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Assessing winter pasture quality in Sunnfjord wild reindeer area.

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Master's thesis

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December 2019

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Jessheim, November 2019

Trine-Lise Slåtsveen

Cover: Wild reindeer in Sunnfjord. Photo: Kjell Oddvin

Abstract

Winter pastures are bottlenecks for population trends for wild reindeer, and the quality and availability are important parameters when managing populations. Sunnfjord, considered on of the smallest wild reindeer districts in Norway, have never had a comprehensive evaluation of accessible winter pasture within. The aim of study is to assess the quality of winter forage in all tree sub- areas within Sunnfjord wild reindeer area. Result will be focused on field observations and supported by satellite remote sensing data. Field survey was carried out fall 2018 and spring 2019. The method in this study is developed by NINA and has previously been used in various part parts of Norway (i.e. Finnmark, Hardangervidda). Five sample sites was established along 12 transect lines and each sample site was comprised of five sample plots in a cross shaped grid. Lichen and winter forage biomass (g/m^2) was later estimated using a formula Established by Gaare et al. (1999) and Wielgolaski (1975). A satellite remote sensed based approach was applied to map current lichen and green cover and to perform change detection over the whole range of Sunnfjord. For thus purpose a Sentinel-2 and Landsat 5 Thematic mapper ™ was used. Sunnfjord had and overall of 117 g/m2 in field plots, identical to heavy grazed areas in Finnmark and Hardangervidda. Still, it was better than expected considering costal areas in Norway have more suitable summer pastures and less suitable winter pastures. Winter forage biomass varied among areas, area 1 and 2 had the highest average g/m2, almost twice that of area 3. Height, and lichen cover was also highest in area 2. Satellite remote sensing results found no change in lichen and green cover between areas. Unlike previous studies, no interaction was found between field and satellite result, which could be a result of the method in use. During a 11year period from 2008-2019 an increase in green cover was observed. Lichen had decreased in area 1 and 2, while area 3 could be considered to have no change. No correlation was found between precipitation- and temperature values and lichen biomass. However, other results in this study support the assumption that climate have a role for determining vegetation composition within sub-areas. Based on result derived in this study, care should be taken within Sub-area 1 and 3. Population in area 2 may slightly be increase. However, surveillance of herds condition in the form registered slaughter weights is necessary

Keywords: Sunnfjord, Remote sensing, Winter pasture, Feltruter, Wild reindeer

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1. Introduction

Reindeer or Caribou (*Rangifer tarandus*), depending on location, is a keystone species in the circumpolar region and is an important resource for local and indigenous communities (Andersen & Hustad, 2004; Dale et al., 2017; Jordhøy, Binns, & Hoem, 2006; Mowat & Heard, 2006). Reindeer previously inhabited most of Europe, apart from a small population on the Kola peninsula in Russia , Norway is today the only country left in Europe with a significant population of the original wild Tundra reindeer (*Rangifer tarandus tarandus*) which is divided in to 23 more or less isolated populations (Benberg et al., 2016; Bevanger, n.d.; Gunn, 2016; Gunn, Kutz, & Russell, 2018). Hence ,Norway have important national and international responsibility in ensuring the species survival and maintaining functioning habitats (Bråtå, 2005). Which is becoming increasingly difficult considering increasing human disturbances, fragmentation of suitable habitats and climate change.

Reindeers are adapted to large seasonal variations in food availability which require extensive seasonal movement over large areas. In summer reindeer forage on different vascular plants (i.e. herbs, shrubs and graminoids) and chose quality over quantity (Benberg et al., 2016; Skogland, 1990; Warenberg, 1982). During winter reindeers preferably feed on Terricolous and Fruticose lichens , mainly *Cladonia arbuscula, C. mitis, C. rangiferina, C.stygia, C. stellaris* , *Flavocetraria* and *Cetraria islandica* which can constitute between 50 -80 % of the food intake (Boertje, 1990; Skogland & Gaare, 1975; Storeheier, Mathiesen, Tyler, & Olsen, 2002). During a day, one reindeer can consume 2-5 kg lichen in dry matter (Holleman, Luick, & White, 1979).

Lichens are slow growing and often form dense mats on dry, well-drained ridges located on acidic and poor soils where there is little or almost no snow in winter. (Gaare, 1994). Due to excessive grazing and trampling in some regions, increase in industrial forestry and vegetation greening as a result of increased nutrient availability and global warming , lichens have experienced rapid decline in various parts of the Arctic and Alpine habitats (Cornelissen, Lang, Soudzilovskaia, & During, 2007; Heggenes et al., 2017; Kumpula, Colpaert, & Nieminen, 2000; Post, Steinman, & Mann, 2018; Virtanen, Eskelinen, & Gaare, 2003).

Lichens, although high in energy, have a low nitrogen content. Thus, wild reindeer cannot survive on lichens alone, but depend on a mixed diet of lichens, mosses and vascular plants (Storeheier et al., 2002; Warenberg, 1982). Although lichens is the most favoured food source in winter , it is evident that reindeer don't depend on lichen for survival (Sormo, Haga, Gaare, Langvatn, & Mathiesen, 1999). Rather it appears that the species most commonly foraged by reindeer depends mostly on the local plant community and climate conditions such as snow depth and ice cover (Johnson, Parker, & Heard, 2001; Warenberg, 1982).

It is hypothesised that the quality of summer pastures is important for individual body weight, whereas quantity and quality of winter forage determine the carrying capacity within the habitat (Benberg et al., 2016). Skogland (1985, 1990) claimed that accessibility of winter forage determine calf survival and timing of births. If winter conditions are though, the female must assure her own survival on the expense of the calf. However, this theory has been disputed by others (M. Heggberget, 1998; Post & Klein, 1999; Reimers, 1982). Although scientist not yet agree on the importance of summer and winter forage, winter is likely to be the season when suitable pastures are most restricted.

Wild reindeer is to this day the most studied wild animal in Norway, noticeably due to its cultural importance. The Norwegian government has allocated considerably resources in to the managing of wild reindeer (Reimers, 1986). Knowledge concerning population numbers- and structure, food availability and the effect it has on animal's condition have long been fundamental in this research (Andersen & Hustad, 2004; Benberg et al., 2016; Punsvik & Jaren, 2006). Such knowledge has not always been easy or cheap to acquire. In recent years however, comprehensive digital vegetation maps have become more available. Today, satellite remote sensing is one of the most common methods used when monitoring vegetation and change over large and inaccessible areas, and is good complementary data to traditional information and field estimates (Falldorf, Strand, Panzacchi, & Tømmervik, 2014; Macander, Frost, & Palm, n.d.; Nordberg & Allard, 2002; Jérôme Théau & Duguay, 2010)

Although some wild reindeer management areas have received lot of attention the past decades (i.e. Hardangervidda, Nordfjella, Setesdal), others have never even seen a scientist (Benberg et al., 2016). Sunnfjord is one such area. Established in 1968, Sunnfjord wild reindeer society have had a close count on the health and demography of its herd. However, except from a vegetation mapping by plane in 2004 (Andersen & Hustad) and 2017 (Kjørstad et al.) there has never been a comprehensive evaluation of accessible pastures in Sunnfjord.

1 Introduction to *Rangifer tarandus*

1.1 Status

Caribou or reindeer depending on location, is the only species within its genus. Based on skull measurement, antlers and behaviour, Grubb (2005) listed 14 subspecies of which *eogroenlandicus* and *dawsoni* are now extinct. Today it is common classified *Rangifer* in to eight subspecies as shown in Figure 1(Benberg et al., 2016). Depending on behaviour or environmental condition these are again divided in to three major groups, the most numerous being Tundra -and mountain reindeer (*R. t. tarandus*, *R. t. granti* and *R. t. groenlandicus*) counting 75 % of the total wild reindeer population, followed by forest reindeer (*R. t. fennicus* and *R. t. caribou*) (14% of total) and the Arctic reindeer (*R.t platyrgynchus*¸ extinct- *R. t. eogroenlandicus* and *R. t. peayi;* 11 % of total; (Andersen & Hustad, 2004; Gunn, 2016).

Rangifer occur between 50 and 81 degrees in a circumpolar distribution (Figure 1) and inhabits most of North- America , Greenland , North- Europe, Siberia and Mongolia (Benberg et al., 2016; Gunn, 2016). While most caribou in North- America have never been domesticated (apart some smaller populations in Alaska), more than three quarters (3.4 million) of the Eurasian populations is considered semi- domesticated (Falldorf, 2013; Gunn, 2016; International center for reindeer husbandry, n.d.).

Previous mid 1990s the total number of wild reindeer and caribou were estimated the be roughly 4.8 million individuals, the past 10-25 years however the overall trend has been a 40 % decline in population setting the current estimate to approximately 2.9 million (Gunn, 2016; Gunn et al., 2018). Two million caribou inhabit North- America and Greenland, while 849 700 wild reindeer inhabits Eurasia (table 1; (Benberg et al., 2016; Gunn, 2016).

Apart from a small population on the Kola peninsula in Russia, Norway is the only country left in Europe with a significant population of wild Tundra reindeer (*Rangifer tarandus tarandus*). Approximately 25 000 individuals inhabit mountain areas in Southern Norway in 23 more or less isolated populations (see Figure 2 for distribution of wild reindeer areas in Norway), the largest counting app. 7000 animals and the smallest only 50 (Benberg et al., 2016; Punsvik & Jaren, 2006). Although all are considered wild, only 6000 originate from the early European wild reindeer, the rest is a mix between wild and semi- domesticated reindeer or is introduced semi- domesticated reindeer (Benberg et al., 2016).

Table 1. Population numbers and the time of last count for each country with viable populations of wild reindeer

Country	Population	Last counted
Alaska	660 000	2010
Canada	1 300 000	2015
Greenland	73 430	2015
Norway (mainland)	6 000	2012
Svalbard	10 100	2009
Finland	1 100	2014
Russia	831 500	2015
Mongolia	< 1000	2006
Total	2 890 410	

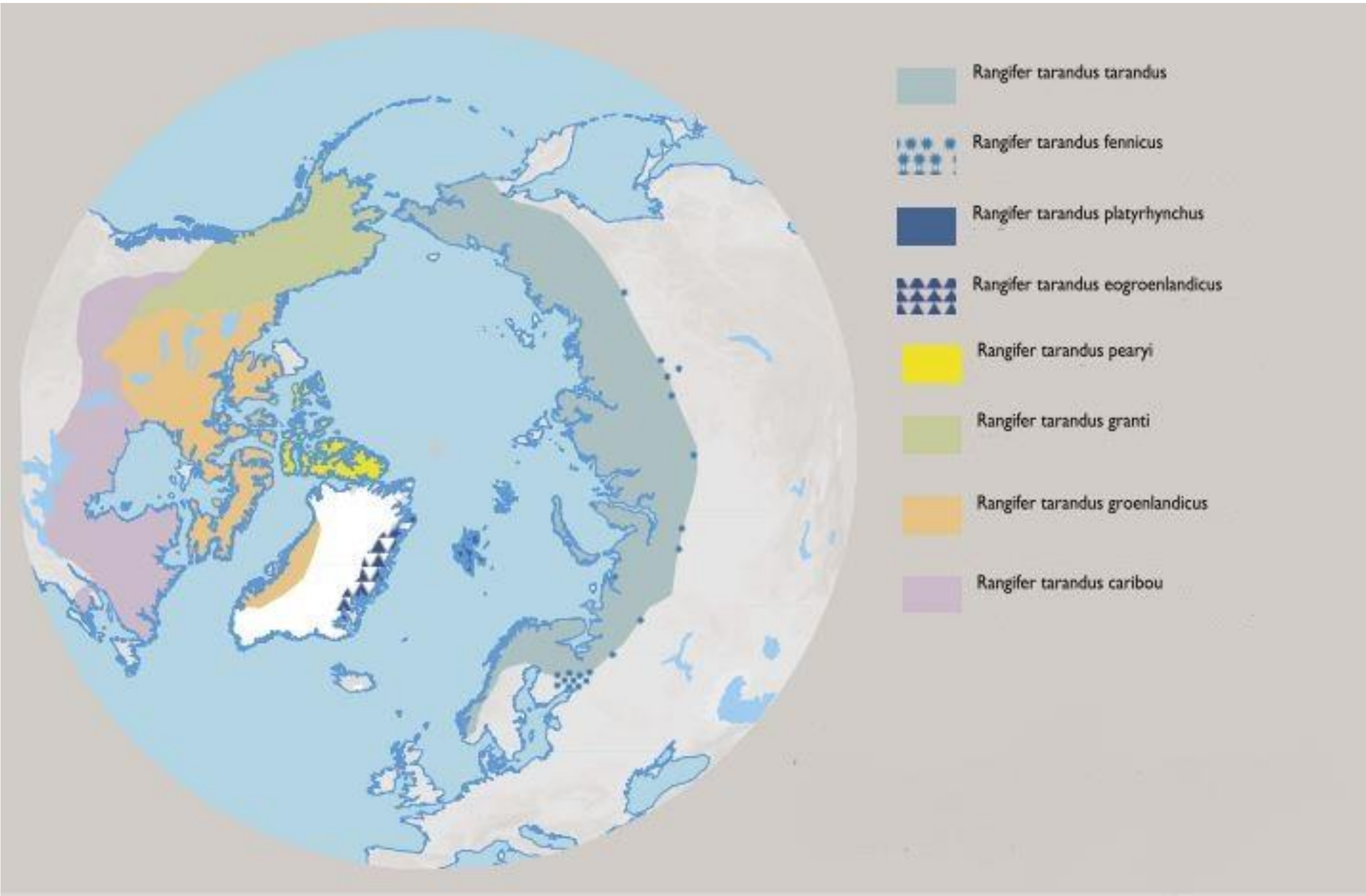

Figure 1.The global distribution and subspecies of Rangifer tarandus (Andersen & Hustad, 2004)

