

Norwegian University of Life Sciences  
Faculty of Environmental Science and Technology  
Department of Ecology  
and Natural Resource Management

Philosophiae Doctor (PhD)  
Thesis 2014:15

# Effects of vegetation and grazing preferences on the quality of alpine dairy products

Effekter av utmarksbeite og beitepreferanser  
på melke kvalitet i seterregionen

Hanne Sickel



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Drøbak, 16. Januar 2014  
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## **Abstract**

Sickel, H. Effects of vegetation and grazing preferences on the quality of alpine dairy products. Norwegian University of Life Sciences, Philosophiae Doctor (PhD) Thesis 2014:15, ISSN 1503-1667, ISBN 978-82-575-1190-6

This PhD study has been a part of a larger research project where the main objective was economic and ecological sustainable agriculture in alpine areas for the production of food of high quality and maintenance of the summer farming landscape. The project was conducted at Bioforsk Øst Løken under the responsibility of Dr. Tor Lunnan. The main aim of the present PhD-thesis was to generate knowledge of possible effects of vegetation composition and grazing preferences on the quality of alpine milk. The study sites were two summer farms situated in two different alpine regions in south-central Norway, i.e. Valdres and Hallingdal, with dairy cattle grazing alpine ranges.

In the first study of the thesis (Paper I), the content of  $\alpha$ -tocopherol in Norwegian alpine grazing plants were investigated. Our results show that alpine ranges provide fodder with high levels of  $\alpha$ -tocopherol. The overall mean content of  $\alpha$ -tocopherol was  $141 \pm 34 \mu\text{g g}^{-1}$  DW and high levels of  $\alpha$ -tocopherol were found in herbs, sedges and woody species. Plants from light and shady habitats did not differ in their  $\alpha$ -tocopherol content, which was idiosyncratic as indicated by significant interactions between species, sampling occasion, site and tissue type.

Area use, grazing patterns and grazing preferences of free ranging dairy cattle in the two alpine rangelands were investigated by field work and high frequency GPS data combined with detailed vegetation maps. Models for interpretation of cattle behaviour on alpine rangelands from high frequency GPS data were developed (Paper II). By using parameters derived from the GPS data, the behaviour could be classified into walking, grazing and resting. Using this method, it was possible to classify grazing behaviour correctly with as much as 92 percent accuracy. Furthermore, a system was made for assessing the uncertainty in classification of the GPS points, thereby making it possible to quantify the uncertainty in the analysis when doing analysis in Geographical Information Systems (GIS) where GPS points are overlaid on categorized layers.

The movement and grazing patterns of the herds based on vegetation mapping, GPS recording, and supplementing field work, are presented in Paper III. Daily, average walking

distances were 4700 m and 4800 m at site 1 and 2, respectively. The cows stuck together and did typically use different routes from day to day, giving the grazing habitats possibility to recover between grazing events. Grazing was the main activity and the cows preferred to graze light-open, grass and herb rich vegetation types. Also seasonal grazing differences were uncovered.

Fatty acid composition and the content of various antioxidants and volatile compounds in the milk from the grazing period were investigated and are presented in Paper IV. Possible connections between grazed plant groups and the milk quality were also examined.

The results of the statistical modeling indicate that the different plant groups on the rangelands were significantly related to specific chemical components in the milk. Analytical results which characterize the milk from summer farms in this project, and which can be said to give rise to unique milk products are, therefore, low contents of the unfavourable fatty acids C14:0 and C16:0, high levels of the favourable fatty acids C18:3 n-6 and CLA, a low ratio omega-6:omega-3 and a relative high number of terpenes.

This study shows that the cattle utilize the summer farming landscape extensively and prefer light-open, grass and herb rich vegetation types when available. Thereby they contribute to maintenance of semi-natural species rich habitats. Moreover, milk produced on species rich rangelands are characterized by a healthier fatty acid composition and a higher content of terpenes. This can be utilized as a win-win situation and give potential for unique alpine products, thereby supporting alpine farmers. However, the study also reveals that grazing is not enough to keep the summer farming landscape light open. To maintain the biodiversity and grazing value of semi-natural species rich habitats it may therefore be necessary to supply grazing with clearing of bushes and trees, preferably in the localities where the cattle choose to graze.

Keywords: alpine rangelands, biodiversity, grazing preferences, milk quality, GPS,  $\alpha$ -tocopherol

## Sammendrag

Sickel, H. Effekter av utmarksbeite og beitepreferanser på melke kvalitet i seterregionen, Norges miljø- og biovitenskapelige universitet, PhD-avhandling 2014:15, ISSN 1503-1667, ISBN 978-82-575-1190-6

Dette doktorgradsarbeidet har vært en del av et større forskningsprosjekt der hovedfokuset har vært økonomisk og økologisk bærekraftig landbruk i fjellområder. Dette landbruket produserer mat av høy kvalitet og bidrar til å opprettholde seterlandskapet. Prosjektet har vært gjennomført ved Bioforsk Øst Løken med Dr. Tor Lunnan som leder. Målet med denne doktorgradsavhandlingen har vært å skaffe kunnskap om mulige effekter av vegetasjonssammensetning og beitepreferanser på melk fra fjellområder. Dette har vært studert på to setre med frittgående kyr i to forskjellige fjellområder i sentrale Sør-Norge, henholdsvis i Valdres og Hallingdal.

I den første artikkelen i denne avhandlingen (Paper I) er innholdet av  $\alpha$ -tokoferol i beiteplanter i norske fjellområder blitt undersøkt. Våre resultater viser at fôr fra alpine beiter inneholder høye nivåer av  $\alpha$ -tokoferol. Gjennomsnittsinholdet var  $141 \pm 34 \mu\text{g/g}$  tørrvekt og høye nivåer ble funnet i urter, starr og forvedete vekster. Planter fra lysåpne og skyggefulle områder hadde likt innhold av  $\alpha$ -tokoferol.

Arealbruk, beitemønstre og beitepreferanser hos frittgående melkekyr i de to fjellområdene har blitt undersøkt ved hjelp av data fra feltarbeid og høyfrekvent GPS logging kombinert med detaljerte vegetasjonsskart. Modeller for å kunne tolke kyrenes oppførsel på fjellbeite fra dette har blitt utviklet (Paper II). Ved å bruke parametere avledet fra GPS dataene, har adferden kunne blitt klassifisert som henholdsvis beite, gange eller hvile. På dette viset har det vært mulig å tolke opp til 92% av beiteadferden korrekt. Dessuten har det blitt laget et system for å anslå usikkerheten i klassifisering av GPS punkter når disse kombineres romlig med kategoriserte lag i et geografisk informasjonssystem (GIS).

Bølingenes bevegelses- og beitemønstre tolket ut fra GPS data og feltarbeid og kombinert med vegetasjonsskart er presentert i Paper III. Kyrene gikk i gjennomsnitt henholdsvis 4700 m og 4800 m pr dag i Valdres og Hallingdal. Bølingene gikk samlet og brukte forskjellige ruter for hver dag. Dermed fikk beiteområdene mulighet til å hente seg inn igjen mellom hver gang de ble beitet. Kyrene brukte mesteparten av tiden til å beite og de foretrakk da å beite på

lysåpne, gras- og urterike vegetasjonstyper. Det ble også registret noen sesongmessige variasjoner i beitemønsteret.

Fettsyresammensetningen og innholdet av forskjellige antioksidanter og flyktige komponenter i melken har også blitt undersøkt. Resultatene fra dette finnes i Paper IV. Her har også mulige sammenhenger mellom hvilke planter som har blitt beitet og melke kvaliteten blitt undersøkt. Statistiske modeller indikerer at forskjellige plantegrupper i utmarka henger signifikant sammen med spesifikke stoffer i melken. Analyser som er gjort for å karakterisere melken fra setrene i dette prosjektet viser hvordan denne melken har unik sammensetning med lavt innhold av de uheldige fettsyrene C14:0 og C16:0, høyt innhold av de gunstige fettsyrene C18:3 n-6 og CLA, et lavt forhold mellom omega-6 og omega-3 og et høyt antall terpenener.

Arbeidet viser at kyr utnytter seterlandskapet ekstensivt og foretrekker vegetasjonstyper som er lysåpne og rike på gress og urter. Dermed bidrar de til å vedlikeholde seminaturlige habitater med høy biodiversitet. Dessuten er melk produsert på beite i artsrik utmark karakterisert med en sunnere fettsyresammensetning og høyt innhold av terpenener. Dette gir dermed en vinn-vinn situasjon hvor det produseres unike utmarksprodukter som dermed gir en inntektsmulighet for gårdbrukere i fjellområder. Vi ser imidlertid at dagens beitetrykk ikke er nok til å holde seterlandskapet åpent. For å vedlikeholde biodiversiteten og beitepotensialet i seminaturlige artsrike habitater, kan det derfor være nødvendig å supplere beite med å fjerne busker og trær, helst i de områdene hvor kyrne foretrekker å beite.

Emneord: fjellbeite, biodiversitet, beitepreferanser, melkekvalitet, GPS,  $\alpha$ -tokoferol

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Papers I-IV

## **List of original papers**

This thesis is based on the following papers referred to in the text as follows:

### **Paper I**

Sickel, H., Bilger, W. & Ohlson, M. 2012. High Levels of alpha-Tocopherol in Norwegian Alpine Grazing Plants. *J. Agric. Food Chem.* 60: 7573-7580.

### **Paper II**

Sickel, M., Steenhuisen, F., Sickel, H., Norderhaug, A. & Ohlson, M. Use of high frequency GPS data to classify cattle behaviour on heterogeneous rangelands. Submitted manuscript.

### **Paper III**

Sickel, H., Sickel, M., Steenhuisen, F., Ohlson, M. & Norderhaug, A. Vegetation preferences and animal behaviour of free ranging dairy cattle in two alpine rangelands – a high frequency GPS study. Manuscript.

### **Paper IV**

Sickel, H., Eldegard, K., Lunnan, T., Norderhaug, A., Ohlson, M., Petersen, M.A. & Abrahamsen, R. K. Influence of grazing plants on fatty acid composition, antioxidants and terpenes in milk from alpine rangelands. Manuscript.

Paper I is reproduced with kind permission of the publisher American Chemical Society.

## Introduction

Agriculture is still one of the most important businesses for settlement in alpine regions in Norway (Skarstad et al. 2008). In such areas, the traditional production system for milk production has been summer farming on alpine rangelands. Historically, the grazing resources in the northern boreal and low alpine vegetation zones were especially important and mountainous summer farms were the basis for Norwegian pre-industrial agriculture (Det Kgl. Selskap for Norges Vel 1948-1974, Reinton 1963, Moen 1999).

