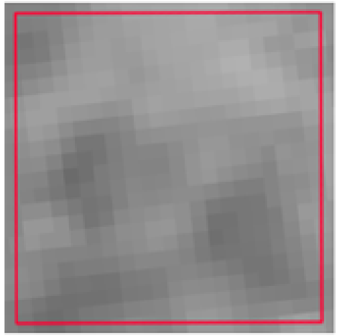
[1] All species identified in the sampling plot. Plant coverage assessment in parentheses.

Table A1. Results of soil moisture classification, NDVI, IVOMD, DM, ash, weight from plot, ratio of plant types, assessment of plant coverage of both greenness and species and RGB and NDVI images on the sampling plots.

Sampling plot	Area	Soil moisture classification	Mean NDVI-value	Mean IVOMD (%)	Mean IVOMD (%) of moss	DM (g/kg)	Ash (g/kg)	Weight from plot (g)	Ratio grasses/semi-grasses/herbs : dwarf shrubs	Greenness (%)	Species[1]	RGB-image	NDVI-image
4	Large mire	Dry	0.5	63.8		930.5	34.7	194.0	1 : 0	76.6	*Molinia caerulea* (57.4%), *Carex nigra ssp. juncella* (19.1%)		
5	Large mire	Semi-wet	0.0	63.7		927.9	34.9	100.0	1 : 0	31.3	*Carex rostrata* and ev. other *Carex* species (31.3%)		
6	Large mire	Dry	0.4	67.7	25.6	923.5	30.00	140.0	1 : 0	68.8	*Molinia caerulea* (62.6%), *Carex nigra ssp. juncella* (6.3%), *Equisetum fluviatile* (0.0%), unspecified moss (0.0%)		

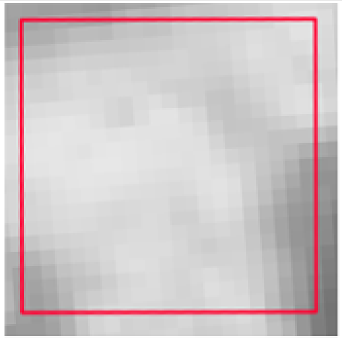
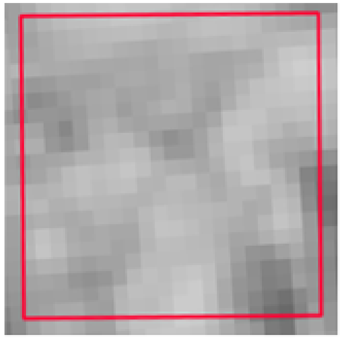
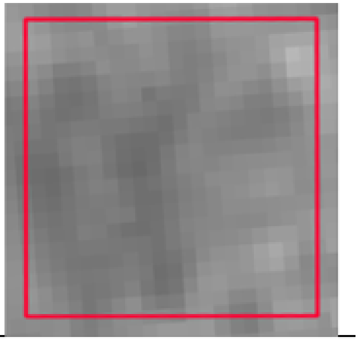
[1]All species identified in the sampling plot. Plant coverage assessment in parentheses.

Table A1. Results of soil moisture classification, NDVI, IVOMD, DM, ash, weight from plot, ratio of plant types, assessment of plant coverage of both greenness and species and RGB and NDVI images on the sampling plots.

Sampling plot	Area	Soil moisture classification	Mean NDVI-value	Mean IVOMD (%)	Mean IVOMD (%) of moss	DM (g/kg)	Ash (g/kg)	Weight from plot (g)	Ratio grasses/semi-grasses/herbs : dwarf shrubs	Greenness (%)	Species[1]	RGB-image	NDVI-image
7	Large mire	Semi-wet	0.1	44.1		930.2	22.2	65.0	1 : 0	20.0	*Carex livida* and ev. another unspecified low *Carex* (16.6%), *Eriophorum angustifolium* (3.3%), *Equisetum fluviatile* (0.03%), unspecified moss (20.0%)		
8	Large mire	Dry	0.1	56.4	20.6	935.9	30.9	107.0	1 : 3.2	67.8	*Calluna vulgaris* (42.6%), *Molinia caerulea* (10.5%), *Betula nana* (8.9%), *Carex vaginata* (5.8%), *Sphagnum* (moss) (3.0%)		
9	Large mire	Dry	0.4	36.4		934.4	27.6	180.0	1 : 2.3	80.5	*Vaccinium uliginosum* (30.0%), *Calluna vulgaris* (11.2%), *Rubus chamaemorus* (10.2%), *Eriophorum vaginatum* (8.0%), *Vaccinium myrtillus* (6.0%), *Betula nana* (6.0%), *Carex nigra ssp. juncella* and *Carex rotundata* (6.0%), *Andromeda polifolia* (2.0%), *Vaccinium vitis-idaea* (1.0%), *Equisetum fluviatile* (0.0%), *Sphagnum* (moss) (3.6%)		