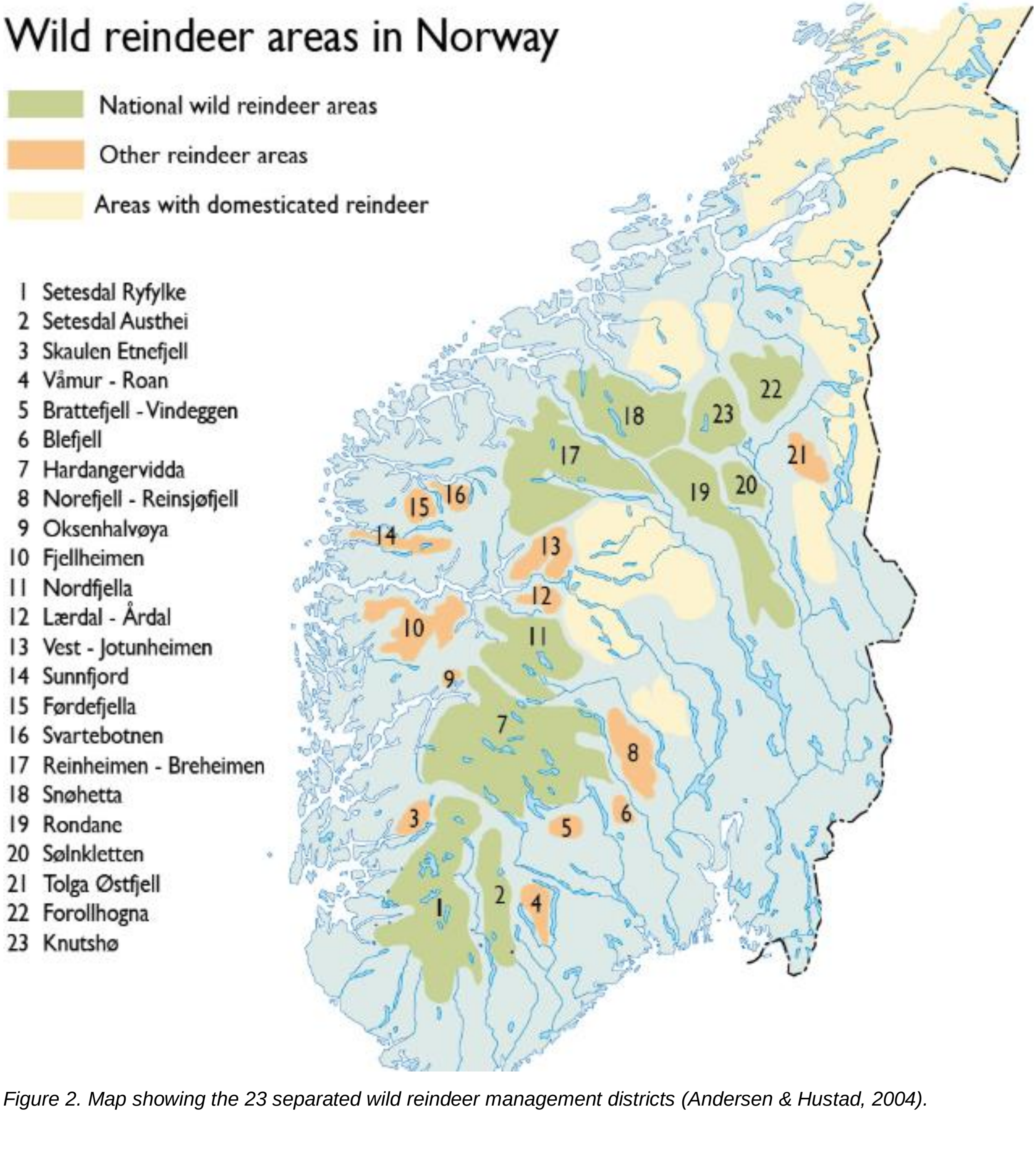

Figure 2. Map showing the 23 separated wild reindeer management districts (Andersen & Hustad, 2004).

2 History of Sunnfjord wild reindeer association.

In 1965 a local enthusiast named Reidar Farsund proposed to introduce reindeers to Sunnfjord mountain area. The same had been done in Førdefjella in the middle of the 1950s, which today is considered on the of the 23 wild reindeer areas (Romtveit, Punsvik, & Strand, 2018). Hence in 1968, three years after the suggestion, Sunnfjord wild reindeer association was established. First reindeers were bought from Fram reindeer husbandry in Valdres and introduced to Sunnfjord the 12th of December 1970. In all 77 animals was released, 30 females and 47 calf's which of 37 were females and 10 were bucks (J.O. Flaten, personal communication 28. October 2018). Due to topography and highways the reindeers where divided in to three separate areas, 26 where released in the upper hills of Jølster (area 3), 25 on Kinnaheia (area 2), the last 26 was set free on Langeland in Førde/ Gauler (area 1 (J.O. Flaten, personal communication 28. October 2018). In 1971, another 28 animals was bought and introduced to the area (Romtveit et al., 2018). Further introductions have happened sporadically during the past decades. In 1996 nine bucks were released and evenly divided between the sub-areas, then 10 more individuals were introduced in 2001 and again 21 animals in 2004 (Romtveit et al., 2018).

The first hunt took place in 1975. The reindeer association dispensed permits to hunt 20 animals of one's own choosing, the same arrangement continued next year which lead to a severe decline in buck numbers and the hunt had to be ceased already in 1977 (J.O. Flaten, personal communication 28. October 2018; Romtveit et al., 2018). In 1978 they tried voting for a new quota specifying sex and age which was overruled! (J.O. Flaten, personal communication 28. October 2018). Two years later however, they saw the need and hunting quotas for sex and age was established.

In recent years there has been a request from the reindeer association to increase the winter population from about 100-120 animals to 150-170, as a result the hunting quotas that generally has remained about 20 licences have been reduced (Romtveit et al., 2018).

3 Aim of the study

Winter pastures are bottlenecks for population trends for wild reindeer, and the quality and availability are important parameters when managing populations. The size of the reindeer population must be proportion to the quantity and quality that is available in the winter habitats to keep it sustainable (Ecological carrying capacity). The local wild reindeer society wish to increase the overall herd size from 125 to approximately 170 overwintering animals.

The main aim of this study is to evaluate winter pastures in Sunnfjord wild reindeer area and to improve the environmental quality norm of wild reindeer in Norway and future management of Sunnfjord`s wild reindeer. By comparing field observations with satellite data and earlier studies I will try to assess lichen and green vegetation abundance in Sunnfjord three sub-populations. Does the quality of winter pastures differ between the habitats and in that case, why? Further I want to discuss if climate could affect vegetation composition and this could affect future management. Results will be focused on field observations and supported by satellite data.

The main questions of the thesis will be;

1) What is the current state of lichen and green biomass in Sunnfjord?
2) Does the quality of winter pastures differ between Sub-areas?
3) How much of the variation in Sunnfjord pasture quality can be explained by climate?
4) Can satellite derived vegetation indices detect pattern observed by field observations?
5) Is there any changes in magnitude and spatial distribution of these vegetation indices between 2008-2019? A satellite study using to different satellite sensors.

4 Materials and method

4.1 Study area

Sunnfjord, one of 23 wild reindeer areas in Norway, is located on the West coast in Sogn og Fjordane county (**Error! Reference source not found.**). The area extends from the coast in the West to Grovabreen in the East, extending true Askvoll, Gauler, Førde and Jølster municipality. The area covers approximately 700 km^2 and is considered one of the smallest wild reindeer areas in Norway (Benberg et al., 2016).The main area is divided in to three sub-areas or sub-populations by two main roads crossing the mountains (E39 and FV13). Area 1 is situated between Førdefjorden in the North and Dalsfjorden in the South and spans from the coast to E39. Area 2 is encircled by E39, FV610 and FV13. Area 2 extend from FV13 in the West and Grovabreen to the East (**Error! Reference source not found.**).

The area is managed by Sunnfjord wild reindeer committee which is responsible for over 600 landowners. Their earlier population goal has been close to 125 overwintering animals. For a long time, population numbers have remained between 100 -120 animals. After 2016 herd size increased and in 2018 they counted 124 animals: 28 in area 1 (outer), 54 in area 2 (middle) and 32 in area 3 (inner) (Flaten, J.O, personal communication, 28, October 2018). Growth in population numbers is illustrated with calving numbers in Table 2. Yearly calving numbers for Sunnfjord wild reindeer area since 2011..

Table 2. Yearly calving numbers for Sunnfjord wild reindeer area since 2011.

Year	Area 1	Area 2	Area 3	Sum
2011	4	10	7	21
2012	5	13	7	25
2013	7	17	3	27
2014	6	17	6	29
2015	5	8	1	14
2016	12	15	6	33
2017	12	12	8	32
2018	8	15	8	31

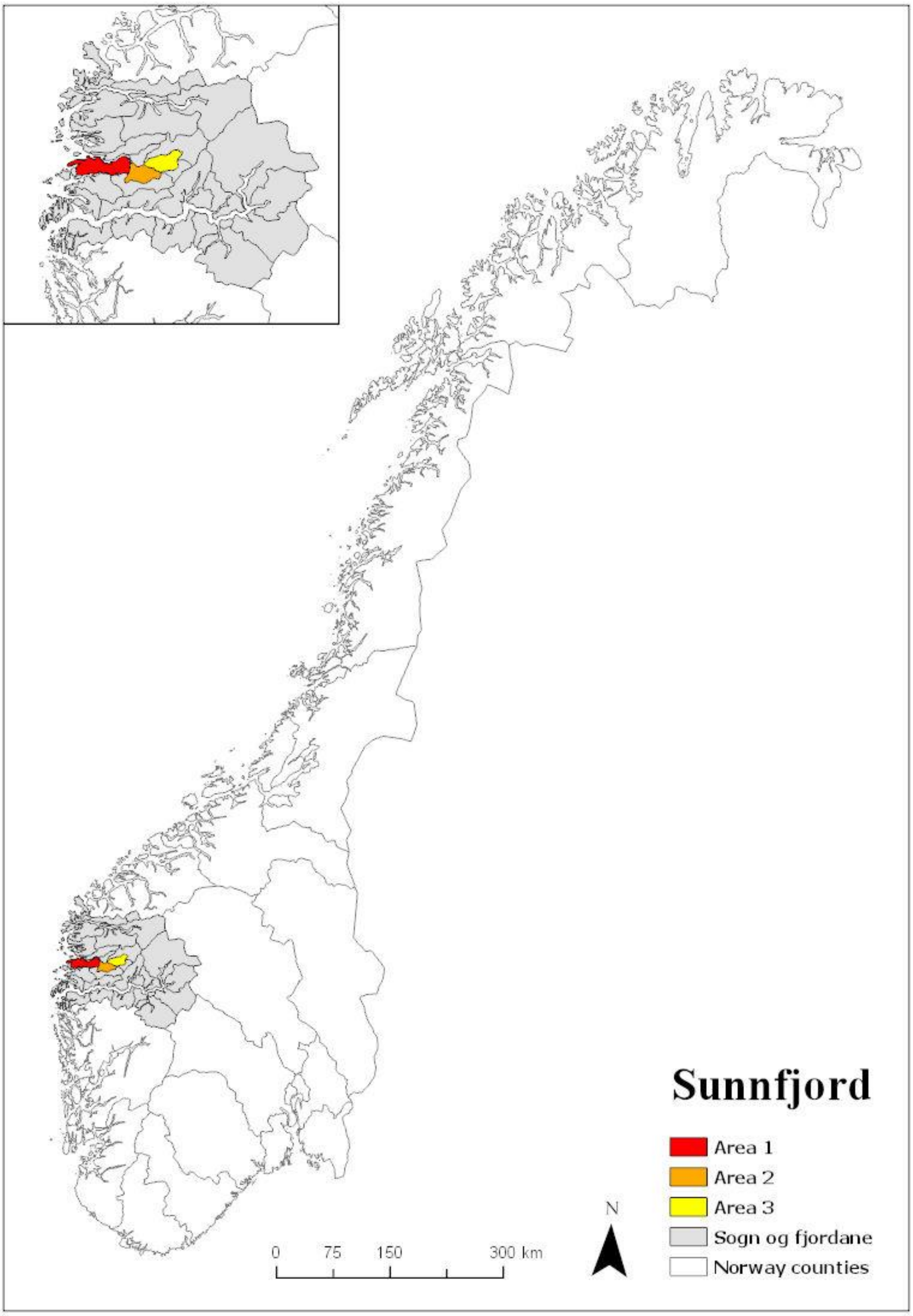

Figure 3.Overview of Sunnfjord wild reindeer area and its sub-areas.

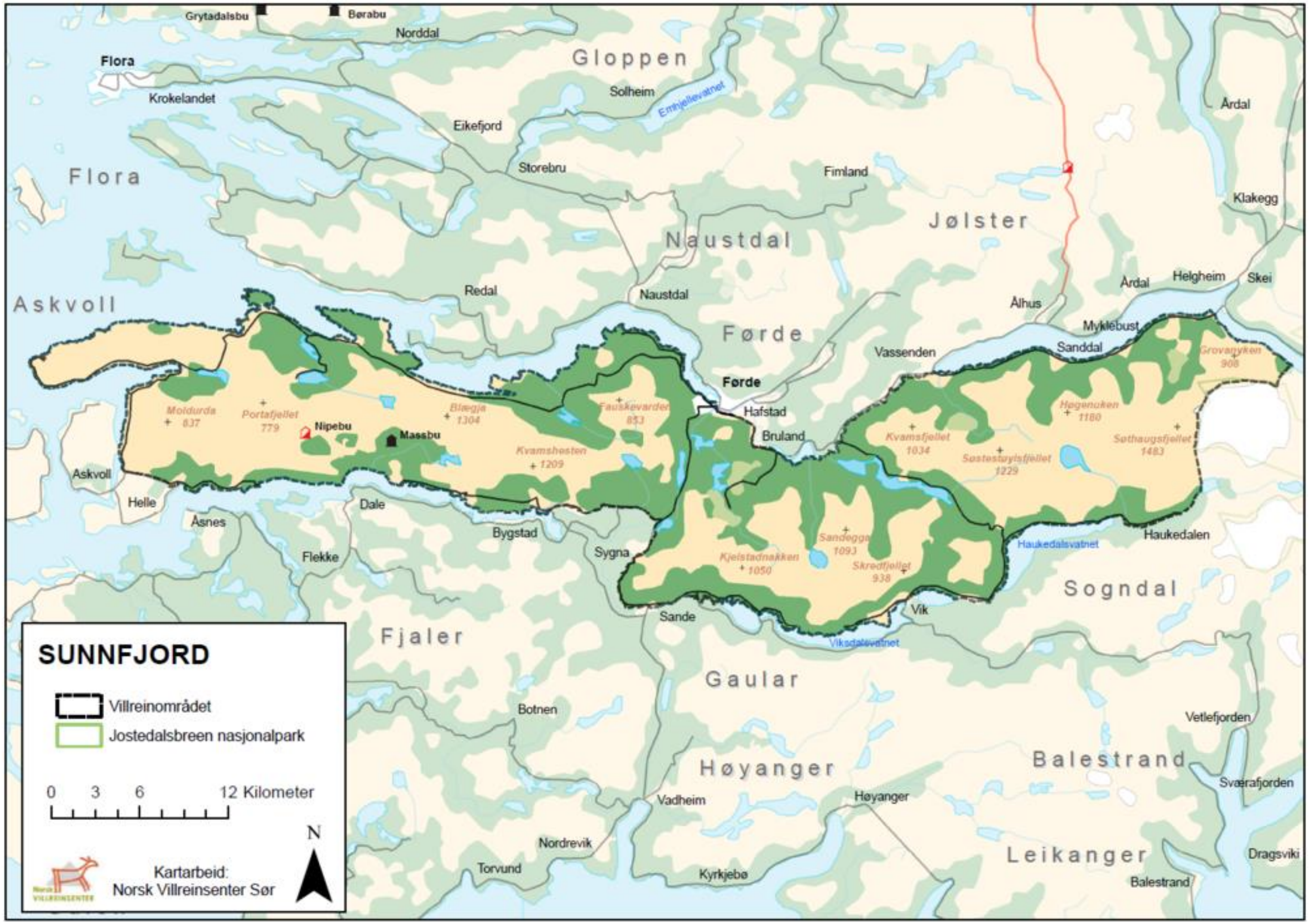

Figure 4.Overview of Sunnfjord wild reindeer area (Villreinsenter, n.d.).

