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LAND RESOURCE CLASSIFICATION IN MOUNTAIN AREAS

Examination of the classification system used in land resource mapping of Norwegian mountain areas

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NORSK INSTITUTT FOR SKOG OG LANDSKAP

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Cover photo: Mountain area in Lyngen, Troms County. Photo: Linda Aune-Lundberg, Skog og landskap©

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SAMMENDRAG

AR-FJELL er den norske arealressursdatabasen for fjellområdene. AR-FJELL distribueres ikke som et separat datasett, men ligger sammen med N50 data fra Statens kartverk, til grunn for arealklassifikasjonen for fjellområdene i arealressurskartene AR50 og AR250. Istedenfor å dokumentere klassifikasjonen i disse to produktene hver for seg, er det utarbeidet en (foreløpig) dokumentasjon av det underliggende AR-FJELL datasettet.

Alle AR-FJELL klassene er dokumentert gjennom beskrivende statistiske ”profiler” av det faktiske innholdet i hver klasse. Hver enkelt AR-FJELL profil er utarbeidet på grunnlag av en ”overlay” operasjon mellom AR-FJELL og et utvalg AR18X18 flater (utvalgsflater fra programmet Arealregnskap for utmark). Ut fra dette datasettet er det generert statistikk som viser prosentvis fordeling av vegetasjonsklasser innenfor hver AR-FJELL klasse. I tillegg er det sett på fordeling av AR-FJELL klasser i høydelaget, samt fordeling av AR-FJELL klasser innenfor vegetasjonstypene i AR18X18 utvalget.

AR18X18 foreligger (i 2011) kun for deler av Norge. Undersøkelsen av AR-FJELL klassene må derfor betraktes som foreløpig og bør gjentas når det foreligger et komplett AR18X18 datasett. Dette forventes i 2015.

Undersøkelsen er gjennomført med økonomisk støtte fra Norsk Romsenter.

SUMMARY

AR-FJELL is the Norwegian land resource database for the mountain areas. AR-FJELL is not distributed as a separate product from Skog og landskap, but does – together with topographic data (series N50) from the Norwegian Mapping Authority (Statens kartverk) form the basis for the classification of mountain areas in the national land resource maps AR50 and AR250.

The five Norwegian AR-FJELL classes are documented through descriptive statistical “profiles” of the actual content of each class. Profiles of the AR-FJELL classes were obtained through a GIS overlay operation between AR-FJELL and the available AR18X18 (Land resource accounting for the Norwegian outfields) survey plots. The distribution of vegetation classes for each AR-FJELL class was compiled from this overlay. The report also consider the distribution of the AR-FJELL classes by elevation asl and the distribution of the vegetation types in the AR18X18 sample.

AR18X18 is (2011) only available for parts of Norway. The study should be repeated when a full national coverage is available. This is expected in 2015.

The study was carried out with funding from the Norwegian Space Centre.

Nøkkelord:	AR-FJELL, Norge, arealressurskart, arealstatistikk,
Key word:	AR-FJELL, Norway, land cover maps, land resources,
Andre aktuelle publikasjoner fra prosjekt:	Aune-Lundberg, L. & Strand, G.-H. 2010. Corine land cover classes. Examination of the content of CLC classes in Norway. Rapport fra Skog og landskap 05/10: 42 s.