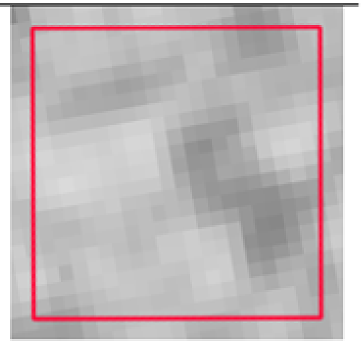
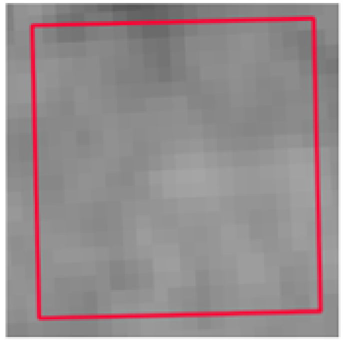
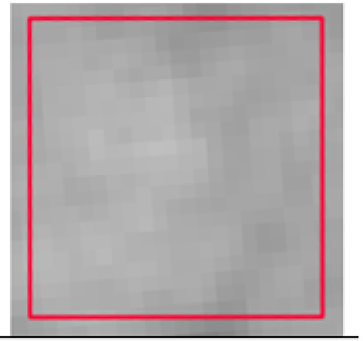
[1]All species identified in the sampling plot. Plant coverage assessment in parentheses.

Table A1. Results of soil moisture classification, NDVI, IVOMD, DM, ash, weight from plot, ratio of plant types, assessment of plant coverage of both greenness and species and RGB and NDVI images on the sampling plots.

Sampling plot	Area	Soil moisture classification	Mean NDVI-value	Mean IVOMD (%)	Mean IVOMD (%) of moss	DM (g/kg)	Ash (g/kg)	Weight from plot (g)	Ratio grasses/semi-grasses/herbs : dwarf shrubs	Greenness (%)	Species[1]	RGB-image	NDVI-image
10	Clear-cut	Dry	0.7	87.0		923.5	51.3	106.0	1 : 0	85.3	*Deschampsia flexuosa* (85.3%)		
11	Clear-cut	Dry	0.5	64.4		928.9	37.9	102.0	1.4 : 1	53.0	*Vaccinium myrtillus* (31.0%), *Deschampsia flexuosa* (22.1%), unspecified moss (0.9%)		
12	Small mire	Semi-wet	0.1	69.2		931.3	22.9	16.0	1 : 0	15.3	*Trichophorum cespitosum* and *Carex pauciflora* (15.3%), *Sphagnum* (moss) (39.9%)		

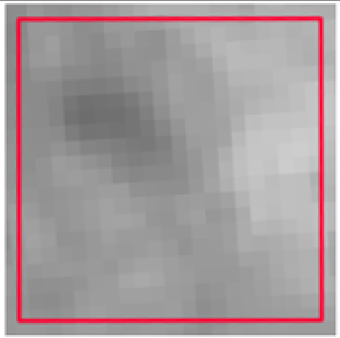
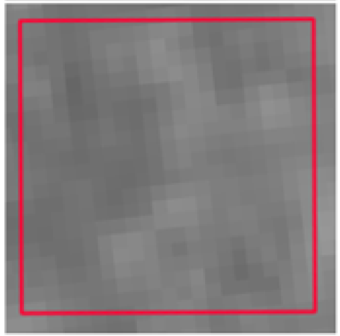
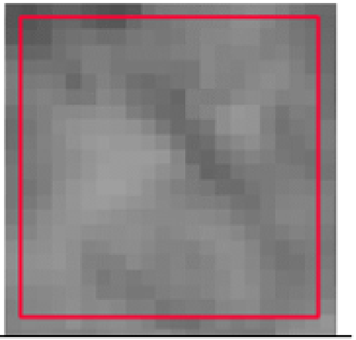
[1]All species identified in the sampling plot. Plant coverage assessment in parentheses.