4.2 Sunnfjord natural environment

Sunnfjord wild reindeer population lives on the periphery of their natural habitat. The area lies on the border between oceanic and inland climate (Kjørstad et al., 2017). Although local climate is strongly affected by coastal orientation it has typical characterizations such as high precipitation rates, strong winds in exposed areas, high humidity, cool summers and relatively warm winters, which can be a challenge during winter, but provide lush summer pastures and contribute early onset of spring (Harstveit, 2018). In the East lies Grovabreen, a smaller glacier detached from Jostedalsbreen, with surrounding valleys. Sunnfjord wild reindeer area have several valleys, previously just for agriculture. Today these old farmlands provide important summer pastures and calving grounds for reindeer. In winter Sunnfjord reindeer migrate to higher altitudes (Romtveit et al., 2018;Figure 5).

The vegetation in Sunnfjord is somewhat different in character and composition from East to West as a result of variation in altitudinal gradients. The east has more distinct mountain vegetation, whereas coastal areas have increasing elements of forest and shrub vegetation. (Figure 6). Although, not apparent in the vegetation map, marsh vegetation was more prominent in West than East. Forest vegetation is primarily linked with lower-lying valley bottoms and consist of a mix between deciduous and coniferous forest, were elements of coniferous trees decrease towards the coast. Above the treeline (app. 500-600 meters above sea level) vegetation shift to different heather- and ridge vegetation. In area 3 (East) there is increasing cover of extreme snow patches, glaciers, grass meadows and leeward vegetation, whereas area 1 and 2, which is situated lower ,have more elements of heath vegetation.

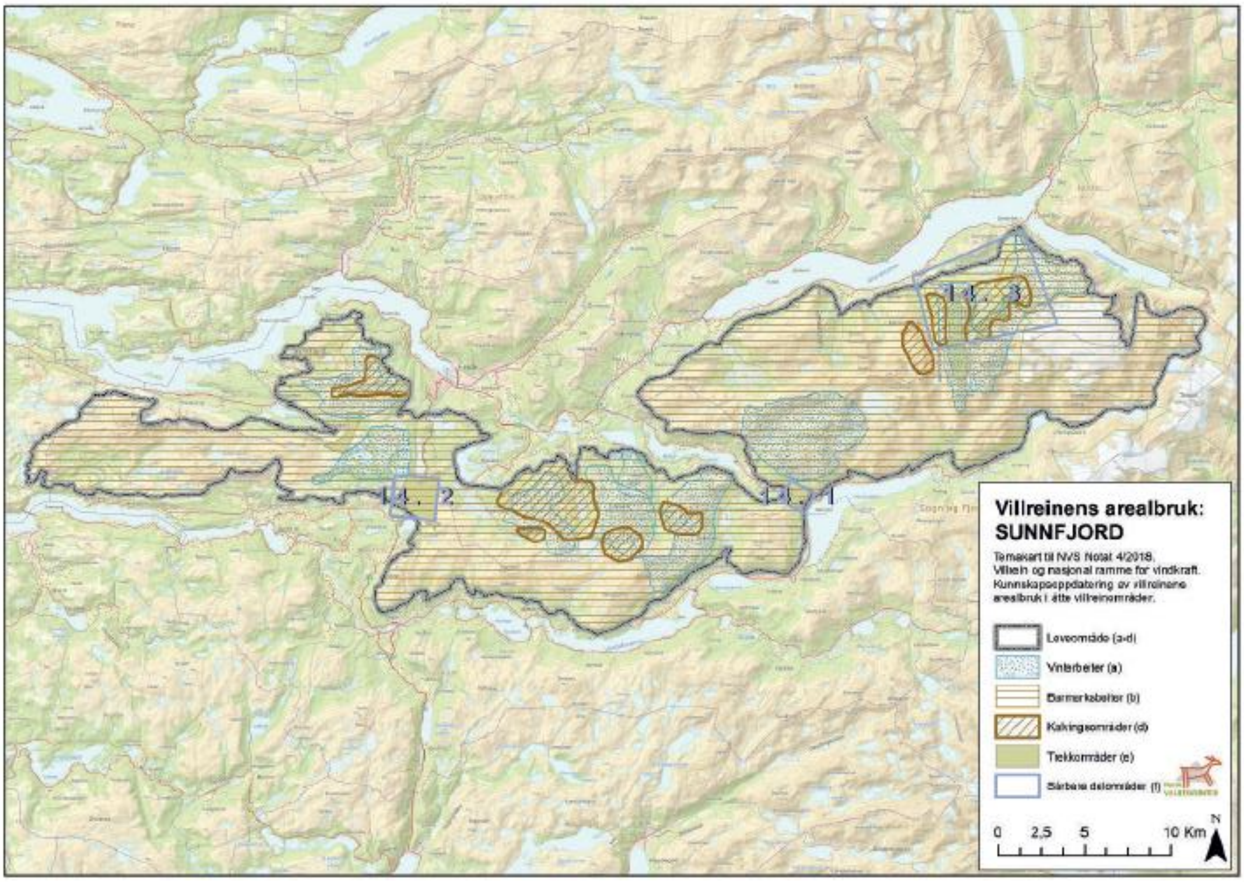

Figure 5. Wild reindeer's area uses in Sunnfjord. Grey outline is the boarder of the whole area. Winter pastures are displayed in blue with dots, brown is calving areas, horizontal light brown stripe show potential summer pastures.

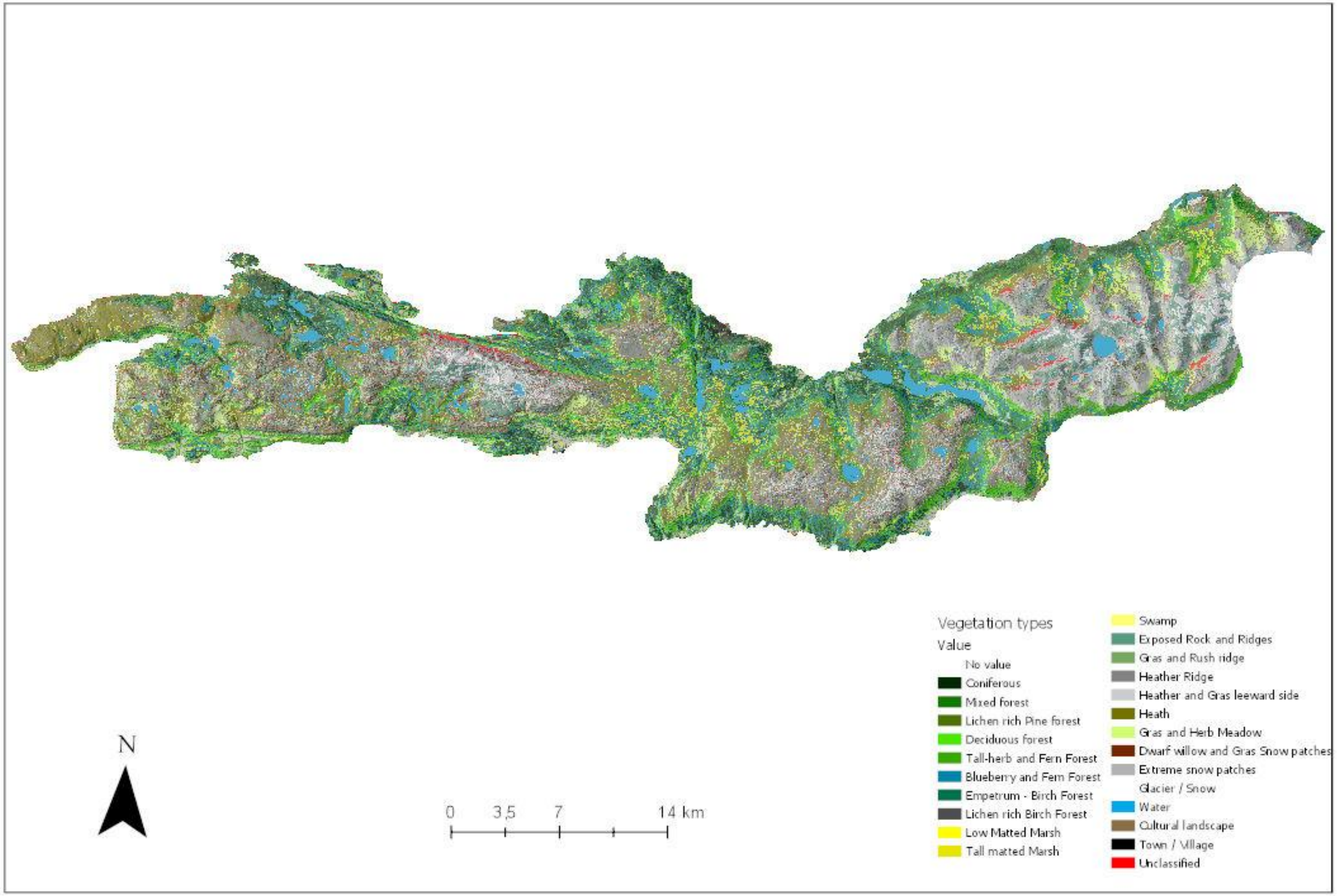

Figure 6. Satellite based vegetation map. Sunnfjord wild reindeer area, Sogn og Fjordane, Norway, divided in to 24 vegetation classes based on a report from Johansen, Aarrestad and Øien (2009)

4.3 Satellite images.

4.3.1 Landsat 5 TM and Sentinel-2 scenes

Sentinel-2 and Landsat 5 TM scenes were used in this study. Sentinel-2 images was acquired 10:56 28th of July 2019 from Sentinel Hub, European Space Agency (ESA)[1], while Landsat 5 images was obtained 10:30 28th of July 2008 from U.S. Geological Survey[2.] Both maps use datum ETRS 1989 and are projected to UTM Zone 32 for this study. Sentinel-2 data was acquired as a Level-1C orthoimage product, i.e. a map projection of the acquired image using a digital elevation model (DEM) to correct ground geometric distortions. Pixel radiometric measurements are provided in Top-Of-Atmosphere (TOA) reflectance. The Landsat-5 Thematic Mapper (TM) sensor provided image data as Level-1TP quality, meaning precision and terrain corrected data. Precision and terrain correction provide radiometric and geodetic accuracy by incorporating ground control points while employing a DEM for topographic displacement. Ground control points used for Level-1TP correction are currently based on the Global Land Survey (GLS) reference database.

The Landsat 5 TM satellite was launched 1th of March 1984 and was deactivated 5th of June 2013. The satellite had a 185 km swath width and uses a Thematic mapper (TM) sensor which capture images with two different spatial resolutions (pixel size): blue, green, red NIR, SWIR 1 and SWIR 2 has a pixel size of 30 meter, and one thermal with 120 meters (Earth observing system, n.d.). In this study band 3 visible red, band 4 NIR (near infrared) and band 5 SWIR 1 (near infrared) was used, all with a pixel size of 30 meter (Table 3). Landsat 5 TM scenes was only applied for the purpose of change detection between 2008 and 2019.

The Sentinel-2A and Sentinel-2B satellites flies in the same orbit around earth but phased with 180° giving it a repeat cycle of 5 days by equator and approximately 3 days in Scandinavia, capturing high-resolution, multi-spectral images. The first satellite was launched 23th June 2015 and the second 7th of March 2017 (SUHET, 2015). It has a 290 km wide swath and both satellites carry a single multi-spectral instrument (MSI) acquiring data in 13 different spectral bands in the visible/near infrared (VNIR) and short wave infrared spectral range (SWIR) with three different spatial resolutions (10, 20 and 60). Blue, green, red and NIR (band

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[1] https://www.sentinel-hub.com/

[2] https://www.usgs.gov/

2-4 and 8) has a 10 x10 meter pixel size, tree red (5-6), narrow NIR (8a) and two SWIR (10-11) range with pixel size of 20 meters, and coastal aerosol, water vapour and SWIR-Cirrus has a 60 meters pixel size (SUHET, 2015). For this study band 4,7,8 and 11 were used (Table 3). Sentinel-2 scenes was applied for calculating present situation for lichen, green vegetation and moisture/water and in change detection analyses

Sentinel-2 images has a finer spatial resolution compared to Landsat 5, which is likely to better detect smaller patches of lichen and therefore give more accurate and detailed results then Landsat scenes. Sentinel-2 satellites also have a higher radiometric resolution compared to Landsat imagery. Which is expressed as a bit number, usually from 8-16 (SUHET, 2015). Radiometric resolution is used to describe an images ability to discriminate between minor differenced in light energy. A high radiometric resolution imagery will therefore be more sensitive to small changes in reflected radiance (SUHET, 2015). The resolutions of Sentiel-2s MSI instrument is 12 bits, meaning it can detect over a range of 0 to 4095 potential reflected radiance intensity values, whereas Landsat 5 TM uses 8 bits which range from 0-255 different radiance intensity values (Earth observation system , n.d.; SUHET, 2015).

Table 3. Details of Sentinel-2 and Landsat 5 TM satellite bands.

Satellite	Band nr.	Wave length (µm)	Spatial resolution	Band name
Sentinel-2	3	0,525-0,595	10	Visible red
	4	0.635 -0.695	10	Red
	8	0.727-0.957	10	NIR
	11	1.520-1.700	20	SWIR
Landasat 5 TM	2	0,52-0,60	30	Visible green
	3	0.63 - 0.69	30	Visible red
	4	0.76 - 0.90	30	NIR
	5	1.55 - 1.75	30	SWIR 1

4.3.2 Satellite based environmental indices

All analyses were performed in ArcGIS pro using Sentinel-2 (band 3, 4, 8 and 11) and Landsat 5 TM scenes (band 2-5). Before starting analysing, all satellite scenes were exported to tiff files. Sentinel- 2 and Landsat 5 TM scenes did not cover the coast so the polygon for Sunnfjord wild reindeer area had to be altered before extracting data. This should not affect the results as the reindeer rarely or never migrate so far west. Because Sunnfjord wild reindeer areas is divided in to three separate sub-areas, three new polygons were created using an already existing polygon for Sunnfjord wild reindeer area and then splitting it by following the contour of the main roads dividing the areas. Sentinel- 2 scenes (band 3,4,8 and 11) and Landsat 5 TM scenes (band 2-5) was later extracted to fit within Sunnfjord wild reindeer area.