Summer farming is associated with several cultural as well as natural values by expressing e.g. a long history of utilization of natural resources, cultural traditions and a practical “know how” based on generations of local experience about successful and non-successful agricultural practice. In addition summer farming activities created many different semi-natural vegetation types (Tunon et al. in press.). Semi-natural grasslands created by mowing and grazing are among the most species-rich habitats in northern Europe (Kull & Zobel 1991, Austrheim et al. 1999, Eriksson et al. 2002). However, the agricultural practice has changed during the last century and milk production in alpine areas has decreased considerably during the last 100 years. The trend is fewer and larger units in the lowlands with high yielding dairy cows which have high energy needs and require concentrates and cultivated grass with a higher energy content and digestibility than natural growing feeding plants (Spörndly 2013). Today, the grazing maintains landscape qualities, grazing resources and a high biodiversity which are important common goods and a contribution to local resource exploitation and self-sufficiency. If the traditional and extensive production systems shall survive, it is necessary to bring in a new economy, which makes it possible to compete with bulk products from intensive and large-scale production systems (Asheim et al. in press). One strategy, which has proved to help alpine farmers in e.g. France and Italy, is diversification of dairy products, based on scientific evidence, which may give products from extensive product systems in alpine regions a better price in the market (Lombardi 2008).

In Norway, about 1200 mountainous summer farms are still in use. At these summer farms, the dairy cows are let out for grazing in the summer farming landscape between morning and evening milking. The free ranging animals have thus the possibility to select which vegetation types and which plant species within the habitats they should graze (Milne et al. 1979), and studies have shown that free ranging cattle are able to choose a diet of better quality than the average vegetation of offer (Prache et al., 1998; Rook et al., 2004). The diet selection is influenced by many different factors. Here, animal morphology and physiology as

well as learning processes and ecological factors have been shown to be important (Demment and Vansoest 1985, Provenza and Balph 1988, Launchbaugh and Howery, 2005). For farmers who need to clear overgrown areas to secure good grazing conditions for the cattle in summer farming landscapes where the utilization has decreased, it is important to know which vegetation types the cows prefer.

### **Main objective**

The main objectives in my PhD-project were to investigate

1. Levels of an antioxidant (vitamin E) in Norwegian alpine grazing plants
2. Area use, grazing patterns and grazing preferences of free ranging dairy cattle in two alpine rangelands
3. Fatty acid composition and the content of various antioxidants and terpenes in the milk from the dairy cattle in the study areas
4. Possible connections between alpine rangelands, grazed plants groups and milk quality



Photo: H. Sickel

## **Materials and methods**

### **Study sites**

The study sites are two summer farms situated in two different alpine regions in south-central Norway, Valdres and Hallingdal, with dairy cattle grazing alpine ranges. The sites are referred to as site 1 (in Valdres) and 2 (in Hallingdal), respectively. Site 1 (60°57'N; 8°49'E) is situated approximately 910 m a.s.l., in the northern boreal vegetation zone (Moen 1999). Site 2 (60°32'N; 8°11'E) is located approximately 1040 m a.s.l. in the transition between the northern boreal and low alpine vegetation zone. For further details, see e.g. Paper I.

### **The herds**

The animals in both herds are of the breed Norwegian Red. At site 1, the herd consisted of 12-14 dairy cattle and 7-9 heifers while the herd at site 2 consisted of 18-20 dairy cattle and 1-3 heifers. The average age of the dairy cattle who wore GPS was  $3.0 \pm 1.5$  years at site 1 and  $3, 6 \pm 1, 3$  years at site 2. The oldest GPS cow was 7 years old at site 1 and 6 years old at site 2 whereas the youngest was 2 years old at both sites. The average amounts of given concentrates were  $5, 2 \pm 0, 9$  kg/day at site 1 and  $5, 9 \pm 1, 5$  kg/day at site 2. The GPS cows at site 1 milked on average  $15, 8 \pm 3, 9$  kg/day while the GPS cows at site 2 milked  $22, 7 \pm 5, 0$  kg/day.

### **Sampling of grazing plants to tocopherol analysis**

Twenty-two plant species were collected in semi-natural grasslands from the sites in July and August 2009. The samples were collected in two habitat types, viz. light exposed open and shady forested regrowth habitats. All sampling took place between 0900 and 1700h because diurnal changes in tocopherol levels are small during this period of the day. Vegetative tissue (leaves) was sampled from all species and mostly from lower parts of the plants since many of them (especially the grasses and the herbs) have their leaves based near the ground. Reproductive tissue (flowers or bulbils) was sampled from a sub-set of four species. Details of the analysis is given in Paper I.

### **GPS collars and field studies**

Global positioning system (GPS) units were utilised for tracking the grazing cattle. Five dairy cows in the herds wore collars with GPS units while they were out grazing between morning and afternoon milking during two study periods (in July and August) in 2007-2009. The GPS units were logging the geographical position and time every 5<sup>th</sup> second. The data from all days

were integrated in a Geographical Information System(GIS), thus; the movement of the cows could be analysed and presented on maps.

In 2008, parallel field studies of animal behaviour were done during the periods when the cattle wore GPS collars. There was nine and ten observation days at site 1 and 2, respectively, and the GPS cows were observed approximately 8-10 hours a day. The behaviour was finally classified as grazing, walking or resting. Further details are given in Paper II.

### **Vegetation maps**

Vegetation maps, based on aerial photo interpretation and field work, were made from both study areas. Digital aerial photos of the type near-infrared colour photos (CIR) with a pixel resolution of 0.20 m x 0.20 m on ground level were used for interpretation. CIR aerial photos have many advantages and are especially useful for vegetation mapping compared to true colour or black and white panchromatic aerial photos (Ihse, 2007). Natural and semi-natural vegetation types available for grazing were interpreted according to a classification system based on Sickel *et al.* (2004). The vegetation maps were used together with GPS data in GIS analysis. Details are given in paper III.

### **Milk sampling procedures, analysis and herds**

In all study years (2007-2009), milk samples (morning milk) were taken from 9-10 individuals in each herd, once in July and once in August at both study sites for analysis of fatty acid composition, carotenoids, vitamin E and terpenes. Also, milk samples taken from each individual cow were subject to standard quality analysis of the content of fat and protein, flavour and urea levels, by authorized analytical laboratories and milk graders in the TINE dairy company as a part of their quality evaluation system for raw milk samples. For the sensory evaluation of the flavour of the milk a hedonic scale from 1 to 5, with 5 as best score, was used.

Analyses of tocopherol and carotenoids were performed at a commercial laboratory using HPLC with fluorescence and diode array detectors, respectively. Methylated fatty acids were analysed at the same laboratory using GC with flame ionization detector. Terpenes were sampled using a head space method and subsequently analyzed using GC-MS at the University of Copenhagen. The analysis procedures are detailed described in Paper I.

### **Microhistological analyses of faeces**

In 2007 and 2008, faeces samples were collected each day, 7-2 days before the milk sampling, mostly in the morning, picked up just after the cows had deposited them. In 2007, 38 and 48 samples were collected from site 1 and site 2, respectively. In 2008, 50 samples were collected from each site. The faeces samples were prepared for microhistological analyses following the procedures of Garcia-Gonzalez 1984. The species and plant families detected were grouped in 5 functional groups: woody species, unidentified woody species, grasses, sedges, herbs and Pteridophytes. See details in Paper IV.

### **Vegetation composition and grazed plant groups**

The herds grazed on alpine rangeland 9-11 hours per day, after being milked in the morning and until they returned to the milking barn in the afternoon. After being milked in the afternoon, the cattle were let out in fenced cultivated pastures at the summer farms where they spent the night resting and grazing until they were milked in the morning.

The composition of the vegetation on grazing localities within the rangeland vegetation types was documented by pin-point analysis. A grazing locality was defined as a place where the cattle stopped for grazing for about 10 minutes or more. The boundaries of each grazing locality were visually and subjectively defined and transects (usually three transects of 50-75 m) were randomly stretched across the locality (see Figure 1). A pin, length 2 m and 1 cm in diameter, was placed numerous times in a vertical position along the transects. Every time the pin was placed (“a pin-point”) it was with a random distance of 1 m, 2 m or 3 m to the previous pin-point. The plant species that touched the pin were recorded once per pin-point. The number of pin-points per grazing locality varied from 100-170 at site 1 and from 42-190 at site 2, in attempt to capture the usual and abundant species within the locality, e.g. species rich localities with a heterogeneous distribution of the species needed more pin points than species poor with homogeneous distribution. Lists with total number of pin-point registrations per recorded plant species were made from all localities. Lists from localities belonging to the same vegetation type were merged, ending up with a frequency list of recorded species per vegetation type. The frequencies of species were grouped in five different functional plant groups: grasses, herbs, sedges, woody species and pteridiopythes respectively, and the proportion of each plant group within the vegetation type were calculated. All together 15 localities were investigated with pin-points at site 1 and 20 at site 2 during the study period 2007-2009.

Within the grazing localities, grazed plant species were recorded by plot analysis on grazed patches. A grazed patch was defined as a patch where a cow had been observed

grazing continuously in 1 minute or more. Five grazed patches from each locality were marked with wooden sticks and analysed within few days by putting down a frame sized 0.5m x 0.5 m around the stick (see Figure 1). All species within the plot were recorded and scored with respect to whether they had been grazed on or not. Thus, every grazed plant species was recorded grazed only once per plot. Also, the frequency of the species within the frame was calculated in two ways. 1. The plot was divided in 25, equal sized small plots, by threads. A pin was put down in each frame corner and in the intersections of the threads, in total 20 pin-points per plot. Every species which touched the pin was recorded (once per species). 2. All species were identified within the plot and given a subjective frequency measure (seldom, normally abundant, dominant).

The vegetation composition of the cultivated pastures was measured by pin-point analyses with the same methodology as described above with regard to grazing localities.

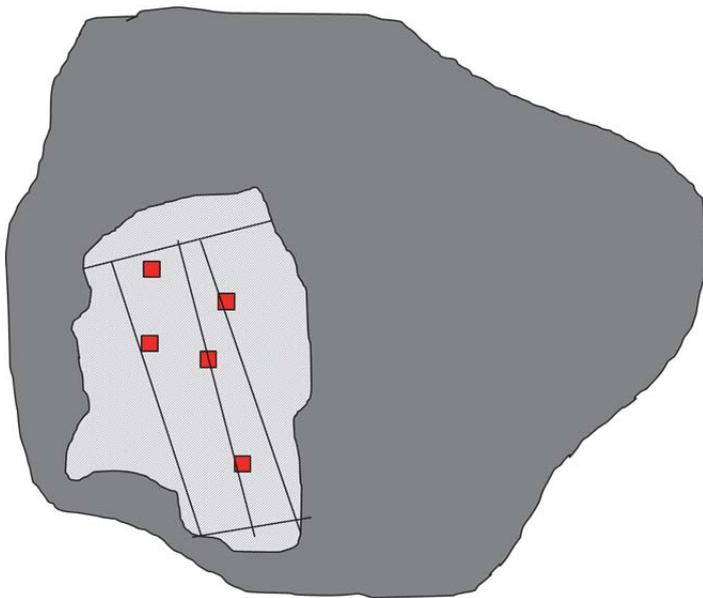


Figure 1. Illustration of a vegetation type (dark grey); a grazing locality (light grey) within the vegetation type; grazed patches (red) and transects (lines) within the grazed locality.