Table A1. Results of soil moisture classification, NDVI, IVOMD, DM, ash, weight from plot, ratio of plant types, assessment of plant coverage of both greenness and species and RGB and NDVI images on the sampling plots.

Sampling plot	Area	Soil moisture classification	Mean NDVI-value	Mean IVOMD (%)	Mean IVOMD (%) of moss	DM (g/kg)	Ash (g/kg)	Weight from plot (g)	Ratio grasses/semi-grasses/herbs : dwarf shrubs	Greenness (%)	Species[1]	RGB-image	NDVI-image
13	Small mire	Semi-wet	0.3	47.4	16.1	927.8	26.2	121.0	1 : 2.2	65.0	*Empetrum nigrum* (35.3%), *Rubus chamaemorus* (19.7%), *Vaccinium uliginosum* (3.9%), *Rhododendron tomentosum* (3.0%), *Pinus sylvestris* (1.4%), *Betula nana* (1.3%), *Carex pauciflora* (0.4%), unspecified moss (31.0%)		
14	Small mire	Wet	0.1	54.5	16.0	922.6	38.7	25.0	1 : 0	17.5	*Eriophorum scheuchzeri* (17.5%), *Andromeda polifolia* (0.0%), *Vaccinium oxycoccos* (0.0%), *Sphagnum* (moss) (70.1%)		
15	Ley	Dry	0.5	74.6		921.5	51.5	194.0	1 : 0	100.0	*Agrostis capillaris* (70.6%), *Rhinanthus minor* (23.0%), *Trifolium repens* (4.8%), *Achillea millefolium* (1.0%), *Ranunculus acris* (0.6%), *Leontodon hispidus* (0.0%), *Euphrasia* (0.0%)		

[1]All species identified in the sampling plot. Plant coverage assessment in parentheses.

Table A1. Results of soil moisture classification, NDVI, IVOMD, DM, ash, weight from plot, ratio of plant types, assessment of plant coverage of both greenness and species and RGB and NDVI images on the sampling plots.

Sampling plot	Area	Soil moisture classification	Mean NDVI-value	Mean IVOMD (%)	Mean IVOMD (%) of moss	DM (g/kg)	Ash (g/kg)	Weight from plot (g)	Ratio grasses/semi-grasses/herbs : dwarf shrubs	Greenness (%)	Species[1]	RGB-image	NDVI-image
16	Ley	Dry	0.4	76.8		911.1	44.4	135.0	1 : 0	100.0	*Agrostis capillaris* and *Poa* (54.0%), *Rhinanthus minor* (30.4%), *Ranunculus acris* (6.4%), *Leontodon hispidus* (5.0%), *Trifolium repens* (1.7%), *Sagittaria sagittifolia* (1.7%), *Euphrasia* (0.8%)		
17	Mire with reeds	Dry	0.0	72.5		935.3	40.3	86.0	1 : 0	61.9	*Molinia caerulea, Carex vaginata* and *Trichophorum cespitosum* (53.0%), *Potentilla erecta* (8.9%)		
18	Mire with reeds	Semi-wet	0.1	78.1		933.5	50.6	75.0	1 : 0	80.6	*Molinia caerulea, Carex vaginata and Trichophorum cespitosum* (46.4%), *Phragmites australis* (28.9%), *Potentilla erecta* (5.3%)		

[1]All species identified in the sampling plot. Plant coverage assessment in parentheses.