Two different models were used to model pasture quality in this study: the Normalized Difference Lichen Index , NDLI ($\frac{(Band\ 11-Band\ 3)}{(Band\ 11+Band\ 3\ )}$ and $\frac{(Band\ 5-Band\ 2)}{(Band\ 5+Band\ 2)}$), Normalized Difference Vegetation Index, NDVI ($\frac{(Band\ 8-Band\ 4)}{(Band\ 8+Band\ 4)}$ and $\frac{(Band\ 4-Band\ 3)}{(Band\ 4+Band\ 3)}$). When analysing present pasture condition only sentinel-2 scenes were used.

The value ranges for the environmental indices varies from -1 to 1. NDVI values close to -1 correspond to water, -0.1 – 0.1 correspond to barren rock areas, sand or snow, 0.2 – 0.4 indicate shrub and grassland whereas high values approaching 1 represent temperate or tropical rainforest (sentinel-hub.com). Lichen values have not been known to exceed values higher than 0,6. Values on the negative side of the scale correspond to water bodies, urban development and impediments such as bare rock, snow and glaciers.

Before analysing change detection Sentinel-2 10-meter pixel bands and 20-meter pixel bands were resampled to 30-meter pixel bands (same as Landsat 5 TM scenes). Change analyses was then performed on 2008 and 2019 scenes for each environmental indices by subtracting 2019 with 2008 data using raster calculator (image) in ArcGIS Pro. Furthermore, values from the environmental satellite indexes and change detection analyses were extracted to field plots for further analyses in Excel and R commander. Last, descriptive statistic was exported to excel.

4.4 Field sampling and analyses

4.4.1 Field sampling and experimental design

Field work took place mid-September from 12-17 2018 and 18-19 of May 2019. Due to heavy snow fall we were not able to conclude the last day of sampling and therefore had to come back in spring after snow melt. This should not affect the result as lichens are slow to grow.

Sites were established at approximately 300-500 meters intervals along 12 transects situated within the reindeer’s winter grazing areas (Figure 7). As a consequence of Sunnfjord‘s steep topography transects were unable to follow a specific cardinal direction and alternately followed the shape of the landscape. Four transects were placed within in each subarea (n=12) and each transect had 5 sites (n=60). Sites were mainly located on open windswept and exposed ridges where reindeer commonly graze during winter. Each Site covered approximately 10 m x 10 m depending on the topography and comprised of five sample plots in a cross shaped grid (n=300; Figure 7).

For each site we randomly chose a centre plot by throwing an object overhead backwards. Following plot was then preferably placed 5 meters in each cardinal direction. In case a plot should happen to be allocated in a puddle, open rock area or cliff the line was shrunk or stretched. In each plot we placed a 50 cm x 50 cm frame grid with 25 10 x 10 cm squares, which was used to measure percentage lichen and green cover. All mat forming lichens of *Cladonia spp.* and *Cetraria islandica* was measured. For green index, grasses, sedges and dwarf shrubs such as *Vaccinium myrtillys* and *Vaccinium vitis-idaea*. *Betula spp.*, *Empetrum nigrum* and *Calluna vulgaris* was included, bare rocks and gravel were not included in the estimates. Each centre plot was protected against grazing using Elfa mesh baskets, which measure's 42, 7 cm x 52,7 cm x 18,5 cm and are white painted steel mesh. All plots were positioned using a Garmin Eltrex30 GPS bought in 2012 and marked with steel nails in each corner for later recovery. Photographic documentation was taken at each plot using a CAT s60 smart phone with 13-megapixel camera.

Following measurements were noted: (1) Percentage lichen coverage using visual field estimation (VFE), (2) Percentage green cover (VFE), (3) Height and depth of lichen in each corner of the grid, (4) Dominating lichen species. (5) potential lichen cover, (6) longitude and latitude. For each plot I calculated average lichen height with percentage cover for estimating lichen volume.

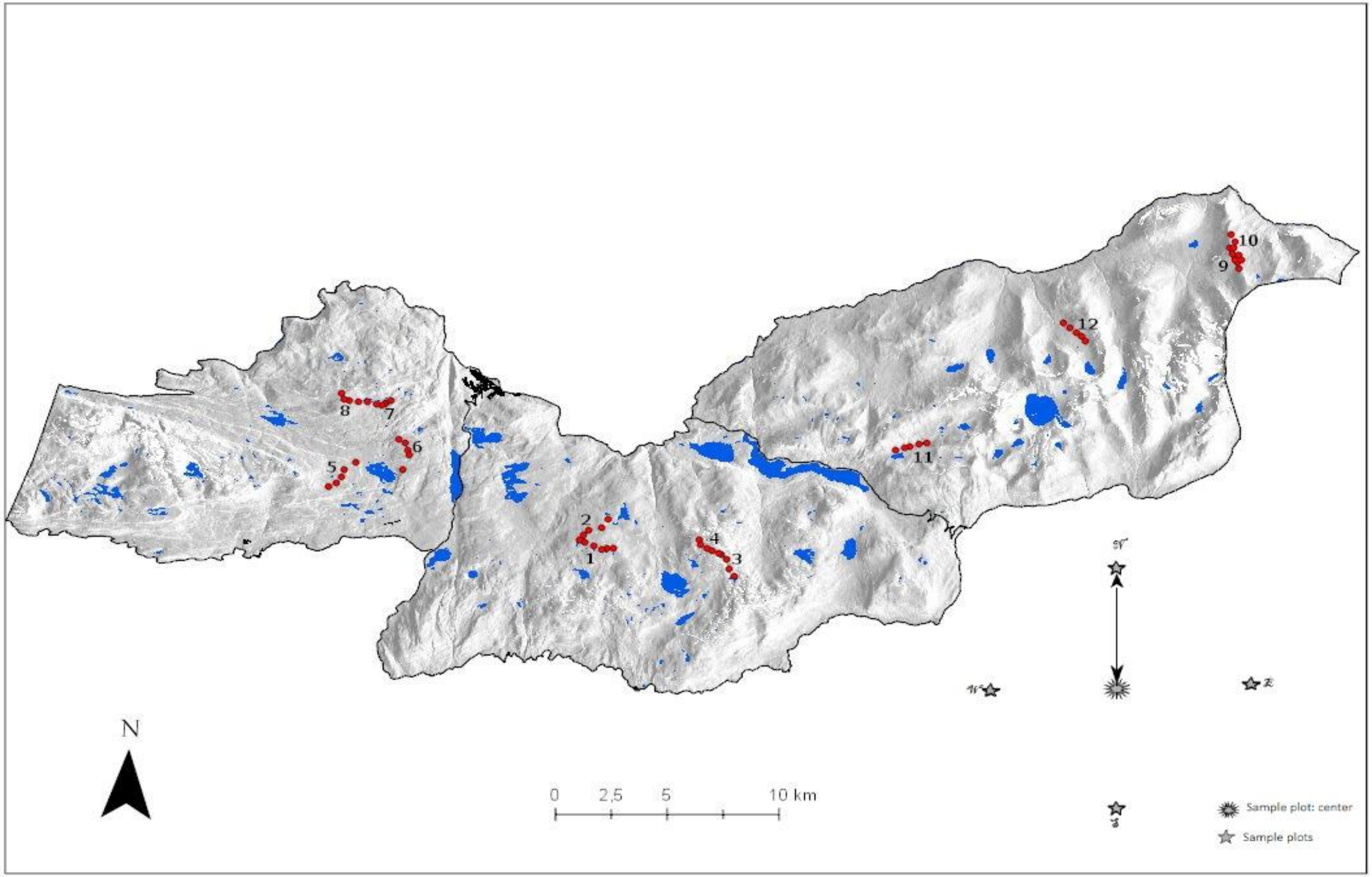

Figure 7. Sunnfjord wild reindeer area. Each transect is marked with numbers from 1-9 and red dots represent individual sites. Blue are water bodies and the gathering of black in North-West is Førde town. Cross shaped grid placed at each site is shown in bottom right corner (Tømmervik, Bjerke, Laustsen, Johansen, & Karlsen, 2013).

4.4.2 Estimating lichen and green biomass from field routes

For estimating lichen biomass (g/m^2) a formula established by Gaare et al. (1999) was used. First volume V (dm^3/m^2) was estimated by multiplying average height t for each plot whit percent coverage in a 50x50 cm square route.

$$V = d\ x\ t\ x\ 0{,}01$$

Lichen biomass L is then calculated by employing the average value of 22 and multiplying by volume. Although there is some uncertainty in the context between volume and biomass the regression coefficient is strong (r^2 = 0.92; Gaare et al., 1999; Tømmervik, Bjerke, Gaare, Johansen, & Crittenden, 2011).

$$L = (22\ \pm 1{,}5)\ x\ V$$

It is likely that reindeer in Sunnfjord does not depend on lichen alone in winter, but also forage on various green and evergreen plants. Wielgolaski (1975) found that green biomass for Hardangervidda, which is the best comparison to Sunnfjord, was 72 g/m^2. Green index X for Sunnfjord was estimated using the following formula.

$$G = \frac{72\ x\ D}{100}$$

Where D is percentage green cover. Winter diet index g/m^2 (Lichen and greens) is found by simply adding green index G to lichen index L.

$$g/m^2 = G + L$$

In 2017 an independent expert group developed a classification system for the environmental quality standard (Kjørstad et al.). Current state is to be divided in to three categories based on a traffic late system (Bad , Medium and Good) were Bad is considered not approved and Medium and Good was considered approved (Figure 8)

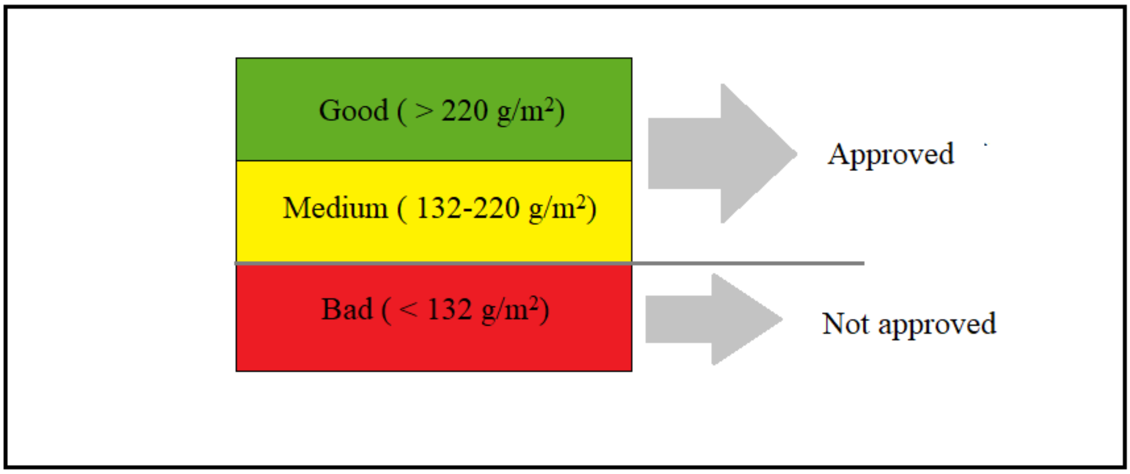

Figure 8. Division of current state categories in the environmental quality standard for reindeer (Kjørstad et al., 2017).

4.4.3 Statistical analyses

All statistical analyses were performed in Microsoft Excel and/or R commander. When comparing biomass (g/m^2), cover (%) and lichen height (mm) between sub-areas measurements from all plots were used (n = 300). When extracting results from environmental indices, only values from centre plots were used (n = 60). This was done because plots in the same site generally fell within the same pixel value, with some very few expectations. The statistical signification threshold was set to p <0,05 and the 95% confidence intervals were found by calculating standard deviation (SD) from data by using the following equation: $2\ x\ \frac{SD}{\sqrt{n}}$. All figures and tables are created in Excel.

Because Sunnfjord wild reindeer area divided in to three separated herds or sub-areas each area was looked at individually. To test for variation in biomass (lichen and green), lichen and green cover, and height variation between sub-areas, a one-way ANOVA was performed in R. To explain variation in biomass, lichen and green was testes against each other with a two-ways ANOVA.

NDLI and NDVI was plotted against each other with a linear regression to support findings performed in GIS. To test for a connection between field estimates and satellite scenes a linear regression was performed between lichen g/m^2 from field and values extracted from NDLI in GIS. Because area 3 should have less interference from larger shrubs and trees this area was tested separately.

Difference in winter pasture indices from field estimates were visually assessed using percentage of total biomass for each area. Sunnfjord wild reindeer association wish to increase herd size in all or some areas. So far there is no standard for how large the ratio Good, Medium / Bad should be before increasing herd size and still have a healthy population (H. Tømmervik, personal communication, 27. September 2019). However, the Good and Medium column should be significantly higher than Bad. I would only recommend increasing population in areas were the Good and Medium column is three times that of Bad.

4.4.4 Weather data

Precipitation, snow depth and temperature are recorded by the Norwegian meteorological institute and downloaded from "senorge"[3] Each data set has a 1 km^2 spatial resolution and 24hour time resolution (07:00 winter time and 08:00 summer time). Data was extracted from each of the 12 transect lines and mean value was calculated.

Snow depth is shown in cm and is calculated using the snows water equivalent and snow density. Precipitation (mm) measure snow fall, sleet and rain which is based on air temperature variations (- 0.5 – 2.0 °C). Air temperature shows the average daily temperature estimations from several weather stations in the area.

Temperature, snow depth and precipitation were tested against time (1971-2019) with a linear regression to look for changes over time. Normal July Temperature and topography data was downloaded from raster map in GIS and run in Excel. A one-way ANOVA was then performed to test for changes between areas.

[3] www.senorge.no

5 Results

5.1 Field plot data

5.1.1 Cover, height and Biomass

No variation in lichen cover was found within area 1, 2 and 3 (p=0,77). however, there was a difference in green cover ($F_{2, 294} = 2.77$, $p = 0.06$). Area 1 had the highest coverage reaching an average of 14.08 % within field routes. Moving further inland, green forage decreased. Area 2 had 12, 9 % cover and area 3 had 9,9 % green cover (Figure 9).