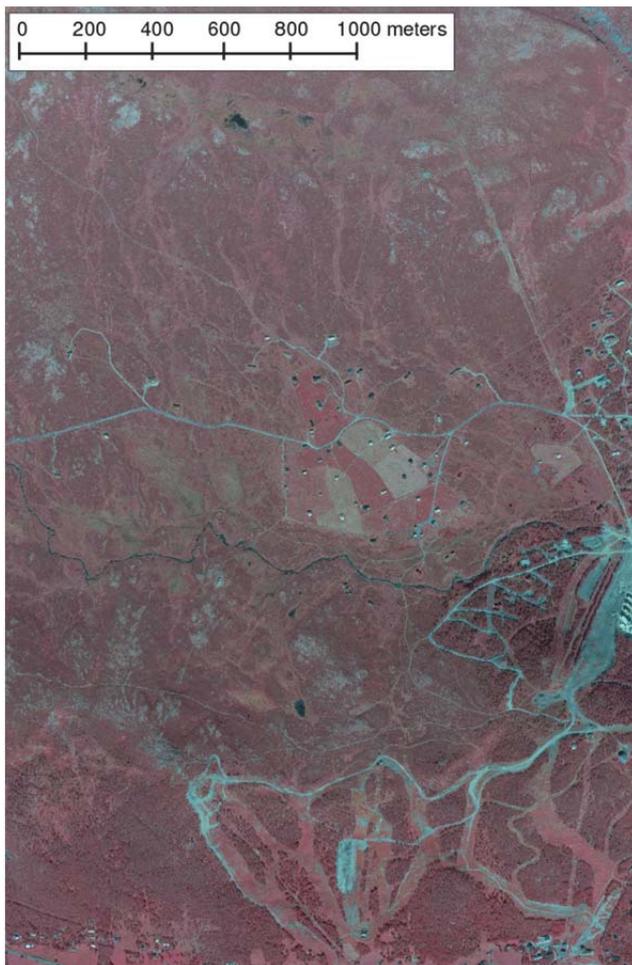
### **Statistical analysis**

One way and two-way analyses of variance (ANOVA) for comparisons among plant species, habitats, sampling occasions, sites, and tissue types have been used (Paper I and IV). The analyses were performed by the software Minitab 16. Paired-sample t tests were used to test

for significant differences. Kruskal-Wallis one-way ANOVAs and Mann-Whitney U tests (nonparametric test) were used on the terpene data (see details, Paper IV).

GPS models: For the analysis, the data were stored in a PostGIS 1.5 (PostGIS Project Steering Committee, 2013) enabled PostgreSQL 9.1.8 (PostgreSQL Global Development Group, 2013) database. The data were recorded as geographical coordinates, but to simplify the further processing, they were reprojected to UTM zone 32 within PostGIS. To do the analyses, the dataset were pulled into R 2.14.1 (R Development Core Team, 2008). The scripts used in the analyses are available at <http://github.com/sickel/cowplot> at commit f4353c8.

To investigate potential relationships between diet and the chemical composition of the milk, generalised linear mixed modelling was performed using the milk data as response variables and different measures of cow diet as explanatory variables. Data were collected from five GPS cows in July and August in 2007-2009, but the five individuals were not the same in all months/years (a total of 10 different individuals at site 1 and 11 different individuals at site 2). For details about the modelling and analysis, see Paper IV.



CIR photo, site 1 in Hallingdal (23.08. 2007, Terratec).  
Photo resolution: 1 pixel = 20 cm x 20 cm on the ground

## **Main results from the original papers**

### *Paper I*

The content of tocopherol antioxidants (vitamin E) in vegetative and reproductive parts of 22 grazing plants was estimated in two alpine areas used for summer farming. The overall mean content of  $\alpha$ -tocopherol was  $141 \pm 34 \mu\text{g g}^{-1}$  DW and grasses had much lower content ( $29 \pm 12 \mu\text{g g}^{-1}$  DW) than herbs ( $224 \pm 96 \mu\text{g g}^{-1}$  DW), sedges ( $192 \pm 78 \mu\text{g g}^{-1}$  DW) and woody species ( $189 \pm 52 \mu\text{g g}^{-1}$  DW). Highest and lowest species-specific levels were  $664 \pm 92$  and  $2 \pm 1 \mu\text{g g}^{-1}$  DW, respectively. Plants from light and shady habitats did not differ in their  $\alpha$ -tocopherol content, which was idiosyncratic as indicated by significant interactions between species, sampling occasion, site and tissue type. Our results show that alpine ranges provide fodder with high levels of  $\alpha$ -tocopherol.

### *Paper II*

Models for interpretation of cattle behaviour on alpine rangelands from high frequency GPS data were developed. By using parameters derived from the GPS data, the behaviour has been classified into walking, grazing and resting. Using this method, the classification was correct for 83 and 86% of observations for two different locations and it was possible to classify grazing behaviour correctly with as much as 92 percent accuracy. This is better than what previously has been achieved by only using GPS data. Furthermore, a system was made for assessing the uncertainty in classification of the GPS points, thereby making it possible to quantify the uncertainty in the analysis when doing analysis in Geographical Information Systems (GIS) where GPS points are overlaid on categorized layers. These uncertainties have to our knowledge previously been ignored in rangeland studies of domestic animals.

Especially in heterogeneous landscapes with fragmented and narrow areas, the correct classification may be uncertain for a high percentage of the GPS fixes. Such uncertainties are important to quantify.

### *Paper III*

Movement and grazing patterns of two cow herds grazing in two different species rich Norwegian alpine, summer farming landscapes, were studied during two periods each year in 2007 – 2009 based on vegetation mapping, GPS recording, and supplementing field work. Daily, average walking distances were 4700 m and 4800 m at site 1 and 2, respectively. The cows stuck together and did typically use different routes from day to day, giving the grazing

habitats possibility to recover between grazing events. Grazing was the main activity and the cows preferred to graze light-open, grass and herb rich vegetation types. However, site 1 was more overgrown than site 2 and the cattle therefore had to graze more in forests there. The weather seemed to influence the grazing preferences. For instance, the cattle grazed moist and wet vegetation types more when the summer was warm. Also seasonal grazing differences were uncovered.

#### *Paper IV*

There is little knowledge about the quality of Norwegian alpine milk products and how this quality is related to the species composition of the grazing plants. The main aim of this study was therefore to characterize milk from alpine rangelands with regard to fatty acid composition and content of some secondary plant metabolites, and to identify potential relationships between chemical compounds in the milk and distinct plant groups in the diet. The results of the statistical modelling indicate that the different plant groups on the rangelands were significantly related to specific chemical components in the milk. Analytical results which characterize the milk from summer farms in this project, and which can be said to give rise to unique milk products are, therefore, low contents of the unfavourable fatty acids C14:0 and C16:0, high levels of the favourable fatty acids C18:3 n-6 and CLA, a low ratio omega-6:omega-3 and a relative high number of terpenes.

### **Supporting results**

#### *The vegetation on grazing localities and grazed patches*

Proportions of total species that touched the pin point (called N registrations in table 1) and plant groups in the grazed localities within nine of the vegetation types at site 1 are listed and ranked in Table 1. Grasses and woody species have the highest proportions in most of the vegetation types. The exceptions are thinned tall herb forest and cleared birch forests where herbs are more abundant than woody species, and rich fens where sedges are more abundant than both grass and woody species.

Proportions of species and plant groups in grazed patches within grazed localities at site 1 are listed and ranked in Table 2. Analyses of patches exist from six grazed vegetation types. On grazed patches in five of the vegetation types, grass is the most abundant plant group. The exception is on rich fen, where sedges are more abundant in the patches. The most abundant

grass species in the patches are *Avenella flexuosa*, *Agrostis capillaris* and *Anthoxanthum odoratum*. In rich fen abundant sedges on patches are *Carex dioica*, *Carex vaginata* and *Carex lasiocarpa* and abundant grass species *Avenella flexuosa* and *Molinia caerulea*.

At site 2 (Table 3), grass is the most abundant plant group in grazed localities within most vegetation types except in tall herb mountain birch forest which has more herbs than grass species, in grazed bilberry-blue heath heath where woody species are most abundant and in rich fens where sedges is most abundant. Analyses of grazed patches exist from six of nine vegetation types with investigated grazed localities (Table 4). The most abundant plant group in the patches is grass except in tall herb mountain birch forest where herbs are more abundant than grass. *Avenella flexuosa* and *Agrostis capillaris* are the most abundant grass species in most vegetation types. The exceptions are cabin lawns where sawn *Festuca rubra* is the dominating grass species. On damp grassland *Nardus stricta* is also a common grass species. In tall-herb mountain birch forest and in re-vegetated areas, *Viola biflora* is a common herb species in the grazed patches.



The herd at site 2, Hallingdal. Photo: K. Norderup



GPS mounted to the collar of one cow at site 2. Photo: K. Norderup

Table 1. The ten highest ranked species within grazing localities in investigated vegetation types, site 1, calculated as proportions of total species that touched the pin point (N registrations).