CONTENT

1. INTRODUCTION

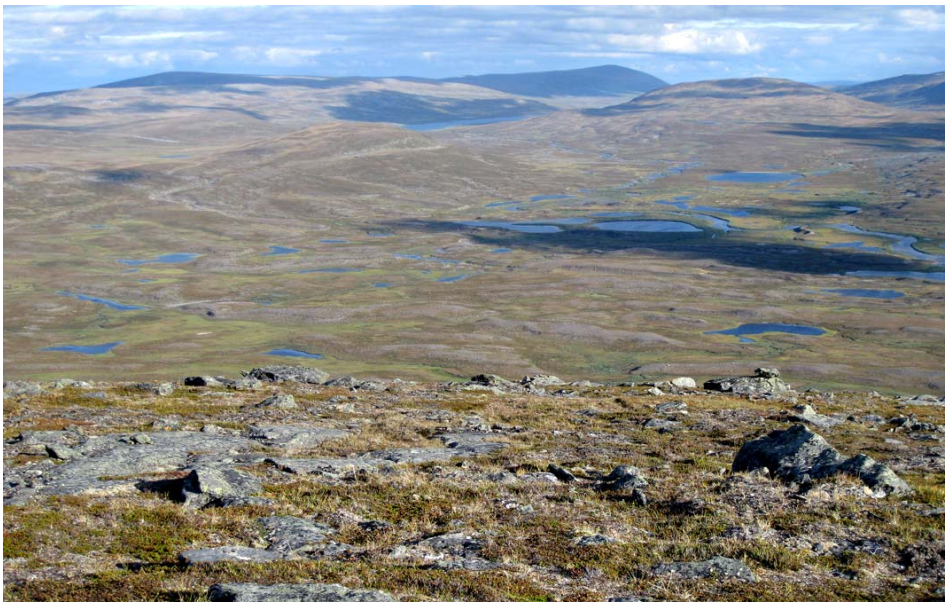
AR-FJELL is the Norwegian land resource database for the mountain areas. It is not a product that is distributed in its own right, but forms the basis for several other land resource map products. AR-FJELL is based on semi automatic satellite image interpretation. It is therefore not a "real" map of land cover types but offers information about areas with similar spectral values in the satellite images for mountains and other open areas. This information is assumed to be related to the luxuriance of the vegetation. AR-FJELL has national coverage and is tailored for mapping in scale 1:50 000, with a minimum mapping unit of 5 hectare and a geometric accuracy of 20 meters. The dataset provides input for the land resource maps AR50 (scale 1:50 000) and AR250 (1:250 000) and is also used in the production of the Norwegian CORINE Land Cover 2000 and 2006.

AR-FJELL represents a partition of the mountain areas into five classes based on spectral signature. These classes are expected to be related to vegetation cover and the classes are labelled accordingly. This study is a preliminary examination of the validity of the assumption about a relationship between the spectral classes and the actual land cover.

The study was carried out using a (GIS) overlay between AR-FJELL and more detailed land cover maps compiled from in situ field inventory. The source was a subset of the AR18X18 national area frame survey of land resources (Strand and Rekdal 2006). AR18X18 is a Norwegian national area frame survey of land resources emphasizing the outfields. Sample sites of 1500 x 600 meters (0.9 km^2) are distributed along a systematic 18 x 18 km grid across the whole country. A land cover map (approximately scale 1:20 000) for each sample site is compiled in the field using aerial photographs. An overlay between AR-FJELL and the AR18X18 samples that were available by the implementation of the project was carried out using GIS software. This produced a (sample based) "profile" offering a description of the statistical distribution of land cover classes for each AR-FJELL class. These profiles were used to assess the content of the AR-FJELL classes and can be used as a reference by users of AR-FJELL.

Potential applications of AR-FJELL in addition to the production of AR50 and AR250 are outfield pasture assessments (Rekdal et al 2009), CORINE land Cover (CLC 1994, Büttner et al 2002), GAP analysis (Jennings 1999) and quantitative description of the land cover in protected areas.

The project was carried out with partial funding from the Norwegian Space Centre.



Figur 1. Mountain area in Målselv, Troms County. Photo: Finn-Arne Haugen.

2. ABBREVIATIONS

AR18X18: An area frame (sampling) survey of land cover and related land resources. The survey will be completed in 2015, but a subset was available for the present study

AR250: Land resource map with minimal mapping units linked to cartography in scale 1:250 000

AR50: Land resource map with minimal mapping units linked to cartography in scale 1:50 000

AR-FJELL: Land resource map of mountain areas (input to AR50 and AR250). Produced by semi-automatic clustering of satellite images. The classification system consists of five, essentially spectral, classes that are interpreted as makeshift land cover classes.

ASL: Above sea level

CLC: CORINE Land Cover. European programme for harmonized pan-European land cover mapping

CORINE: Coordination of information on the environment. Environmental information programme operated by EEA

EEA: European Environmental Agency

ELC: Expected land cover. Used to explain the (informal) expectation about the land cover composition in the AR-FJELL classes as expressed by experienced field surveyors.

GIS: Geographic Information System. Computer software for handling spatial data.