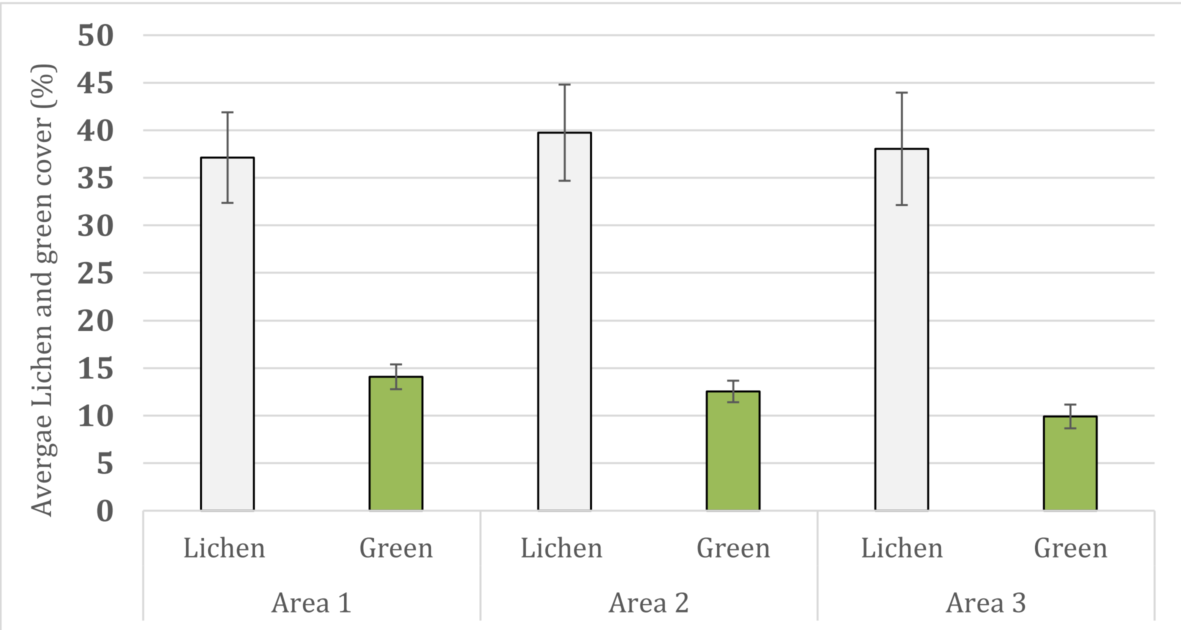

Figure 9. Average percentage cover of lichen and green forage plants in field plots for each area with 95% confidence intervals. Field sampling Sunnfjord, Sogn of Fjordane, Norway, 2018 and 2019.

Lichen heiht was significantly higher in area 2 compared to areas 1 and 3 ($F_{2, 297} = 50.84$, P= <0.001), although area 1 was only 1,5 mm shorter on average (Figure 10). Lichen in area 2 had a mean height of 14.78 mm while area 1 had a mean of 13.02. Area 3 had the shortest mean height, only 6.53 mm, meaning lichen in areas 1 and 2 was almost twice as high as in area 3. When in field it was observed considerably more grazing impact in area 3 compared to areas 1 and 2.

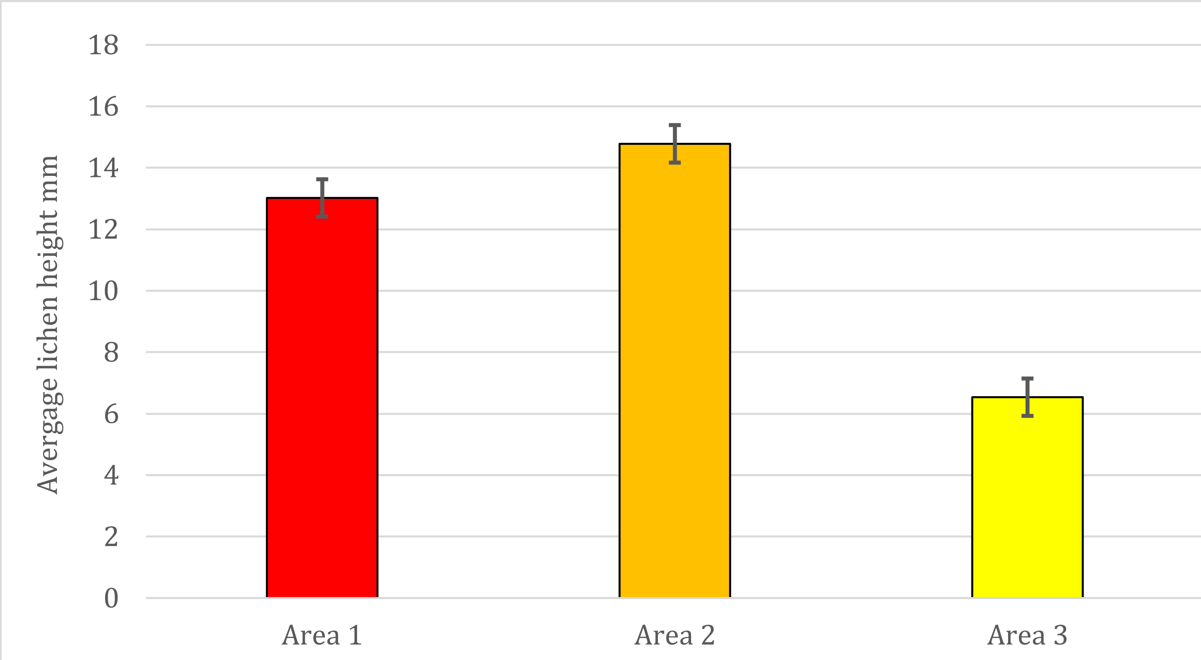

Figure 10. Average height of living lichen forage cover (mm) for each area with 95% confidence intervals. Field sampling Sunnfjord wild reindeer area, Sogn og Fjordane, Norway, 2018 and 2019.

Field data showed that area 2 had higher Winter Forage Biomass (WFB; g/m^2) than 1 and 3 ($F_{2,297}$ = 12.66, p = <0.001; Figure 11). Area 2 had an average of 147 g/m^2, almost double of area 3 with 79 g/m^2, whereas area 1 had 126 g/m^2. Both area 1 and 2 had significantly higher WFB biomass per field plot than area 3 (p = <0.001). It does not appear to be a major difference between area 1 and 2 as the confidence intervals overlap to some extent (figure 1). The difference in biomass within the areas (Figure 12) were generally correlated with the difference in lichen forage biomass (p= <0,001) and less with green forage biomass (p= 0.054). However, green biomass did show a trend.

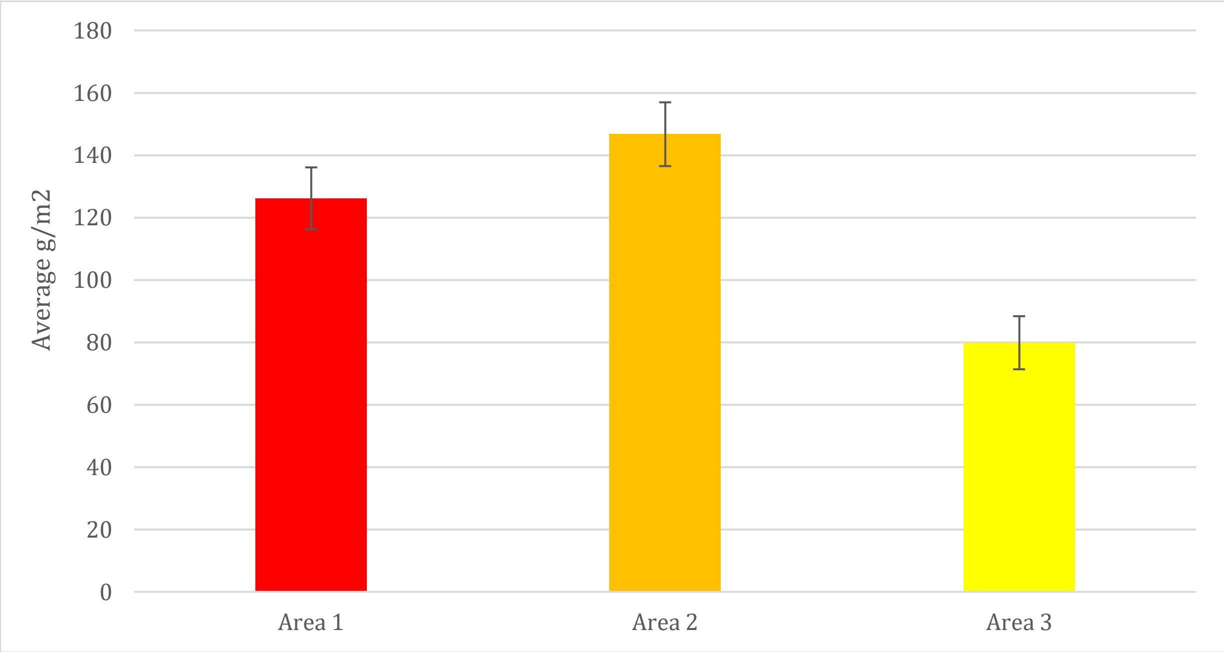

Figure 11. Average forage biomass (g/m2) for each sub-area with 95% confidence intervals. Field sampling Sunnfjord wild reindeer area, Sogn og Fjordane, Norway, 2018 and 2019

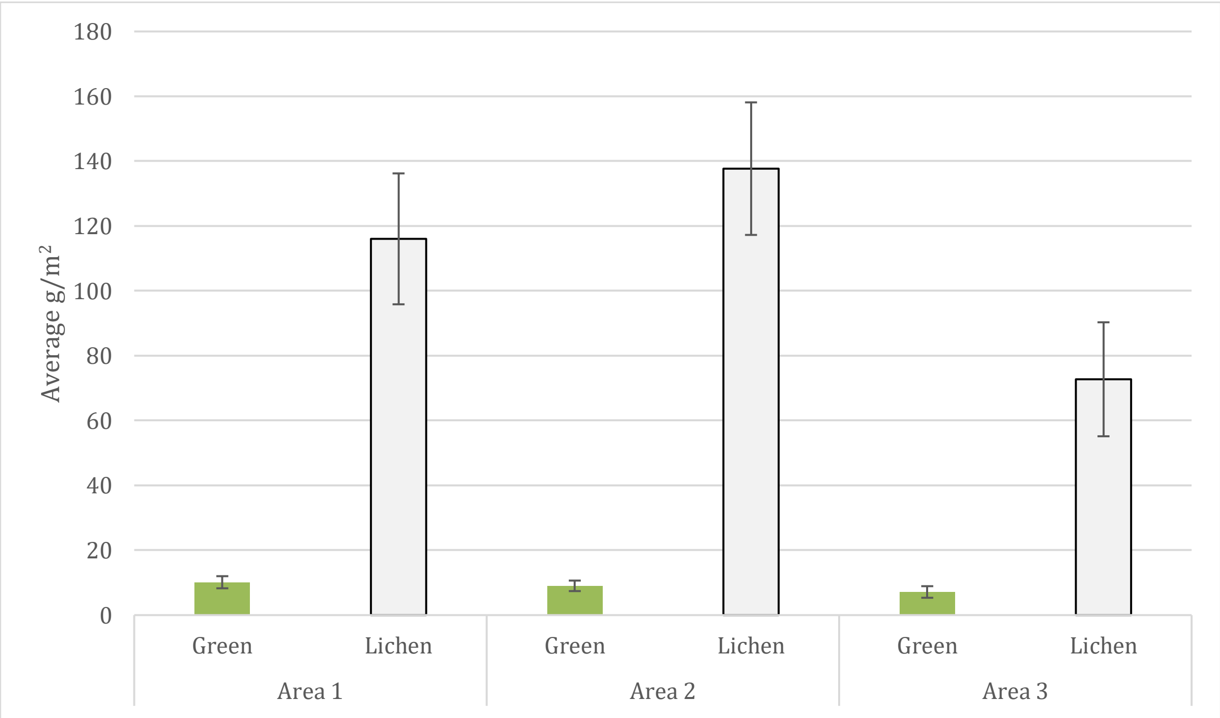

Figure 12. Lichen and green forage biomass in g/m2 for each area with 95% confidence intervals. Field sampling Sunnfjord wild reindeer area, Sogn og Fjordane, Norway, 2018 and 2019

5.1.2 Winter pasture quality categories based in field plots.

All three sub-areas had significantly higher percentage of Medium and Good plots than Bad plots (**Error! Reference source not found.**). Area 2 had the highest percentage, 84.5 % of good and Medium plots versus 15.5 % for Bad plots, area 1 had 74.5 % Good and Medium plots versus 25.25 % Bad plots, while area 3 had 70.1 % Good and Medium plots versus 29.9 % Bad plots. However, field sampling data has not taken epiphytic lichens in to consideration. Altogether, all three subareas had significantly higher percentage of approved (Good and Medium) than not approved (Bad) plots.

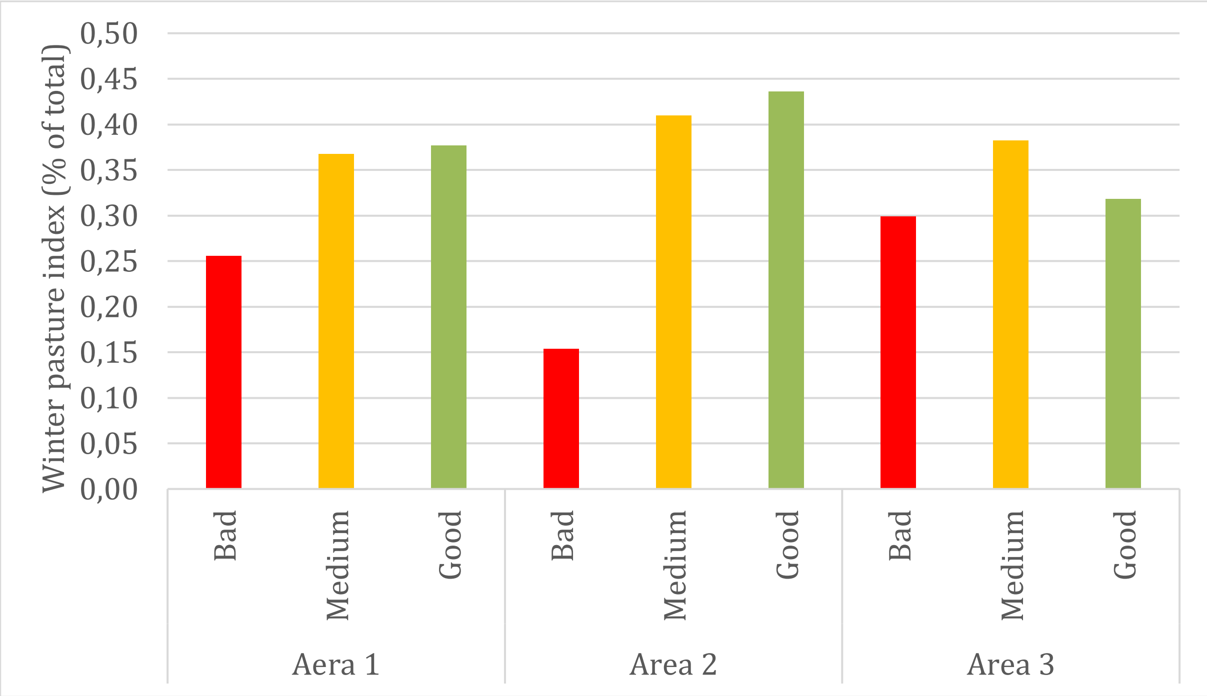

Figure 13.Percentage of total forage biomass g/m2 (lichen and green forage) following the classification system (Good, Medium and Bad) of the environmental quality standard for wild reindeer within the three sub-areas. Field sampling Sunnfjord wild reindeer a

5.2 Satellite based environmental indices of Sunnfjord reindeer district.

5.2.1 Pattern of NDVI, NDWI and NDLI.

Normalized difference lichen indices (NDLI) and Normalized difference vegetation indices (NDVI) were calculated from the Sentinel 2 satellite scene recorded in July 2019. Results are presented in Figure 14 and Table 4.