	Bilberry woodland (sum)	Dry <i>J. communis</i> - <i>B. nana</i> heath (S2a)	Open grassland (G3/G4/G8), intermediate	Regrown intermediate grassland (G4/G8), 60-100% bush cover	Rich scrub-covered fen (M1b/M2), wet (sum)	Swamp woodland (E3c)	Tall-herb mountain birch forest, (C2a) (sum)	Thinned tall-herb birch forest (C2a) (sum)	Tree felling area/cleared birch forest
N localities	4	1	1	1	2	1	2	2	1
N pin points	512	135	170	140	266	122	258	242	147
N registrations	1490	307	413	505	875	531	738	690	305
Sum grasses	39.73 (1)	33.22 (2)	47.22 (1)	31.68 (2)	17.94 (3)	33.33 (1)	44.44 (1)	56.38 (1)	70.49 (1)
Sum woody species	39.33 (2)	52.77 (1)	34.87 (2)	41.58 (1)	25.14 (2)	24.11 (3)	26.42 (2)	9.86 (5)	4.59 (6)
<i>Avenella flexuosa</i>	25.17 (3)	27.69 (3)	22.03 (3)	10.5 (5)	4.0 (11)	3.58 (14)	22.22 (3)	14.06 (4)	20.98 (3)
<i>Juniperus communis</i> coll.	9.26 (4)	16.61 (4)	13.8 (4)	4.36 (12)	1.6 (22)	1.32 (22)	6.91 (7)	2.32 (12)	2.3 (10)
<i>Vaccinium myrtillus</i>	9.06 (5)	7.49 (5)	2.18 (12)	0.99 (23)	2.06 (19)		7.72 (6)	1.01 (20)	
Sum Pteridophytes	8.93 (6)	5.54 (6)	0.48 (19)	0.2 (27)	0.8 (24)	0.75 (25)	4.2 (10)	2.03 (14)	4.59 (6)
<i>Gymnocarpium dryopteris</i>	8.86 (7)	5.54 (6)	0.48 (19)		0.11 (29)		2.71 (13)	1.16 (19)	4.26 (7)
Sum herbs	8.05 (8)	5.21 (7)	13.8 (4)	12.67 (4)	9.14 (4)	24.48 (2)	20.19 (4)	24.78 (2)	16.39 (4)
<i>Empetrum nigrum</i> coll.	6.91 (9)	7.49 (5)	6.05 (8)	8.51 (6)	3.54 (12)	0.56 (26)	0.81 (21)		
<i>Agrostis capillaris</i>	5.91 (10)	0.98 (13)	8.96 (6)	6.14 (9)	1.71 (21)	7.72 (5)	7.99 (5)	19.28 (3)	24.59 (2)
<i>Vaccinium vitis-idaea</i>	5.1 (11)	4.23 (9)	9.2 (5)	3.96 (14)	1.71 (21)	2.07 (19)	4.34 (9)	2.32 (12)	
<i>Betula nana</i>	4.9 (12)	3.91 (10)		1.78 (21)	0.69 (25)	0.38 (27)	2.44 (14)	1.3 (18)	0.33 (16)
Sum sedges	3.96 (13)	3.26 (11)	3.63 (11)	13.86 (3)	46.97 (1)	17.33 (4)	4.74 (8)	6.96 (7)	3.93 (8)
<i>Anthoxanthum odoratum</i> coll.	3.42 (14)		4.12 (9)	5.54 (10)	2.06 (19)	4.33 (10)	6.91 (7)	6.23 (9)	2.3 (10)
<i>Nardus stricta</i>	2.42 (15)	0.98 (13)	7.26 (7)	3.76 (15)	2.51 (17)	4.52 (9)	2.17 (15)	3.33 (10)	4.26 (7)
<i>Vaccinium uliginosum</i>	2.21 (16)	4.89 (8)	0.48 (19)	5.15 (11)	2.86 (15)	2.26 (18)	0.27 (25)		0.66 (15)
<i>Deschampsia cespitosa</i>	1.74 (19)		1.45 (15)	0.4 (26)	2.51 (17)	6.78 (6)	4.2 (10)	8.26 (6)	13.11 (5)
<i>Geranium sylvaticum</i>	1.48 (20)			0.4 (26)	0.23 (28)	3.58 (14)	4.34 (9)	6.38 (8)	3.93 (8)
<i>Poa</i> sp.	0.34 (27)	0.33 (15)	1.69 (14)			1.13 (23)	0.54 (23)	1.3 (18)	2.95 (9)
<i>Alchemilla alpina</i>	0.2 (29)		3.87 (10)				0.95 (20)		0.33 (16)
<i>Carex vaginata</i>	0.2 (29)			2.97 (17)	8.11 (6)	3.95 (12)	0.68 (22)	0.29 (23)	
<i>Calluna vulgaris</i>	0.13 (30)		0.24 (20)	7.72 (7)	0.69 (25)	0.94 (24)		0.29 (23)	
<i>Betula nana</i>	0.07 (31)	7.49 (5)	1.21 (16)	6.73 (8)	4.34 (10)	3.01 (16)	0.95 (20)		
<i>Salix phylicifolia</i>	0.07 (31)		1.21 (16)	1.98 (20)	0.23 (28)	6.4 (7)	0.68 (22)	0.58 (21)	
<i>Carex pallescens</i>	0.07 (31)			3.56 (16)	0.23 (28)	4.71 (8)		0.14 (24)	
<i>Carex nigra</i> coll.			0.24 (20)	2.57 (18)	7.43 (8)	2.82 (17)	0.95 (20)		0.33 (16)
<i>Carex lasiocarpa</i>					8.46 (5)				
<i>Carex dioica</i>				0.99 (23)	7.89 (7)				
<i>Molinia caerulea</i>					4.8 (9)				

Table 2. The ten highest ranked species in the grazed patches in the investigated vegetation types, site 1, calculated as proportions of total species that touched the pin point (N registrations).

	Bilberry woodland, <i>Vaccinium myrtillus</i> - <i>Empetrum nigrum</i> coll. (A4c), 5-59% tree cover	Regrown intermediate grassland (G4/G8), 60-100% bush cover	Rich scrub-covered fen (M1b/M2), wet	Swamp woodland, <i>Salix glauca</i> - <i>Salix</i> <i>lapponicum</i> st., (E3c), 20-59% tree cover	Tall-herb mountain birch forest, (C2a), 20-59% tree cover	Thinned tall-herb mountain birch forest (C2a)
N patches	15	5	10	5	5	5
N pinpoints	300	100	200	100	100	100
N registrations	642	367	626	391	266	263
Sum grasses	58.26 (1)	38.96 (1)	21.57 (3)	34.19 (1)	48.5 (1)	57.41 (1)
<i>Avenella flexuosa</i>	40.81 (2)	11.17 (5)	8.15 (7)	12.3 (3)	33.83 (2)	16.73 (3)
Sum woody species	23.68 (3)	30.79 (2)	22.52 (2)	7.83 (5)	26.32 (3)	14.07 (5)
<i>Agrostis capillaris</i>	9.81 (4)	8.99 (6)	1.92 (15)	8.15 (4)	1.13 (18)	16.35 (4)
Sum herbs	9.5 (5)	16.89 (3)	11.02 (6)	14.86 (2)	13.91 (4)	25.86 (2)
<i>Vaccinium myrtillus</i>	8.88 (6)	0.82 (19)	1.44 (16)	1.92 (11)	9.02 (6)	2.28 (12)
Sum Pteridophytes	5.61 (7)	0.27 (21)	0.16 (23)	0.32 (20)	3.76 (12)	
<i>Gymnocarpium dryopteris</i>	5.61 (7)			0.16 (21)	3.76 (12)	
<i>Empetrum nigrum</i> coll.	5.14 (8)	8.72 (7)	4.79 (10)	0.16 (21)	3.01 (13)	
<i>Anthoxanthum ododratum</i> coll.	4.52 (9)	6.81 (9)	2.88 (12)	7.83 (5)	9.4 (5)	11.79 (6)
<i>Vaccinium vitis-idaea</i>	3.74 (10)	3.81 (14)	2.56 (13)	1.12 (15)	6.02 (8)	4.56 (9)
<i>Deschampsia cespitosa</i>	2.96 (12)		0.32 (22)	3.35 (7)		0.38 (17)
Sum sedges	2.96 (12)	13.08 (4)	44.73 (1)	5.27 (6)	7.52 (7)	2.66 (11)
<i>Maianthemum bifolium</i>	2.8 (13)	0.82 (19)	0.16 (23)	2.56 (8)	4.89 (9)	3.8 (10)
<i>Ranunculus acris</i> ssp. <i>acris</i>	1.25 (18)		0.64 (20)	2.4 (9)		1.9 (13)
<i>Potentilla erecta</i>	0.47 (20)	2.72 (15)	2.4 (14)	2.08 (10)	1.5 (17)	
<i>Carex</i> sp.	0.31 (21)	5.45 (10)	0.16 (23)	1.92 (11)		
<i>Festuca ovina</i> ssp. <i>ovina</i>	0.16 (22)	5.18 (11)		1.12 (15)		9.13 (7)
<i>Calluna vulgaris</i>		7.36 (8)	1.92 (15)			5.7 (8)
<i>Campanula rotundifolia</i>		2.18 (16)		0.32 (20)		3.8 (10)
<i>Carex vaginata</i>		0.54 (20)	11.5 (5)		4.51 (10)	0.76 (16)
<i>Carex dioica</i>			13.26 (4)			
<i>Carex lasiocarpa</i>			7.19 (8)			
<i>Molinia caerulea</i>			5.27 (9)			
<i>Carex nigra</i> coll.			4.79 (10)	0.96 (16)		
<i>Trifolium repens</i>						4.56 (9)

Table 3. The ten highest ranked species within grazing localities in investigated vegetation types, site 2, calculated as proportions of total species that touched the pin point (N registrations).