Appendix 4

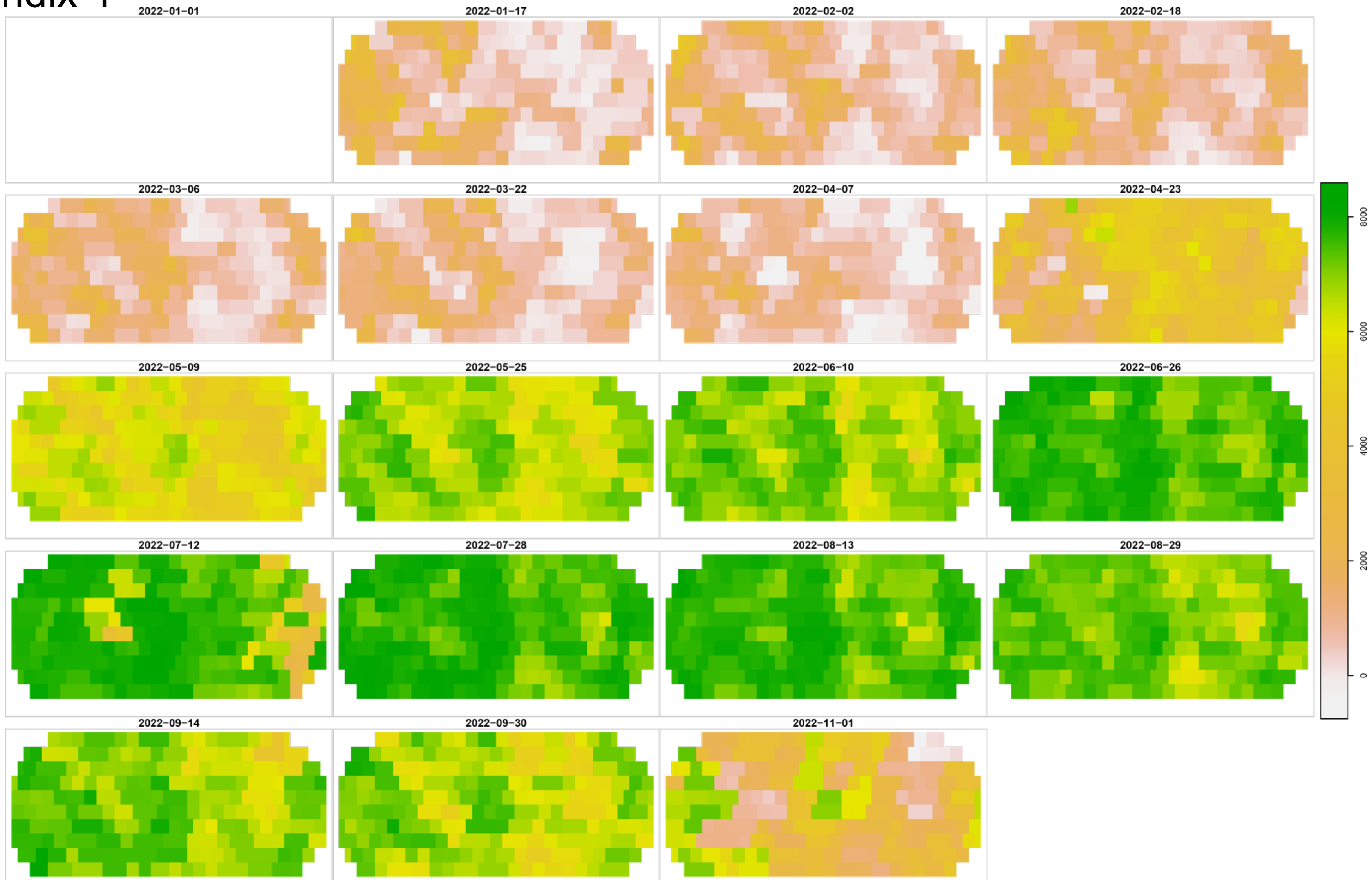


Figure A15. NDVI-values in the year 2022 for the area around the sampling sites. The data is obtained from Google Earth Engine Engine (2022).

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file. If you are more than one author, the checked box will be applied to all authors. Read about SLU's publishing agreement here:

- https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.