Table 4. Descriptive statistic from environmental indices in ArcGIS Pro

Index	Area	Mean	Median	Min	Max	StdDev
NDLI	All	0,30	0,38	-0,93	0,87	0,24
	Area 1	0,29	0,36	-0,93	0,66	0,25
	Area 2	0,3	0,38	-0,88	0,67	0,25
	Area 3	0,31	0,38	-0,91	0,87	0,21
NDVI	All	0,56	0,64	-0,42	0,98	0,22
	Area 1	0,56	0,65	-0.33	0,88	0,22
	Area 2	0,59	0,64	-042	0,89	0,19
	Area 3	0,52	0,6	-0.35	0,98	0,24

NDLI (top, Figure 14), is defined by a green to red colour scale, dark green pixels correspond to low lichens occurrence, whereas red correspond to high lichen occurrence. Generally, lichen occurrence appears to increase at higher elevation and decrease downwards. Sunnfjord wild reindeer area has a mean lichen occurrence of 0,30. Area 3 has the highest lichen occurrence with an average NDLI of 0,31, area 2 has 0,3 and area 1 0,29. Standard deviation intervals were large for all areas suggesting no variation in lichen cover between sub-areas.

Low NDVI values are presented as white pixels, whereas dark green corresponds to pixels with highest vegetation values (bottom, Figure 14). Green vegetation is well represented in Sunnfjord wild reindeer area, having an average of 0.56. All three sub-areas have considerable vegetation coverage; area 1: 0.56, area 2: 0.59 and area 3: 0.52. Highest values for green cover was found in lower altitudes in connection to urban development areas.

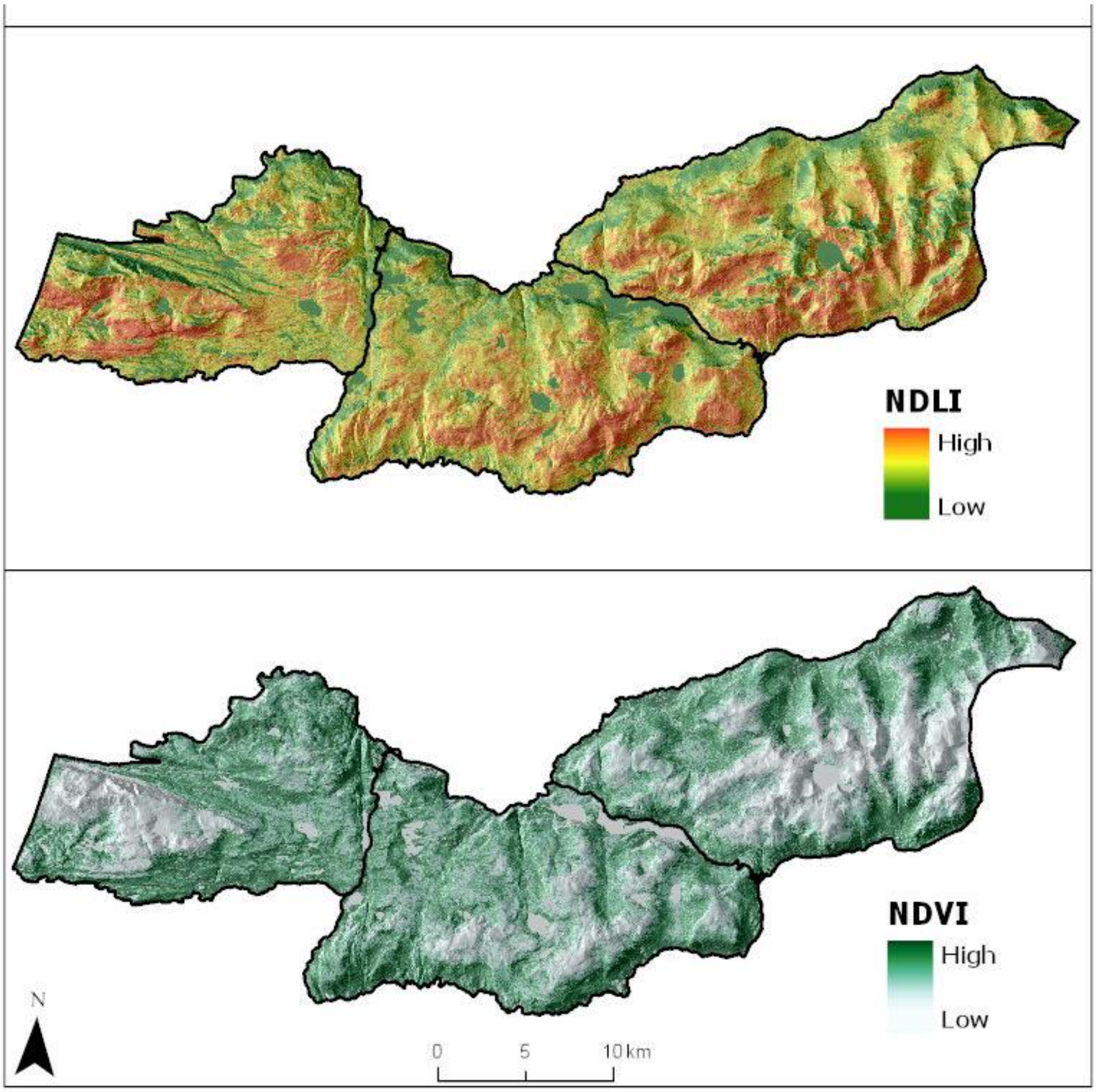

Figure 14. Normalized Difference Lichen Index (NDLI) and Normalized Difference Vegetation Index (NDVI) from Sunnfjord wild reindeer area, calculated using a Sentinel 2 satellite scene from July 2019. Sogn og Fjordane, Norway

5.2.2 Correlation between environmental indices and field estimates.

No correlation was found between lichen field estimates (g/m^2) and NDLI obtained from satellite scenes (Table 5). Area 3 should have less interference from green vegetation (sampling took place above the treeline) and should therefore display a higher correlation between estimates. However, no relationship was found between sampling methods (table 5).

Table 5. Results from a linear regression testing for correlation between field estimates (g/m²) and values from satellite scenes (NDLI)

	N	Intercept	±	slope	±	F value	p value	R2
All	60	114,22	12,44	49,31	98,14	0,25	0,6	0,004
Area 3	20	-0,10	0,02	-0,0001	0,0002	0,28	0,6	0,02

A correlation between NDLI and NDVI values was found (Figure 15). However, R^2 was only 0,34.

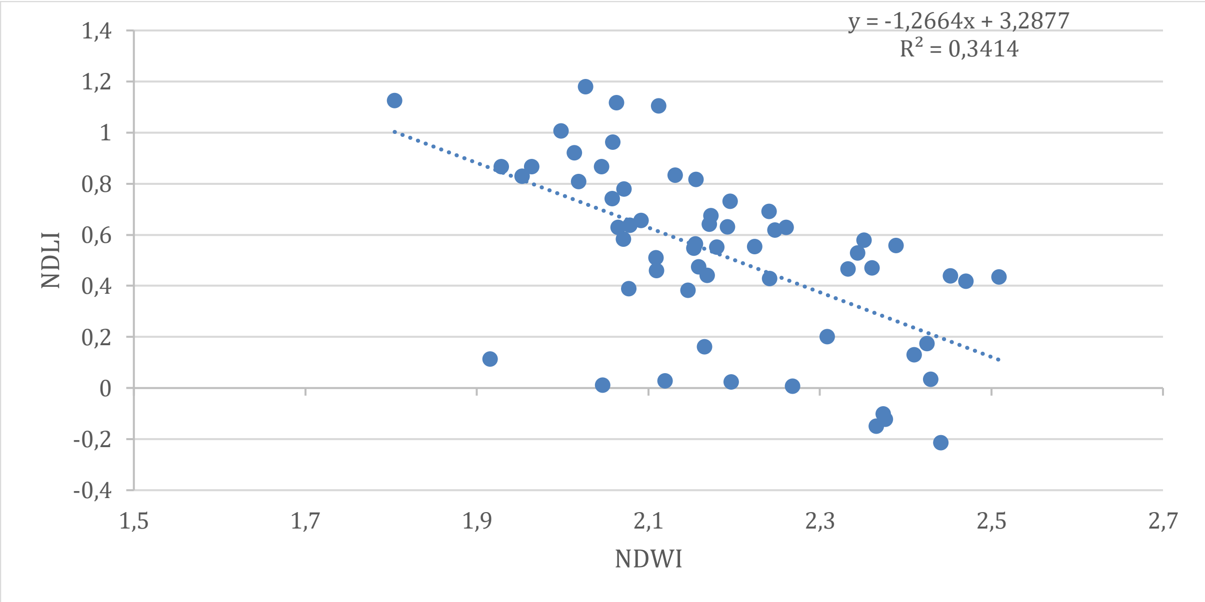

Figure 15.Normalized Difference Lichen Index (NDLI) and Normalized Difference Vegetation Index (NDVI) values extracted from field plots.

5.2.3 Change detection of remote sensed indexes.

Results for Normalized difference lichen indices (NDLI) and Normalized difference vegetation indices (NDVI) change detection is presented in Table 6 and Figure 16.

Using a Landsat 5 TM scene from 27th of July 2008 and a Sentinel 2 satellite scene from 27th of July 2019, lichen and vegetation indices were compared to study pattern of changes. During a 11year period Sunnfjord has experienced an increase in green cover, whereas lichen cover had decreased in areas 1 and 2 (-0,069 and -0,07), area 3 had no change (-0.000; Table 6).

Green and lichen cover the larges positive increased in mountain areas (Figure 16). The highest negative NDLI values were found in connection to lowland and urban developments or water bodies, whereas the lowest negative values for changes in green cover was found in in connections to valleys sides.

Table 6. descriptive statistic from change detection analyses performed in ArcGIS Pro.

Index	Area	Mean	Median	Min	Max	StdDev
NDLI	All	-0,048	-0,062	-1,12	1,34	0,15
	Area 1	-0,069	-0,065	-1,12	1,24	0,12
	Area 2	-0,07	-0,068	-0,96	1,12	0,09
	Area 3	-0,000	-0,053	-0,93	1,34	0,2
NDVI	All	0,06	0,11	-0,77	0,9	0,19
	Area 1	0,11	0,11	-0,62	0,9	0,09
	Area 2	0,1	0,11	-0,69	0,85	0,09
	Area 3	0,12	0,012	--0,77	0,81	0,1

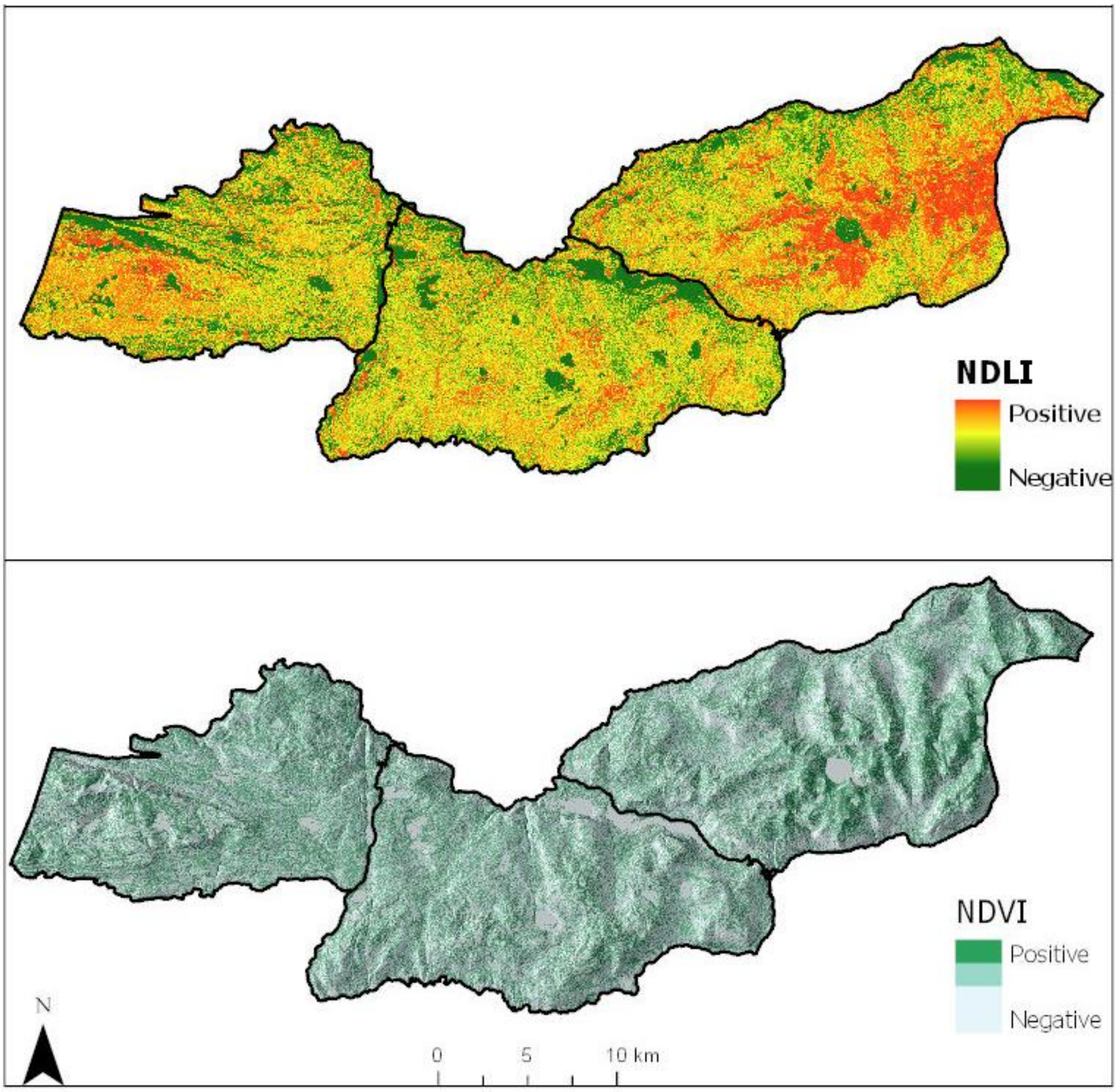

Figure 16. Change detection analyses for Normalized Difference Lichen Index (NDLI) and Normalized Difference Vegetation Index (NDVI) from Sunnfjord wild reindeer area, calculated using a Sentinel 2 satellite scene from July 2019 and Landsat 5 TM scene. Sogn og Fjordane, Norway

5.3 Changes and variation in climatic conditions

Since the beginning og 1971 temperature have had a steady average increase of 0,04°C in Sunnfjord wild reindeer area ($F_{1,47} = 35{,}37$, $p = < 0{,}001$, $R^2 = 0{,}42$;Figure 17). During the same time period no change in precipitation ($R^2 = 0{,}09$) and snow depth ($R^2 = 0{,}04$) was found. Temperature also varied between areas ($p = <0{,}001$; Figure 18). Area 1 had a higher mean July normal temperature (7,5) than area 2 and 3 (5,5 and 5,22). Plots in area 2 and 3 was situated higher than in area 1 ($p = <0{,}001$). Area 1 plots, located closest to the coast, had an average altitude of almost 600, whereas area 2 and 3 plots had a mean elevation of 834 and 871 (Figure 19). Average snow depth increased from coast to inland ($p = <0{,}001$; Figure 20).