	Bilberry woodland (A4c)	Cottage with lawn available for grazing	Damp grassland (G3/G4)	Grazed bilberry - blue heath heath (S3/G5), 60-100% bush cover	Intermediate grassland (G4/G8), 20-59% bush cover	Open grassland (G3/G4/G8), intermediate, 0-19% bush cover	Revegetated area	Rich scrub-covered fen (M1b/M2)	Tall-herb mountain birch forest (C2c), 5-59% tree cover
N localities	4	1	3	1	6	2	1	1	1
N pin points	353	63	377	150	812	250	140	146	70
N registrations	1133	135	1191	393	2633	631	492	332	488
Sum grasses	48.46 (1)	52.59 (1)	45.59 (1)	31.55 (2)	43.87 (1)	54.36 (1)	46.14 (1)	11.75 (4)	41.8 (2)
<i>Avenella flexuosa</i>	25.42 (2)		10.75 (5)	31.55 (2)	6.87 (7)	6.5 (8)	16.67 (3)	3.31 (12)	7.38 (6)
Sum woody species	22.51 (3)		28.55 (2)	59.8 (1)	21.72 (3)	12.84 (4)	15.65 (4)	29.22 (2)	2.87 (12)
Sum herbs	17.3 (4)	47.41 (2)	20.65 (3)	2.54 (8)	29.93 (2)	19.97 (2)	32.11 (2)	11.14 (5)	53.07 (1)
<i>Vaccinium myrtillus</i>	8.91 (5)		4.37 (10)	27.23 (3)	2.35 (18)	2.69 (14)	5.49 (9)	0.3 (21)	1.43 (17)
Sum Pteridophytes	7.41 (6)		0.5 (28)		0.65 (29)	0.32 (27)	2.03 (17)		
<i>Gymnocarpion dryopteris</i>	6.27 (7)		0.08 (33)		0.19 (37)		1.22 (21)		
<i>Agrostis capillaris</i>	6.09 (8)	0.74 (7)	11.08 (4)		13.22 (4)	16.96 (3)	9.15 (5)	0.3 (21)	6.76 (8)
<i>Anthoxantum odoratum</i> coll.	5.21 (9)		2.18 (16)		2.39 (17)	2.85 (13)	6.1 (7)		8.81 (4)
<i>Nardus stricta</i>	4.94 (10)		7.72 (6)		10.06 (5)	12.2 (6)	2.64 (14)	5.42 (8)	1.64 (16)
Sum sedges	4.32 (11)		4.7 (9)	6.11 (6)	3.84 (11)	12.52 (5)	4.07 (10)	47.89 (1)	2.25 (14)
<i>Deschampsia cespitosa</i>	4.24 (12)	1.48 (6)	5.79 (7)		3.99 (10)	5.23 (9)	3.66 (11)	0.6 (20)	0.2 (23)
<i>Trientalis europaea</i>	2.38 (17)		0.5 (28)	1.27 (10)	0.23 (36)	0.48 (26)	0.41 (25)		1.02 (19)
<i>Poa</i> sp.	1.77 (19)	5.19 (5)	0.08 (33)		2.28 (19)	3.65 (10)	2.24 (16)	0.6 (20)	6.35 (9)
<i>Empetrum nigrum</i> coll.	1.5 (20)		1.85 (19)	6.36 (5)	2.39 (17)	0.79 (24)	0.41 (25)	4.22 (10)	
<i>Vaccinium uliginosum</i>	1.24 (22)		2.52 (14)	1.53 (9)	0.68 (28)	0.16 (28)	0.2 (26)	5.12 (9)	
<i>Geranium sylvaticum</i>	0.62 (24)		1.93 (18)		2.39 (17)	0.32 (27)	2.44 (15)		7.58 (5)
<i>Carex brunnescens</i>	0.18 (29)		0.5 (28)	1.53 (9)	0.08 (40)	0.95 (23)		0.9 (19)	
<i>Carex bigelowii</i>	0.18 (29)		1.6 (21)	4.58 (7)	2.01 (21)	7.13 (7)	0.61 (24)	0.9 (19)	
<i>Carex nigra</i> coll.	0.18 (29)		0.5 (28)		0.34 (34)	0.63 (25)		19.28 (3)	
<i>Festuca rubra</i> ssp. <i>Rubra</i>	0.18 (29)	45.19 (3)	3.61 (11)		3.08 (14)	0.79 (24)	3.66 (11)	0.9 (19)	5.12 (10)
<i>Leontodon autumnalis</i>	0.09 (30)		2.27 (15)		3.19 (12)	3.49 (11)	5.89 (8)		0.61 (21)
<i>Bistorta vivipara</i>	0.09 (30)		3.36 (12)		5.66 (8)	1.11 (22)	6.5 (6)	0.9 (19)	4.92 (11)
<i>Rumex acetosa</i> ssp. <i>acetosa</i>	0.09 (30)	0.74 (7)			0.04 (41)	1.11 (22)			2.25 (14)
<i>Trifolium repens</i>		42.96 (4)	1.26 (23)		2.89 (15)	2.22 (16)			6.97 (7)
<i>Rumex</i> sp.		1.48 (6)							
<i>Achillea millefolium</i>		0.74 (7)			0.04 (41)	1.11 (22)			
<i>Alchemilla</i> sp.		0.74 (7)	0.76 (25)		0.72 (27)	1.11 (22)	0.2 (26)		0.61 (21)
<i>Ranunculus repens</i>		0.74 (7)				0.32 (27)			
<i>Betula nana</i>			4.95 (8)	22.9 (4)	3.11 (13)	1.58 (20)		5.42 (8)	
<i>Viola biflora</i>			2.77 (13)		4.9 (9)	1.74 (19)	6.1 (7)		9.22 (3)
<i>Salix herbacea</i>			1.85 (19)	0.76 (12)	7.98 (6)	3.17 (12)			
<i>Carex</i> sp.			0.25 (31)		0.42 (32)	0.16 (28)		7.83 (7)	
<i>Trichophorum cespitosum</i>								8.13 (6)	

Table 4. The ten highest ranked species in the grazed patches in the investigated vegetation types, site 2, calculated as proportions of total species that touched the pin point (N registrations).

	Bilberry woodland, <i>Vaccinium myrtillus</i> - <i>Empetrum nigrum</i> coll. (A4C)	Cottage with lawn available for grazing	Damp grassland with <i>Salix</i> spp. (G3/G4)	Intermediate grassland (G4/G8), 20-59% bush cover	Grazed bilberry - blue heath (S3/G5), 60-100% bush cover	Revegetated area	Tall-herb mountain birch forest, low herb st. with scattered tall herbs (C2c), 5-59% tree cover
N patches	20	5	5	15	5	5	5
N pinpoints	400	100	100	300	100	100	100
N registrations	951	205	290	1055	188	319	377
Sum grasses	51.74 (1)	52.68 (1)	50.34 (1)	41.52 (1)	40.96 (1)	45.14 (1)	40.05 (2)
<i>Avenella flexuosa</i>	39.54 (2)		8.97 (6)	1.04 (21)	40.43 (2)	13.17 (4)	10.34 (4)
Sum woody species	26.29 (3)		19.31 (3)	15.36 (4)	35.64 (3)	16.61 (3)	1.59 (14)
<i>Vaccinium myrtillus</i>	16.93 (4)		1.38 (16)	0.28 (28)	25.0 (4)	6.9 (8)	
Sum herbs	15.35 (5)	47.32 (2)	27.93 (2)	39.05 (2)	3.72 (9)	36.36 (2)	56.23 (1)
Sum sedges	5.89 (6)		2.41 (13)	3.79 (12)	19.68 (5)	1.88 (16)	1.59 (14)
<i>Agrostis capillaris</i>	5.57 (7)		18.28 (4)	17.63 (3)		8.15 (7)	9.55 (5)
<i>Trientalis europaea</i>	5.05 (8)				2.66 (10)	0.63 (20)	0.27 (19)
<i>Maianthemum bifolium</i>	4.94 (9)						0.27 (19)
<i>Vaccinium vitis-idaea</i>	3.68 (10)			0.28 (28)		1.88 (16)	0.53 (18)
<i>Nardus stricta</i>	2.63 (12)		13.79 (5)	10.9 (6)			1.86 (13)
<i>Anthoxantum odoratum</i> coll.	1.79 (14)		1.72 (15)	1.23 (20)		9.09 (6)	6.63 (7)
<i>Vaccinium uliginosum</i>	1.68 (15)		4.83 (8)	0.09 (30)			0.27 (19)
<i>Carex bigelowii</i>	1.58 (16)			2.75 (14)	11.7 (6)		
<i>Poa</i> sp.	1.26 (19)	6.34 (5)	0.34 (19)	0.95 (22)		3.76 (12)	4.24 (10)
<i>Acillea millefolium</i>	0.21 (26)	1.46 (7)					
<i>Carex brunnescens</i>	0.21 (26)				7.98 (8)	0.31 (21)	
<i>Deschampsia cespitosa</i>	0.11 (27)	1.95 (6)	2.41 (13)	1.9 (16)		6.58 (9)	
<i>Festuca rubra</i> ssp. <i>rubra</i>		43.9 (3)	4.14 (10)	4.64 (11)		3.45 (13)	5.04 (9)
<i>Trifolium repens</i>		42.93 (4)		7.11 (8)			10.34 (4)
<i>Rumex</i> sp.		1.46 (7)					
<i>Trifolium pratense</i>		0.98 (8)					
<i>Elymus repens</i>		0.49 (9)			0.53 (12)		
<i>Alchemilla</i> sp.		0.49 (9)	0.69 (18)				2.92 (12)
<i>Ranunculus acris</i> ssp. <i>acris</i>			8.28 (7)	0.09 (30)		2.82 (14)	3.71 (11)
<i>Salix herbacea</i>			4.48 (9)	13.18 (5)	10.11 (7)		
<i>Bistorta vivipara</i>			2.76 (12)	7.3 (7)		8.15 (7)	7.96 (6)
<i>Leontodon autumnalis</i>			2.41 (13)	5.59 (9)		3.76 (12)	0.27 (19)
<i>Viola biflora</i>			2.07 (14)	5.31 (10)		10.97 (5)	15.12 (3)
<i>Salix phylicifolia</i>			1.38 (16)			5.33 (10)	
<i>Geranium sylvaticum</i>			1.38 (16)	1.71 (17)		4.7 (11)	5.31 (8)

## General discussion

Free ranging animals have the possibility to select both which vegetation types and which plant species within the habitats they graze (Milne et al. 1979). This study show that the studied dairy cows utilized the summer farming landscape extensively (paper III) and that they selected both vegetation types, grazing localities of selected vegetation types, grazing patches within the localities and plant species they grazed within the patches. The GPS studies of the cattle (paper II and III) revealed that the cattle preferred to graze light-open, grass and herb rich vegetation types. However, site 1 was more overgrown than site 2 and the cattle therefore had to graze more in forests there. At site 2 the cows spent the most grazing time in intermediate grasslands (20-59 % bush cover), bilberry woodland, and grazed bilberry – blue heath heath (60-100 % bush cover), while tall-herb mountain birch forest, more (20-59 % tree cover) or less (60-100 % tree cover) light open, and bilberry woodland (5-19 % tree cover) were most used for grazing at site 1.

The field layer in the grazing localities within the bilberry forests and tall-herb mountain forests at site 1 consisted mostly of grasses (40% and 44% of the registrations, respectively), mainly *Avenella flexuosa*, *Agrostis capillaris* and *Anthoxanthum odoratum*, and woody species (39% and 26 % of the registrations, respectively), mainly *Juniperus communis* and *Vaccinium myrtillus*. In both forest types the cattle chose to graze on patches which were dominated by *Avenella flexuosa*. For this species, the proportion of total registrations was 22-25% in the grazing localities but as much as 34-41% in the grazed patches within the localities. *Agrostis capillaris* was also quite frequently present (10%) in grazed patches in the bilberry forest and *Anthoxanthum odoratum* (10%) in the tall-herb mountain forest. *Vaccinium myrtillus* was frequently present in the patches in both vegetation types (9% in each).

In the most grazed vegetation type at site 2, intermediate grassland, grasses and herbs were the two most dominating plant groups within the grazing localities although woody species were also present with high proportions (44%, 30% and 22% of the total registrations, respectively). The most present plant groups in grazed patches within the grazing localities were grass, 42%, and herbs, 39%. Woody species constituted only 15 % of the patches. The species with highest recorded proportions were *Agrostis capillaris*, *Salix herbaceae*, *Nardus stricta*, *Bistorta vivipara* and *Trifolium repens*. For the two next most grazed vegetation types, bilberry woodland and grazed bilberry – blue heath heath, there was registered 48 % and 32 % grass, respectively, and 23% and 60 % woody species. In bilberry woodland it was also registered 17 % herbs. In grazed patches in these vegetation types the proportion of grass was

52% and 41%, respectively, and constituted mainly, or entirely as for grazed bilberry – blue heath heath, of *Avenella flexuosa*. Woody species made up 26% and 36% in the grazed patches within localities in bilberry woodland and grazed bilberry – blue heath heath, respectively, and constituted mostly of *Vaccinium myrtillus*, but also *Salix herbaceae* in the heath vegetation. In bilberry woodland there was also a quite high proportion of herbs, about 15 %.

The recordings of grazed plant species in the patches (see appendix 5 and 6, paper 4) show that at site 1, *Avenella flexuosa* and *Anthoxanthum odoratum*, were recorded grazed in all patches where they were found in the most grazed vegetation types, bilberry woodland and tall herb forest. *Avenella flexuosa* was present in 19 of 20 patches within localities in bilberry woodland and in all the patches analysed in tall-herb mountain forest. *Agrostis capillaris* and *Vaccinium myrtillus* were also frequently present in the patches and grazed in almost all patches where they were found.

In the most grazed vegetation type at site 2, intermediate grassland, many species were recorded grazed in the patches. The most grazed species were *Agrostis capillaris*, *Festuca rubra*, *Anthoxanthum odoratum*, *Trifolium repens*, *Poa alpina*, *Nardus stricta*, *Phleum alpinum*, *Leontodon autumnalis* and *Viola biflora*. In the second and third most grazed vegetation types, bilberry forest and grazed bilberry-blue heath heath, there were much less species recorded grazed in the patches. In bilberry woodland, *Avenella flexuosa*, *Agrostis capillaris* and *Vaccinium myrtillus* were most grazed. In the bilberry-blue heath heath, *Avenella flexuosa*, *Carex bigelowii*, *Vaccinium myrtillus* and *Carex brunnescens* were most grazed.

Figure 2 shows the proportions of plant groups in the grazing localities, the patches and recorded eaten plant groups, at site 1. The proportions eaten of grasses, sedges and herbs are higher than the proportions of these plant groups found in both patches and localities. Woody species and Pteridophytes were also recorded grazed but the proportions of these plant groups were higher in the localities and the patches than recorded grazed. At site 2 (Figure 3), the proportions of sedges and herbs grazed are higher than the proportions in the patches and the localities. The proportion of grasses eaten is nearly the same as at site 1. In other words, the cattle seem to concentrate on grasses, sedges and herbs and consume only small proportions of woody species. Pteridophytes have probably been eaten more or less by accident. These findings are in accordance with Rekdal (2001). According to Rekdal (2001), grass is the most important plant group on alpine rangelands, sedges is the second most important and herbs may also contribute significantly to the diet because some herbs are tasty

and much liked by the cattle. Woody species, especially *Vaccinium myrtillus*, is grazed often late in the season (Rekdal 2001.). Microhistological data of species and plant groups in cattle faeces in this project (see table 6 and figure 1 in paper IV) showed that this is the case also in our study.

Cattle can maximize their daily intake by selecting patches with high digestibility (Bakker 1989). The digestibility of different plant groups from Norwegian rangelands are presented in Garmo (1998): herbs have high digestibility (70-80%), grass and sedges have intermediate digestibility (60-75 % and 50-70 %, respectively) while heather e.g. *Vaccinium myrtillus*, has low digestibility (45-60 %). The grazing preferences found in this study are in accordance with this i.e. the cattle at both sites grazed the plant groups with highest digestibility available in the localities. Furthermore, Michaud et al. (2012) showed that the digestibility and feed value is more stable in species-rich grasslands.



Cows grazing alpine ranges at site 1, partly covered with bushes (*Salix* spp.) and trees (*Betula pubescens* ssp. *czerepanovii* and *Picea abies*). Photo: U. Falkdalen

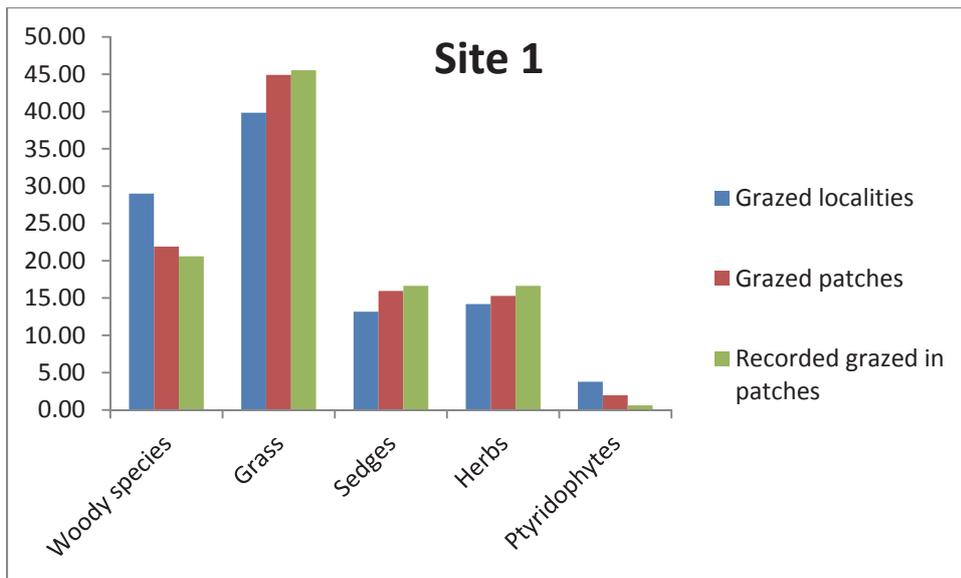


Figure 2. The proportions of plant groups found in grazing localities, grazed patches and recorded grazed within the patches, site 1.

Figure 3. The proportions of plant groups found in grazing localities, grazed patches and recorded grazed within the patches, site 2.

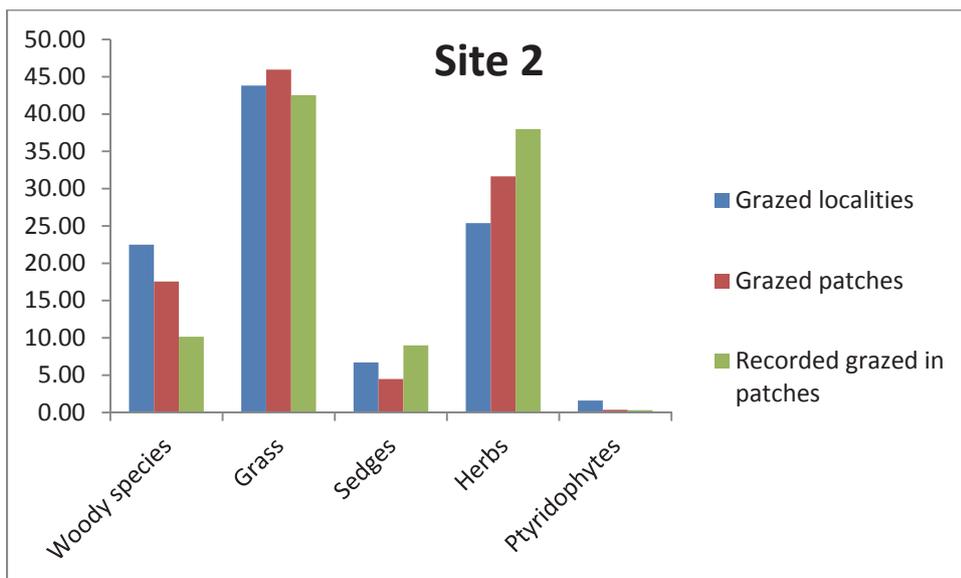


Figure 3. The proportions of plant groups found in grazing localities, grazed patches and recorded grazed within the patches, site 2.

Alpine milk has been found to have a high content of secondary plant metabolites e.g. terpenoid (Bugaud et al. 2001, Martin et al. 2005). Furthermore, feeding on diversified mountain pastures give milk a more favorable fatty acid composition for human health than feeding on less-diversified lowland pastures (Chilliard et al. 2007). It is likely that the bioactive properties of some of the secondary plant metabolites influence the biohydrogenation processes of fatty acids in the rumen of cattle (Lourenco et al. 2008). In this study investigations of the  $\alpha$ -tocopherol content in various grazing plants (paper I) revealed that there are good availability of grazing plants with high levels of  $\alpha$ -tocopherol at both study sites, as there are high levels in sedges, herbs and woody species (Figure 4).

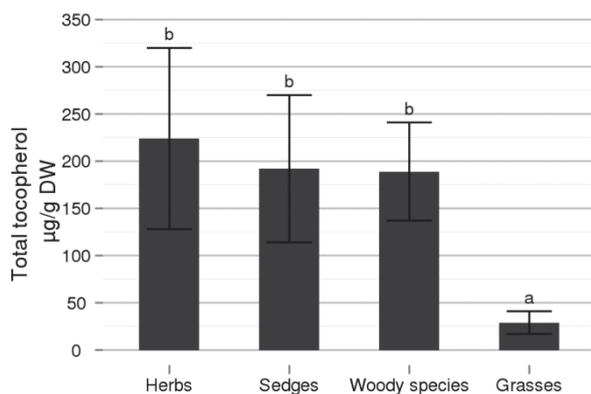


Figure 4. Content of tocopherol in herbs (6 species), sedges (4 species), woody species (4 species) and grass species (8 species) sampled at site 1 and 2. Values are mean  $\pm$  1 SE and different letters indicate significantly different values at the 0.05 level (ANOVA)

In this study we also found that different plant groups are significantly related to some fatty acids and antioxidants in the milk (paper IV). Five of the eight fatty acid variables (C14, C18:1 c9, C18:3, C18:2 and omega 6/omega 3) and  $\beta$ -carotene were found to be significantly associated with at least one of the cow diet variables (see table 10 and figure 2 in Paper IV). The omega 3 fatty acid C18:3 and  $\beta$ -carotene were both positively related to herbs, the omega 6 fatty acid C18:2 n-6 was negatively related to woody species, grass and sedges and the ratio

omega 6/omega 3 was negatively related to grass (plot). Moreover, oleic acid, C18:1 c9 was positively related to woody species and Pteridophytes and the saturated fatty acid C14:0 was on the contrary negatively related to these variables.