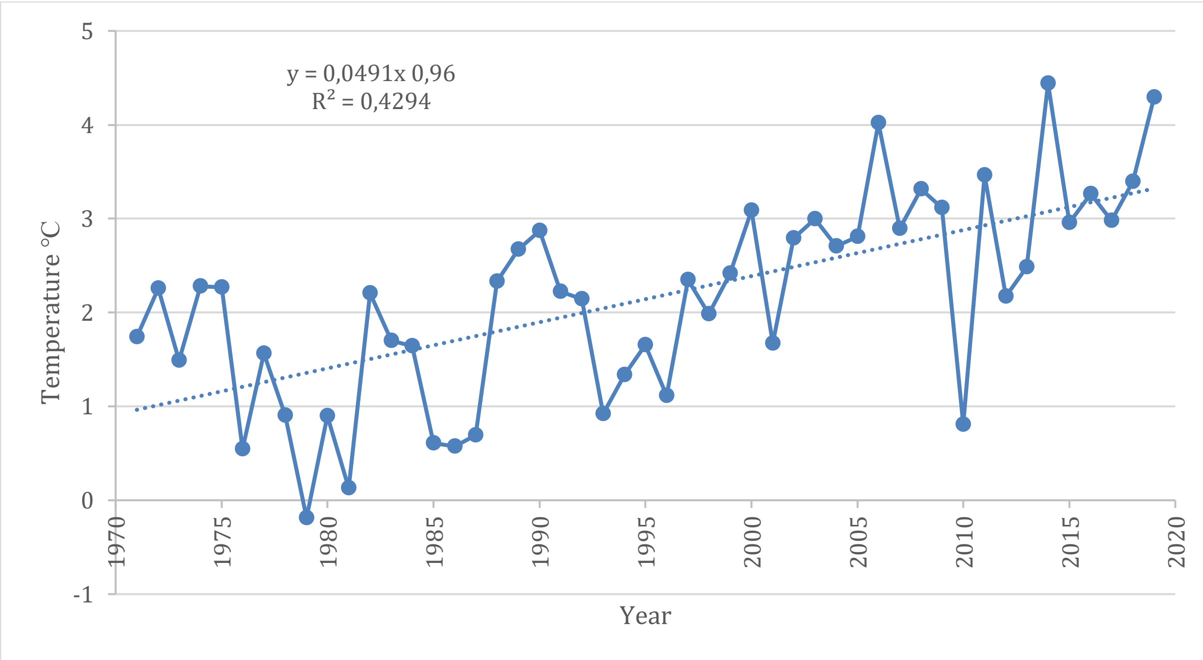

Figure 17.Average yearly temperature ℃ in Sunnfjord wild reindeer area from 1971 to 2019. Data collected by the Norwegian metrological institute.

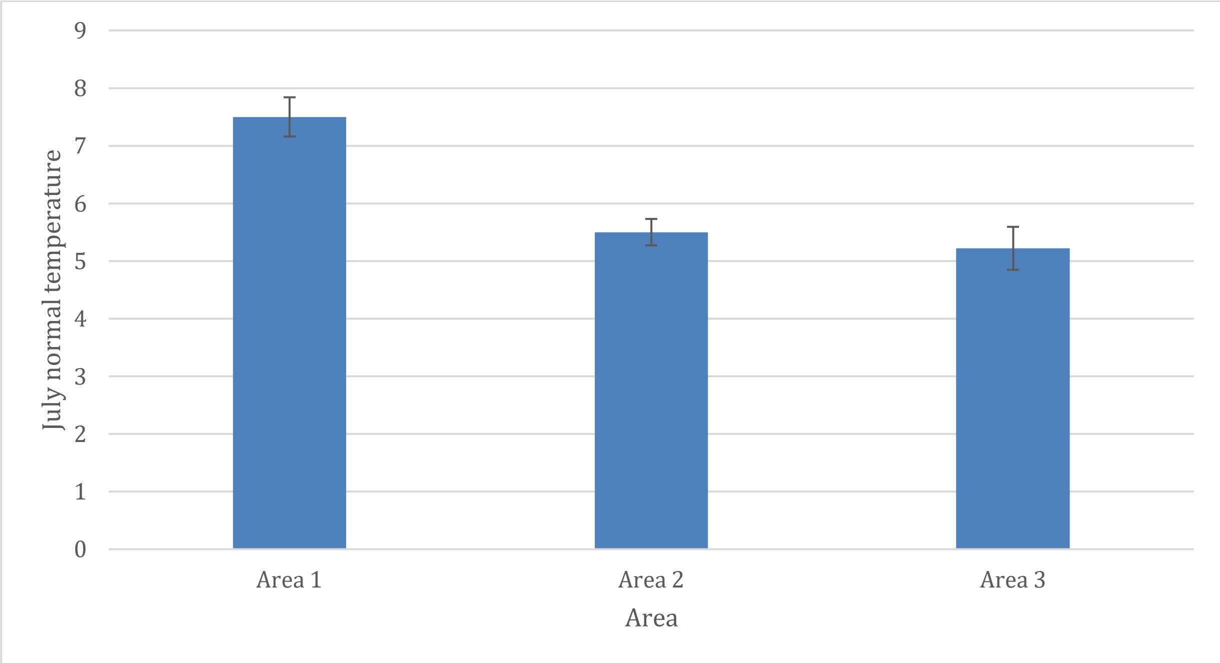

Figure 18. Difference in July normal temperature in Sunfjord wild reindeer area, Sogn og Fjordane, Norway. Data downloaded from raster map in GIS.

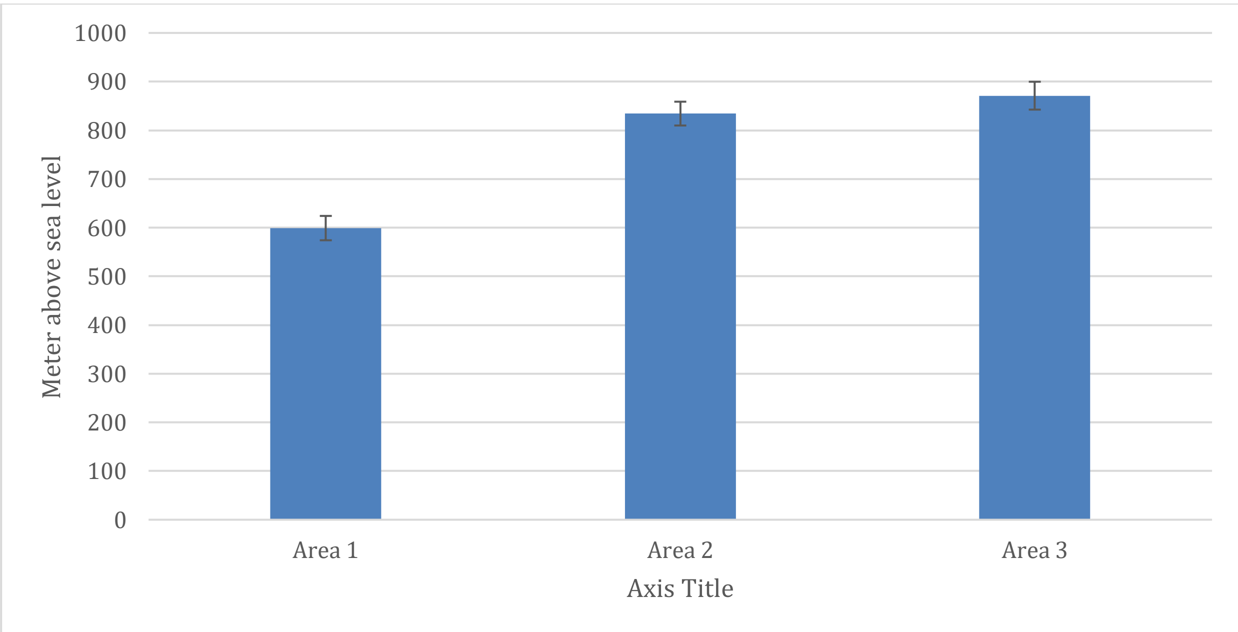

Figure 19. Differende in altitude between Sub-areas in Sunnfjord wild reindeer area, , Sogn og Fjordane, Norway. Data downloaded from raster map in GIS.

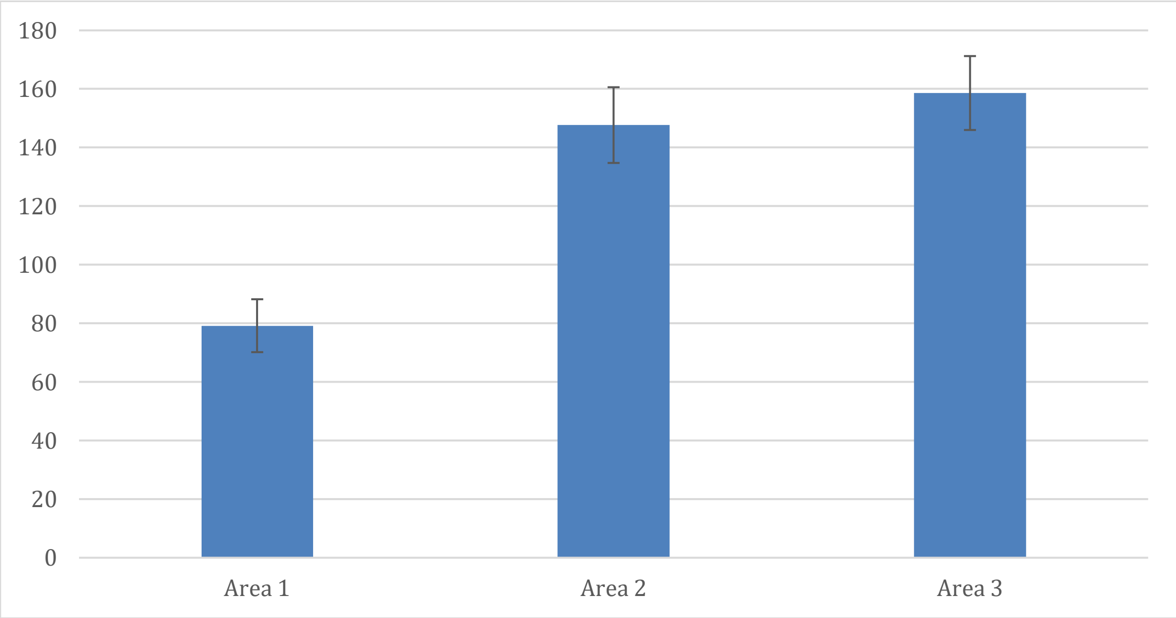

Figure 20. Average snow depth

No correlation was found between temperature / precipitation and lichen biomass and height (Table 8).

Table 5. results from a linear regression testing for connection between lichen height and g/m2 against precipitation and temperature.

		N	Intercept	±	slope	±	F value	p value	R2
Precipitation	**Height**	10	1,62	0,17	-0,02	0,01	3	0,12	0.25
	g/m2	10	1,62	0,16	-0,002	0,001	3,8	0,08	0,29
Temperature	**Height**	59	6,16	0,38	0,08	0,03	6,8	0,01	0,1
	g/m2	59	5,76	0,33	0,00	0,00	1,17	0,28	0,02

6 Discussion

6.1 Current state of winter forage biomass (WFB) in Sunnfjord wild reindeer area.

Generally, lichen rich vegetation and good winter pastures are found in the Eastern and continental part of Norway, whereas lush summer pastures are found on the coast in the West (Andersen & Hustad, 2004). Results from field plots show that Sunnfjord in general have more satisfying winter forage cover (Medium 38,86 %, Good 38,82 % and Bad 22,32 %) than was expected based on two earlier studies mapping vegetation (Andersen & Hustad, 2004; Kjørstad et al., 2017).

The first ever vegetation mapping of Sunnfjord was concluded in 2004 by Andersen & Hustad and was based on aerial photo in the time 1980 – 1989. They found that almost 50 % of the land cover in Sunnfjord was impediments (area not suited for reindeer foraging), whereas only 20 % could be considered suitable winter pastures. In 2017 another investigation of all 23 wild reindeer areas was performed based on satellite derived vegetation maps by NORUT (Johansen, 2009). Kjørstad et al. divided pastures in to 4 categories, two winter pasture categories, two summer pastures and one impediment. They found that most areas in West, including Sunnfjord, had more suitable winter pasture than first expected based on the first vegetation evaluating from 2004. In Sunnfjord 40 % of vegetation cover could be considered good winter forage pastures. However, they also found that almost all wild reindeer areas had a much larger proportion with lichen poor vegetation then they had with.

Overall average WFB for Sunnfjord was 117 g/m^2. Similar estimates have been found on Hardangervidda and in Finnmark (Odland, Sandvik, Bjerketvedt, & Myrvold, 2014; Strand, Gaare, Solberg, & Wilmann, 2004; Tømmervik, Bjerke, Laustsen, Johansen, & Karlsen, 2013). However, results from Hardangervidda came from already grazed plots, while most of Finnmark is considered overexploited by reindeer.

Satellite based environmental indices, showed that Sunnfjord had lichen cover with a median of 0,38. Highest Estimates for NDLI at Hardangervidda has rarely been known to exceed 0,6. Unlike the study from Hardangervidda, which excluded vegetation types low in lichen or unavailable for reindeers during winter (i.e. mires, snow patches, urban landscape, meadows and forest), we included all vegetation type which could have resulted in the high

NDLI estimate in Sunnfjord (Tømmervik, Hans. Personal communication. 27. September 2019).

6.2 Variation in winter pasture quality within and between sub-areas.

Sunnfjord, although considered one managing area, is divided in to three sub-areas by two main roads. There is no known migration between areas. Thus, each area must be manged separately. Additional, based on conversations with board members, herds appear to manage differently.

Field estimates showed that area 2 had the best winter forage quality of the three, whereas area 3 came out the worst. Average lichen height (Figure 10), winter forage g/m^2 (Figure 12) and approved plots (Good and Medium plots; Figure 13) was highest in area 2. Overlapping confidence intervals in Figure 12 , suggest that area 1 and 2 have the same average lichen biomass, almost twice that of area 3. Lichen cover was the only variable not differing between sub-areas, whereas green cover increased from East to West (Figure 9). Earlier studies found strong evidence of an increase in lichen abundance from oceanic to continental / inland areas (Strand et al., 2004). This is the opposite of what was found for Sunnfjord were the highest lichen biomass was observed in the coastal areas, while area 3, which could be considered more continental, had the lowest lichen abundance.

Studied plots within the same area had highly different lichen biomass (LB). In area 2 plots varied from 1,44 g/m2 – 557 g/m2. Average LB was 73 g/m^2 in area 138 g/m^2 in area 2.

A study from Hardangervidda found that heavily grazed areas had average lichen biomass of app. 100 g/m^2 ,while not grazed further inland had LB exceeding 700 g/m^2 (Odland et al., 2014). In interior Finnmark average g/m2 within plots varied from 81 g/m2 -260 g/m2 (Tømmervik et al., 2013). Both Hardangervidda and Finnmarksvidda is considered heavily overgrazed. Suggesting that lichen biomass in all three areas of Sunnfjord are close to its critical value to ensure survival of present herds.

When foraging in winter, reindeer can consume up 70 % of the entire lichen mat within a grazing area. It is estimated that reindeer could graze 30 m2 per day , and therefore an average of 90-100 g/m2 should be available in the habitat (Kumpula et al., 2000). Odland et al. found that 86 g/m2 was equivalent to 50 % lichen cover with 3 cm thickness. Under such lichen conditions, reindeer number on winter ranges should not exceed 5-7 individuals per km^2. In

Sunnfjord neither sub-area exceeded 40 % lichen cover, and although average lichen height in area 2 was almost twice that of area 3, none exceeded 15 mm. However, it is important to keep in mind that we only measured the living part of lichen, and therefore the actual thickness of lichen mats would be greater. Based on counts from 2018 Sunnfjord now have 124 overwintering animals divided in to three separate herds, hence each induvial have app. 5,6 km^2 of the total area to their disposal. Although this estimate does not take difference in seasonal pastures in to consideration, it is unlikely that lichen mats in Sunnfjord suffer from overexploitation.

If lichen mats are insufficient or not available, reindeer have been found to replace terrestrial lichen with arboreal lichen and increase intake of vascular plants (Ferguson, Gauthier, & Messier, 2001; Helle & Tarvainen, 1984). Results in this study show that palatable winter green cover increased from Area 3 to area 1 (Figure 9). Further, although average green biomass (GB) did not significantly vary among sub-areas, a trend for increasing GB from area 3 to area 1 was found (Figure 12). It is possible that reindeer in area 1 and 2 depend less on ground lichen and more on vascular plants and arboreal vegetation during winter. Egilsson (1983, referred to in Þórisson, 2018. p. 112) observed how two reindeer herds on Iceland had dietary differences. Area 1, were heathland and mountain vegetation was more prominent, reindeer mainly fed on lichen. Whereas area 2, which is one of few areas in Iceland with unbroken and rich vegetation had higher contents of dwarf shrubs. Similar result was found for two separate herds on Greenland, were the Southern herd fed more on lichen while the Northern herd`s diet consisted of vascular plants. However, while dietary preferences for Icelandic herds were controlled by availability due to overgrazing, the differences on Greenland was assumed to be driven by climatic differences. In the next chapter I discuss how and if climate variables could affect WFB.

In area 3 we found several indications of reindeer foraging on lichen, which was not found in the other areas 1 and 2. Based on these observations it is more conceivable to assume that reindeer in area 3 depend more on lichen during winter than area 1 and 2. When comparing vegetation between areas, we see that the inner habitats have more prominent mountain vegetation and less forest and shrub landscape, which could increasing pressure on lichen mats (Tømmervik et al., 2004). The topography of area 3 is also steeper ant likely have more open and wind-swept ridges, further suggesting increased availability to lichen mats. Strand et al. (2004) found that lichen growing on ridges at Hardangervidda had shown a reduction in height. Indicating increased grazing on mountain ridges. When feeding on lichen reindeer remove several years’ worth of growth, which could explain why lichen height and LB was so low in area 3 compared to the other areas.

Satellite remote sensing could not detect any significant variation in green and lichen cover between sub-areas (Table 4. Descriptive statistic from environmental indices in ArcGIS Pro. A study carried out in Sweden mountain ranges by Nordberg & Allard (2002) found that areas with lichen cover beneath 20 % could not be separated from other types of vegetation. Neither sub-area had field routes with lichen cover under 30 percent. However, all plots in this study were placed on ridges, were lichens are known to thrive (Gaare, 1994), suggesting that the actual observed lichen cover could be less. This is also somewhat confirmed by observation in field. We experienced a more unevenly and spread lichen cover in area 1 and 2 compared to area 3, which might explain why satellite derived results did not coincide with field estimations.

6.3 Comparison of field observations with satellite data.

Mapping by satellite remote sensing have become increasingly popular the past decades. Satellite images can cover larger and more inaccessible areas than precious methods. Although there are still some challenges connected to this method, they make it possible to compare results from several areas in a short period of time (Kjørstad et al., 2017). Remote sensing together with field estimates should be able to provide a more comprehensive results when mapping pasture quality (Falldorf et al., 2014; Rickbeil, Hermosilla, Coops, White, & Wulder, 2017)

Previous studies have shown a good relation between field estimates and results obtained from image analyses (Falldorf et al., 2014; Nordberg & Allard, 2002; Rickbeil et al., 2017; J Théau & Duguay, 2004; Jérôme Théau & Duguay, 2010). In this study no relation was found between lichen biomass estimated in field and satellite derived lichen cover estimates (NDLI)

Individual pixels within a satellite image is rarely pure, instead it is made up by mixture of various surface elements, the reflectance of each element contributes to the overall reflectance output within each pixel (Jérôme Théau & Duguay, 2010). If lichen cover is >20 % within in a pixel , satellite imagery cannot separate lichen from other vegetation which would result in lower NDLI values for that pixel than what is observed in field(Nordberg & Allard, 2002).This could be avoided by using a method called Spectral Mixture Analysis (SMA) which retrieve proportions of reflections within each pixel, which could produce more reliable lichen estimates. However, this has inly been tested on pale species of *Cladonia* (J Théau & Duguay, 2004; Jérôme Théau & Duguay, 2010).

In this study we only used NDLI when comparing field results and satellite data. Falldorf et al. (Falldorf et al., 2014) found that by combining NDLI and NDWI they could retrieve reliable estimations for lichen volume. This relatively new method is called lichen volume estimates (LVE). Relation between ground measurements was predicted to $R^{2=}$ 0,74. For further study I would recommend using LVE instead of just NDLI when trying to estimate observed lichen biomass. Following either of the methods mentioned in this chapter could have increased the relation between field estimates and satellite remote sensing data.

6.4 Changes in magnitude and spatial distribution during an 11years time period.

In this study, a simple change detection analyses were applied across a 700 km2 area in Sunnfjord. Temporal changes in green and lichen cover was detect in all parts of the study area. By visually assessment also cluster of negative and positive change could be identified.
During the period 2008-2009 Sunnfjord have experienced and overall increase in NDVI and decrease in NDLI (Table ; Figure 16). Accumulation of green biomass in Arctic and alpine communities, due to changing climate, have been well documented in earlier studies (Elmendorf, Henry, Hollister, Björk, Bjorkman, et al., 2012; Gómez-bolea, Saiz-jimenez, Bonazza, Messina, & Sabbioni, 2012; Tveraa et al., 2007). Increased competition with vascular plants following a green up is further believed to result in decreasing lichen abundance (Cornelissen et al., 2001; T. M. Heggberget, Gaare, & Ball, 2002; Press, Potter, Burke, Callagan, & Lee, 1998). This study found a negative correlation between lichen cover and green cover, supporting the assumption that lichen decrease with increasing green biomass (Figure 15).

Decline in lichen could indicate intensive grazing or trampling by reindeer herds. (Kumpula et al., 2000; Pegau, 1970). Following heavy depletion of winter pastures, Kumpula et al. (2000) found that lichen mats in Finland would have to remain ungrazed for 18 years before reaching its fully potential. However, as discussed in previous chapters, it is unlikely that winter ranges in Sunnfjord suffer from overexploitation as the reindeer numbers don’t exceed 1 per 5,6 km2.

Whereas green had the same temporal increase within in all sub-areas, lichen cover varied somewhat. Area 1 and 2 all experienced a small decrease in lichen cover, while area 3 can be said to have had not change (mean -0.000). This could potentially be explained by the large positive changes in lichen cover at higher elevations. Area 3 mostly consist of high elevated mountain areas which could result in colder temperatures and conversely limit shrub recruitment (Lantz, Gergel, & Henry, 2012). Several studies from Norway have found that lichen cover have increased in mountain areas following reduction in herd size (Gaare, Tømmervik, Bjerke, & Thannheiser, 2014; Odland et al., 2014; Strand et al., 2004; Tømmervik, Bjerke, Gaare, Johansen, & Thannheiser, 2012; Tømmervik et al., 2013). Falldrof et al. (2012) found that lichen increased more rapidly at Finnmarksvidda than what was first expected due to increasing temperatures and precipitation. Although Finnmark differs in climate and vegetation results could be transferred to Sunnfjord. Warmer temperatures and high precipitation rates on the West coast of Norway could generate advantageous growing conditions for lichen at higher eleveations. However, simultaneous with increase in lichen cover, the same study observed increase in shrubs, which could in the future hamper the positive effect warmer climate have on lichen growth.

Overall, results obtained through satellite derived change detection show the same general trend described in previous studies. Still, it is important to consider limitations when using multi-date and multi sensor imagery. (i.e. spatial resolutions and radiometric resolutions). Although, both images have been radiometric calibrated by both supplies companies, difference in vegetation state, climate conditions cannot be eliminated. Limitation to the dataset could have been further improved by selecting image later in summer or by increasing number of images. Further, previous studies mapping changes in vegetation remove vegetation types not suited for winter foraging. By removing areas not used by reindeer's results derived from this study could have been different.

6.5 Climatic variables.

From 1971 up until 2019 temperature have shown 0,04 °C in average yearly temperature (Figure 17). Precipitation and snow cover did not show any significant increase or decrease during the same period. Nevertheless, Precipitation, and consequently snow cover, is expected to increase by 20-30 % on the West coast of Norway the years to come (Grønås, Kvamme, & Teigen, 2005).

Global climate change, specifically warming and drying, have been suggested as controlling factors for lichen growth in the Arctic and Tundra ecosystems (Epstein, Calef, Walker, & Chapin lll, 2004; Walker et al., 2006). Due to the lack of roots, lichens depend entirely on atmospheric moisture for growth. In periods of drought lichens enter dormancy and all growth is stagnated for that period. Earlier studies have found that an increase in temperature and decrease in precipitation have a negative effect on lichen recovery (Joly, Jandt, Meyers, & Cole, 2006; Klein & Shulski, 2009). A study by Käranlampi (1971), demonstrated how lichen growth was proportional to weekly summer precipitation. This was later confirmed by Tømmervik et al. (2012) which found that an increase in precipitation and cloudy days on Finnmarksvidda had a positive effect on lichen growth, vascular plants and bryophytes. On the other hand, Odland et al. (2014) found that lichen biomass decreased with increasing precipitation and increasing altitude.

Result derived in this study couldn`t find any correlation between lichen biomass and precipitation and temperature (Table 5). However, other results could still suggest that climate have an important role in controlling vegetation composition.

Change detection, which will be discussed in later chapter, showed an overall increase in green vegetation and decrease in lichen cover. Evidence of "shrubification" in arctic and alpine environments due to increase in temperature and precipitation is supported in several studies (Chapin et al., 1995; Cornelissen et al., 2001; Elmendorf, Henry, Hollister, Björk, Boulanger-Lapointe, et al., 2012; Joly, Jeanie Cole, & Jandt, 2007).

Furthermore, temperature (Figure 18), altitude (Figure 19) and snow depth (Figure 20) varied significantly among sub-areas. Transects in area 2 and 3 was located at higher altitudinal gradients compared to area 1. Average normal July temperature was highest in area 1 and lowest in area 3, whereas average snow depth was highest in area 3 and lowest in area 1. If we compare these results with results from field plot data, there should be possible draw some connection. Area 3, which has more prominent mountain vegetation, is situated higher and have low temperatures also have the lowest WFB g/m^2, green cover and lichen height, is. Whereas area 1, with higher temperatures, less snow cover and have lower altitude, also have the highest green cover and acceptable WFB. Suggesting that climatic factors does influence variation in forage among sub-areas (Macander et al., n.d.).

Results in this study could have been improved by using a different dataset when testing for a correlation between temperature/ precipitation and lichen biomass and height. Both temperature and precipitation had large spatial resolutions (1 km^2). Considering Sunnfjord`s large variation in topography substantial local differences is expected within areas. It is unlikely that the dataset in this study would be able to pick up on such variation.

7 Conclusion

As to the main question raised in this study, following answers can be given.

1) The overall winter forage quality in Sunnfjord is good considering the low herd size and expectations from earlier studies. Field estimates showed than Sunnfjord wild reindeer area had an average of 117 g/m^2, whereas satellite data had an average NDLI of 0,30.
2) Winter forage biomass differed between sub-areas. Area 2 had the highest average g/m^2 (LB and WFB), while area 3 had the lowest. Both area 1 and 2 had almost twice as high WFB as area 3. Green cover and GB increased from area 3 to area 1 although results for GB was not significant, they showed a trend. Satellite derived environmental indices shows no significant variation between areas. However, average NDLI Increased from Area 1 to area 3, whereas NDVI was highest in area 2 and lowest in area 3.
3) Sunnfjord had experienced and increase in temperature during the period 1971 -2019. Normal July temperature, snow cover and altitude varied among sub-areas and followed somewhat same patterns as. However, no link between temperature, precipitation and lichen biomass was found, despite that several studies have found a negative or positive correlation between climate factors and lichen cover.
4) LB observed in field was not correlated with satellite derived results for NDLI. Further analyses using LVE or SMA is therefore advice for determine if there is in fact a correlation.
5) Lichen cover show and overall decrease, simultaneously increases in green cover was observed. Lichen cover had decreased most in area 1 and 2, whereas area 3 show little or no change. The largest positive changes in lichen cover was observed in mountain areas where colder temperatures could limit vascular plant recruitment.

Area 3 had the lowest average winter forage g/m^2 and height and some grazing damage could already be observed, Thus, care should be taken. Although area 1 had relatively good winter forage g/m^2 and lichen height I would not recommend increasing herd size in this area based on conversation with board members stating the herd is already struggling. Area 2 had the highest winter forage biomass and could appear to have more evenly distribution of good summer- and winter pastures. Hence, population in area 2 may slightly be increased.

If Sunnfjord wild reindeer association chose to increase herd size I would recommend to start register slaughter weights of all shot reindeer as suggested in “miljøkvalitetsnorm for villrein- forslag fra en ekspertgruppe” (Kjørstad et al., 2017. s. 63-64). I would also like to recommend further study in to the winter diet of reindeer from feces sampling to see if there is variation in preferred forage within herds. Further I would like to suggest digitalising all information on demography and health for easier access.

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