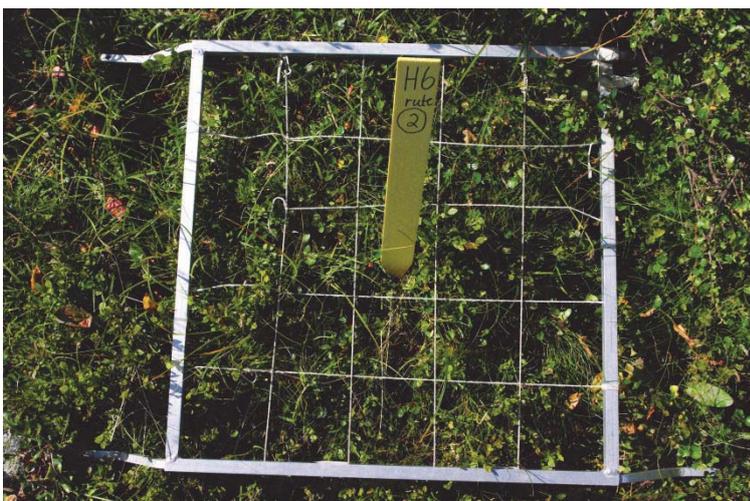
Species rich grassland grazed by a cow at site 2, Hallingdal. More than 30 species per 0,5m x 0,5m could be found in the grass and species rich vegetation types at both sites. Photo: U. Falkdalen

Today, all semi-natural habitats and many of their species are defined as threatened or near threatened in Norway (NT – CR) mainly due to re-growth processes (Lindgaard and Henriksen, 2013). Due to the decrease in summer farming and abandonment or cessation of management, shrubs such as *Juniperus communis* spp., *Salix* spp. and *Betula nana* are invading the summer farming areas, succeeded by forests with *Betula pubescens* ssp. *czerepanovii* or *Picea abies* and many of the semi-natural vegetation types are gradually disappearing (Olsson et al. 2000, Bryn et al. 2001). This encroachment has been going on in a large scale during the last 50-60 years and has caused extensive landscape changes. It has also caused a decrease in biodiversity, as the shrub and forest habitats are less species rich than the semi-natural vegetation types belonging to grasslands. The rangelands in Valdres and Hallingdal are still species rich (see appendix 1) but encroachment with bushes and trees is visible and has many places taken over for the earlier light-open grass species rich habitats. Grazing with cattle is seen as a very good tool to maintain biodiversity in species rich, semi-natural grasslands (Pykälä 2000). In addition to many other good reasons, this is also an important argument for continuing the summer farming practice in alpine rangelands. It is,

however, necessary to supply grazing with clearing of bushes and trees, preferably in the localities where the cattle choose to graze.



Collecting plants for tocopherol analysis. Photo: U. Falkdalen



A plot placed over a grazed patch. Photo: Hanne Sickel

## Conclusions

This study shows that the cattle utilize the summer farming landscape extensively and prefer light-open, grass and herb rich vegetation types when available. Thereby they contribute to maintenance of semi-natural species rich habitats. Moreover, milk produced on species rich rangelands are characterized by a healthier fatty acid composition and a higher content of terpenes. This can be utilized as a win-win situation and give potential for unique alpine products, thereby supporting alpine farmers. However, the study also reveals that grazing is not enough to keep the summer farming landscape light open. To maintain the biodiversity and grazing value of semi-natural species rich habitats it may therefore be necessary to supply grazing with clearing of bushes and trees, preferably in the localities where the cattle choose to graze.



This photo illustrates the importance of grazing of alpine rangelands to maintain light-open, species rich grasslands. When grazing stops (the right side of the fence) the grasslands are invaded by shrubs and trees. This picture is from site 1. Photo: U. Falkdalen

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## Appendix 1. Species lists from the study sites in Valdres (site 1) and Hallingdal (site 2)

<i>Latin names</i>	<i>Norwegian names</i>	Site 1	Site 2
		Valdres	Hallingdal
<i>Achillea millefolium</i>	ryllik	x	x
<i>Achillea ptarmica</i>	nyseryllik	x	
<i>Aconitum septentrionale</i>	tyrihjem	x	x
<i>Agrostis canina</i>	hundekvein	x	
<i>Agrostis capillaris</i>	engkvein	x	x
<i>Agrostis</i> sp.	kvein	x	
<i>Agrostis vinealis</i>	bergkvein		x
<i>Ajuga pyramidalis</i>	jonsokkoll	x	
<i>Alchemilla alpina</i>	fjellmarikåpe	x	x
<i>Alchemilla glabra</i>	glattmarikåpe		x
<i>Alchemilla</i> sp.	marikåpe sp.	x	x
<i>Andromeda polifolia</i>	kvitlyng/kvitbladlyng	x	x
<i>Angelica sylvestris</i>	sløke	x	
<i>Antennaria dioica/alpina</i>	kattefot	x	x
<i>Anthoxanthum odoratum</i> coll.	gulaks	x	x
<i>Arctostaphylos alpinus</i>	rypebær	x	x
<i>Arctostaphylos uva-ursi</i>	melbær	x	
<i>Astragalus alpinus</i>	setermjelt		x
<i>Avenella flexuosa</i>	smyle	x	x
<i>Avenula pubescens</i>	dunhavre	x	
<i>Bartsia alpina</i>	svarttopp	x	x
<i>Betula nana</i>	dvergbjørk	x	x
<i>Betula pubescens</i> ssp. <i>czerepanovii</i>	fjellbjørk	x	x
<i>Bistorta vivipara</i>	harerug	x	x
<i>Botrychium lunaria</i>	marinøkkel	x	x
<i>Calamagrostis canescens</i>	vassrørkvein	x	
<i>Calamagrostis purpurea</i>	skogrørkvein	x	x
<i>Calamagrostis</i> sp.	rørkvein sp.	x	
<i>Calluna vulgaris</i>	røsslyng	x	x
<i>Campanula rotundifolia</i>	blåklokke	x	x
<i>Cardamine pratensis</i> ssp. <i>dentata</i>	sumpkarse	x	x
<i>Carex atrata</i>	svartstarr		x
<i>Carex bigelowii</i>	stivstarr	x	x
<i>Carex brunnescens</i>	seterstarr	x	x
<i>Carex buxbaumii</i> ssp. <i>mutica</i>	tranestarr	x	
<i>Carex canescens</i>	gråstarr		x
<i>Carex cappilaris</i>	hårstarr	x	x
<i>Carex demissa</i>	grønnstarr		x
<i>Carex dioica</i>	særbustarr	x	x
<i>Carex echinata</i>	stjernestarr	x	x
<i>Carex flava</i>	gulstarr	x	x
<i>Carex lachenalii</i>	rypestarr		x

<b>Latin names</b>	<b>Norwegian names</b>	<b>Site 1</b>	<b>Site 2</b>
		<b>Valdres</b>	<b>Hallingdal</b>
<i>Carex lasiocarpa</i>	trådstarr	x	
<i>Carex muricata</i> ssp. <i>muricata</i>	piggstarr	x	
<b>Carex nigra coll.</b>	slåttestarr/stolpestarr	x	x
<i>Carex pallescens</i>	bleikstarr	x	x
<i>Carex panicea</i>	kornstarr	x	x
<i>Carex pauciflora</i>	sveltstarr	x	
<i>Carex paupercula</i>	frynsestarr	x	x
<i>Carex rariflora</i>	snipestarr		x
<i>Carex rostrata</i>	flaskestarr	x	
<i>Carex</i> sp.	starr sp.	x	x
<i>Carex vaginata</i>	slirestarr	x	x
<i>Cerastium cerastoides</i>	brearve		x
<i>Cerastium fontanum</i> ssp. <i>vulgare</i>	vanlig arve	x	x
<i>Chamomilla suaveolens</i>	tunbalderbrå	x	
<i>Chrysosplenium alternifolium</i>	maigull	x	x
<i>Cicerbita alpina</i>	turt		x
<i>Cirsium helenioides</i>	hvitbladtistel	x	x
<i>Coeloglossum viride</i>	grønnekurle		x
<i>Corallorhiza trifida</i>	korallrot	x	x
<i>Crepis paludosa</i>	sumphaukeskjegg	x	x
<i>Crepis paludosa</i>	sumphaukeskjegg	x	
<i>Deschampsia cespitosa</i> ssp. <i>cespitosa</i>	sølvbunke	x	x
<i>Diphasiastrum alpinum</i>	fjelljamne		x
<i>Drosera</i> sp.	myrdoegg sp.		x
<i>Eleocharis</i> sp.	sivaks sp.		x
<i>Elymus repens</i>	kveke		x
<i>Empetrum nigrum</i> coll.	kekling	x	x
<i>Epilobium angustifolium</i>	geitrams	x	x
<i>Epilobium collinum</i>	bergmjølke	x	
<i>Epilobium hornemannii</i>	setermjølke	x	x
<i>Epilobium lactiflorum</i>	hvitmjølke		x
<i>Epilobium palustre</i>	myrmjølke	x	x
<i>Equisetum arvense</i> ssp. <i>arvense</i>	åkersnelle		x
<i>Equisetum hyemale</i>	skavgras	x	x
<i>Equisetum palustre</i>	myrsnelle	x	x
<i>Equisetum pratense</i>	engsnelle	x	x
<i>Equisetum sylvaticum</i>	skogsnelle	x	x
<i>Eriophorum angustifolium</i> ssp. <i>angustifolium</i>	duskull	x	x
<i>Eriophorum vaginatum</i>	torvull	x	x
<i>Euphrasia frigida</i>	fjelløyentrøst	x	x
<i>Euphrasia</i> sp.	øyentrøst sp.		x
<i>Euphrasia stricta</i>	vanlig øyentrøst/ kjerteløyentrøst	x	x
<i>Festuca ovina</i> ssp. <i>ovina</i>	sauesvingel	x	x
<i>Festuca pratensis</i>	engsvingel	x	

<b>Latin names</b>	<b>Norwegian names</b>	<b>Site 1</b>	<b>Site 2</b>
		<b>Valdres</b>	<b>Hallingdal</b>
<i>Festuca rubra</i> ssp. <i>rubra</i>	rødsvingel	x	x
<i>Filipendula ulmaria</i>	mjødurt	x	x
<i>Galeopsis tetrahit</i>	kvassdå	x	
<i>Galium boreale</i>	hvitmaure	x	
<i>Galium uliginosum</i>	sumpmaure	x	x
<i>Gentiana nivalis</i>	snøsøte	x	x
<i>Gentiana purpurea</i>	søterot		x
<i>Gentianella campestris</i>	bakkesøte		x
<i>Geranium sylvaticum</i>	skogstorkenebb	x	x
<i>Geum rivale</i>	enghumleblom	x	x
<i>Gymnadenia conopsea</i>	brudespore		x
<i>Gymnocarpium dryopteris</i>	fugleteig	x	x
<i>Hieracium alpinum</i> coll.	fjellsveve	x	x
<i>Hieracium lactucella</i>	aurikkelsveve	x	x
<i>Hieracium pilosella</i>	hårsveve	x	x
<i>Hieracium</i> sp.	sveve sp.	x	x
<i>Hieracium vulgatum</i> coll.	beitesveve/skogsveve	x	x
<i>Hypochoeris maculata</i>	flekkgrisøre		x
<i>Juncus alpinoarticulatus</i> coll.	skogsiv	x	x
<i>Juncus filiformis</i>	trådsiv	x	x
<i>Juncus</i> sp.	siv sp.		x
<i>Juncus trifidus</i>	rabbesiv		x
<i>Juniperus communis</i> coll.	einer	x	x
<i>Leontodon autumnalis</i>	følblom	x	x
<i>Leucanthemum vulgare</i>	prestekrage		x
<i>Linnaea borealis</i>	linnae	x	x
<i>Listera cordata</i>	småtveblad	x	
<i>Lotus corniculatus</i>	tiriltunge	x	x
<i>Luzula campestris</i>	markfrytle	x	
<i>Luzula multiflora</i> ssp. <i>frigida</i>	seterfrytle	x	x
<i>Luzula multiflora</i> ssp. <i>multiflora</i>	engfrytle	x	x
<i>Luzula pallidula</i>	bleikfrytle	x	x
<i>Luzula pilosa</i>	hårfrytle	x	x
<i>Luzula spicata</i>	aksfrytle		x
<i>Luzula sudetica</i>	myrfrytle	x	x
<i>Lycopodium annotinum</i> ssp. <i>annotinum</i>	stri kråkefot	x	x
<i>Lycopodium clavatum</i> ssp. <i>clavatum</i>	myk kråkefot	x	x
<i>Lycopodium</i> sp.	kråkefot sp.	x	
<i>Maianthemum bifolium</i>	maiblom	x	x
<i>Melampyrum pratense</i>	stormarimjelle/engmarimjelle	x	x
<i>Melampyrum sylvaticum</i>	småmarimjelle/skogmarimjelle	x	x
<i>Melica nutans</i>	hengeaks	x	
<i>Milium effusum</i>	myskegras		x
<i>Molinia caerulea</i>	blåtopp	x	x

<b>Latin names</b>	<b>Norwegian names</b>	<b>Site 1</b>	<b>Site 2</b>
		<b>Valdres</b>	<b>Hallingdal</b>
<i>Montia fontana</i>	kildeurt		X
<i>Myosotis arvensis</i>	åkerfoglemegei		X
<i>Myosotis decumbens</i>	fjellminneblom/fjellfoglemegei		X
<i>Nardus stricta</i>	finnskjegg	X	X
<i>Omalotheca norvegica</i>	setergråurt		X
<i>Omalotheca supina</i>	dverggråurt	X	X
<i>Omalotheca sylvatica</i>	skoggråurt		X
<i>Oxalis acetosella</i>	gjøkesyre	X	
<i>Oxyria digyna</i>	fjellsyre		X
<i>Paris quadeifolia</i>	firblad	X	
<i>Parnassia palustris</i>	jåblom	X	X
<i>Pedicularis palustris</i>	myrklegg		X
<i>Pedicularis palustris</i>	vanlig myrklegg	X	X
<i>Phegopteris connectilis</i>	hengeving	X	
<i>Phleum alpinum</i>	fjelltimotei	X	X
<i>Phleum pratense</i> ssp. <i>pratense</i>	timotei		X
<i>Phyllodoce caerulea</i>	blålyng		X
<i>Picea abies</i>	gran	X	X
<i>Pinguicula vulgaris</i>	tettegras	X	X
<i>Pinus sylvestris</i>	furu	X	X
<i>Plantago major</i> ssp. <i>major</i>	groblad		X
<i>Plantago media</i>	dunkjempe		X
<i>Poa alpina</i>	fjellrapp	X	X
<i>Poa annua</i>	tunrapp	X	X
<i>Poa pratensis</i> coll.	engrapp gruppa ( <i>Poa pra.</i> gruppa)	X	X
<i>Poa pratensis</i> ssp. <i>angustifolia</i>	trådrapp	X	X
<i>Poa pratensis</i> ssp. <i>subcaerulea</i>	smårapp		X
<i>Poa</i> sp.	rapp sp.	X	X
<i>Potentilla crantzii</i>	flekkmure	X	X
<i>Potentilla erecta</i>	tepperot	X	X
<i>Potentilla palustris</i>	myrhatt	X	X
<i>Potentilla</i> sp.	mure sp.	X	
<i>Prunella vulgaris</i>	blåkoll	X	X
<i>Pyrola minor</i>	perlevintergrønn	X	X
<i>Pyrola rotundifolia</i> ssp. <i>norvegica</i>	norsk vintergrønn	X	X
<i>Pyrola rotundifolia</i> ssp. <i>rotundifolia</i>	legevintergrønn	X	X
<i>Pyrola</i> sp.	vintergrønn sp	X	X
<i>Ranunculus acris</i> ssp. <i>acris</i>	engsoleie	X	X
<i>Ranunculus auricomus</i> coll.	nyresoleie	X	X
<i>Ranunculus repens</i>	krypsoleie	X	X
<i>Ranunculus</i> sp.	soleie sp.		X
<i>Rhinanthus minor</i>	småengkall	X	X
<i>Rubus chamaemorus</i>	molte	X	X
<i>Rubus saxatilis</i>	teiebær	X	X

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<i>Rumex acetosa</i> ssp. <i>acetosa</i>	engsyre	x	x
<i>Rumex acetosa</i> ssp. <i>lapponicus</i>	setersyre		x
<i>Rumex acetosella</i> coll.	småsyre	x	x
<i>Rumex longifolius</i>	høymol sp.		x
<i>Sagina saginoides</i>	seterarve	x	x
<i>Salix arbuscula</i>	småvier		x
<i>Salix aurita</i>	ørevier		x
<i>Salix caprea</i>	selje	x	
<i>Salix glauca</i> ssp. <i>glauca</i>	sølvvier	x	x
<i>Salix herbacea</i>	musøre	x	x
<i>Salix lapponum</i>	lappvier	x	x
<i>Salix myrsinifolia</i>	svartvier	x	
<i>Salix myrsinites</i>	myrtevier		x
<i>Salix phylicifolia</i>	grønnvier	x	x
<i>Salix reticulata</i>	rynkevier		x
<i>Salix</i> sp.	vier sp.		x
<i>Saussurea alpina</i>	fjelltistel	x	x
<i>Saxifraga aizoides</i>	gulsildre		x
<i>Saxifraga stellaris</i>	stjernesildre	x	x
<i>Selaginella selaginoides</i>	dvergjamne	x	x
<i>Sibbaldia procumbens</i>	trefingerurt	x	x
<i>Silene acaulis</i>	fjellsmelle		x
<i>Silene dioica</i>	rød jonsokblom		x
<i>Silene vulgaris</i>	engsmelle		x
<i>Solidago virgaurea</i>	gullris	x	x
<i>Sorbus aucuparia</i>	rogn	x	x
<i>Stellaria borealis</i>	fjellstjerneblom	x	
<i>Stellaria graminea</i>	grasstjerneblom	x	x
<i>Stellaria media</i>	vassarve		x
<i>Stellaria nemorum</i>	skogstjerneblom	x	x
<i>Stellaria</i> sp.	stjerneblom sp.	x	x
<i>Tanacetum vulgare</i>	reinfann		x
<i>Taraxacum</i> sp.	løvetann sp.	x	x
<i>Thalictrum alpinum</i>	fjellfrøstjerne	x	x
<i>Tofieldia pusilla</i>	bjønnbrodd	x	x
<i>Trichophorum alpinum</i>	sveltull		x
<i>Trichophorum cespitosum</i>	bjønnskjegg	x	x
<i>Trientalis europaea</i>	skogstjerne	x	x
<i>Trifolium medium</i>	skogkløver		x
<i>Trifolium pratense</i>	rødkløver		x
<i>Trifolium repens</i>	hvitkløver	x	x
<i>Triglochin palustris</i>	myrsaulauk		x
<i>Tussilago farfara</i>	hestehov		x
<i>Urtica dioica</i>	stornesle	x	

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<i>Vaccinium myrtillus</i>	blåbær	x	x
<i>Vaccinium oxycoccus</i> ssp. <i>microcarpum</i>	småtranebær	x	x
<i>Vaccinium uliginosum</i> ssp. <i>uliginosum</i>	blokkebær	x	x
<i>Vaccinium vitis-idaea</i>	tyttebær	x	x
<i>Valeriana sambucifolia</i> ssp. <i>sambucifolia</i>	vendelrot	x	x
<i>Veronica alpina</i> ssp. <i>alpina</i>	fjellveronika		x
<i>Veronica chamaedrys</i>	tveskjeggveronika		x
<i>Veronica officinalis</i>	legeveronika	x	x
<i>Veronica serpyllifolia</i> ssp. <i>serpyllifolia</i>	glattveronika/snauveronika	x	x
<i>Vicia cracca</i>	fuglevikke	x	x
<i>Viola biflora</i>	fjellfiol	x	x
<i>Viola canina</i> ssp. <i>montana</i>	lifiol	x	
<i>Viola epipsila</i>	stor myrfiol	x	x
<i>Viola palustris</i>	liten myrfiol	x	x
<i>Viola palustris</i>	myrfiol	x	x
<i>Viola riviniana</i>	skogfiol	x	



**Paper I**

Sickel, H., Bilger, W. & Ohlson, M. 2012. High Levels of alpha-Tocopherol in Norwegian Alpine Grazing Plants. - J. Agric. Food Chem. 60: 7573-7580.

DOI: [10.1021/jf301756j](https://doi.org/10.1021/jf301756j)

**Paper II**

Sickel, M., Steenhuisen, F., Sickel, H., Norderhaug, A. & Ohlson, M. Use of high frequency GPS data to classify cattle behaviour on heterogeneous rangelands. (Submitted)

**Paper III**

Sickel, H., Sickel, M., Steenhuisen, F., Ohlson, M. & Norderhaug, A. Vegetation preferences and animal behaviour of free ranging dairy cattle in two alpine rangelands – a high frequency GPS study.

(Manuscript)

**Paper IV**

Sickel, H., Eldegard, K., Lunnan, T., Norderhaug, A., Ohlson, M., Petersen, M.A. & Abrahamsen, R. K. Influence of grazing plants on fatty acid composition, antioxidants and terpenes in milk from alpine rangelands.

(Manuscript)





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