LUCAS: Land use/cover area frame survey (Eurostat)

N50: Topographic map with minimal mapping units linked to cartography in scale 1:50 000

NDVI: Normalized Difference Vegetation Index

NIR: Near infrared reflection

PSU: Primary statistical unit

SSU: Secondary statistical unit

3. BASIC DESCRIPTION OF AR-FJELL[1]

AR-FJELL is the Norwegian land resource database for the mountain areas. The product is based on semi automatic satellite image interpretation and shows areas in mountains and other open areas appearing with similar spectral values in the satellite images. This information is (based on the experience from 40 years of remote sensing) assumed to be related to the luxuriance of vegetation, but not directly related to vegetation classes. AR-FJELL has national coverage and is tailored for mapping in scale 1:50 000, with a minimum mapping unit of 5 hectare and a geometric accuracy of 20 meters. The dataset provides input for the land resource maps AR50 (scale 1:50 000) and AR250 (1:250 000) and is also used in the production of the Norwegian CORINE Land Cover 2000 and 2006.

The most common rendition of AR-FJELL - used in AR50, national land resource statistics and as input to CORINE Land Cover - has five classes (Table 1).

Table 1.The five class partition of AR-FJELL. "Code" refers to the signature used in some of the illustrations below. Content is a short description of the "Expected Land Cover" (ELC) as described informally by experienced field surveyors.

Class	Code	Name	Contents
1	1	Abiotic	Areas with more than 75 % of bare soil and gravel, boulder fields or exposed bedrocks
2	2a	Sparse vegetation	Areas with little green substance and low productivity.
3	2c	Lichen	Heath dominated by light-coloured lichen species.
4	2b	Intermediate vegetation	Areas with continuous vegetation with low to intermediate productivity.
5	3	Vigorous vegetation	Areas with continuous vegetation with high coverage of fresh, green plant materials as bilberry, dwarf birch, salix, grass, herbs and frondage.

The five classes were developed by a number of field surveyors with long (up to forty years) experience as land cover surveyors in Norwegian mountains. The surveyors worked with satellite images in an attempt to create a classification system with spectrally homogenous classes and label these according to "expected" land cover content (ELC). It was, however, understood that the class would be heterogeneous in terms of actual land cover content and that the labels should be interpreted as a guideline for users of the classification system, not as an exact description of class content. The surveyors decided to give the classes short, expressive names (Table 1) accompanied by a short, informal textual description (excerpt in Table 1, for full text see Appendix) called the "Expected land cover" or ELC. The ELC was based on the surveyors' assumptions about the content in terms of

- Luxuriant, green vegetation
- Meagre or dry vegetation
- Light-coloured lichen species
- Bare rock, boulders, gravel and sand

[1] This chapter is translated and edited from an unpublished paper (in Norwegian) written by Michael Angeloff and Yngve Rekdal in 2009. The Figures are also prepared by Michael Angeloff.

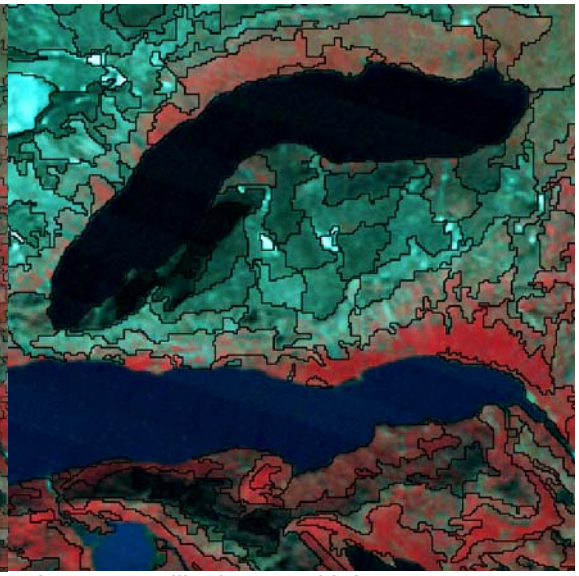
The actual mapping was carried out using a two-step segmentation and classification of satellite images followed by a manual correction of the results. The main data source was 23 Landsat 7 and Landsat 5 images. Another 16 SPOT4 and IRS-1c were used in some areas where Landsat images were unavailable. Most images were from the period 1998-2002. All the satellite images that were used are listed in the appendix of this report.

3.1 Image prosessing

The classification was carried out using the red, green and near-infrared bands of the satellite images. The reflectance in these three bands has been demonstrated to be related to the lushness of the vegetation cover (Goward, Markham et al. 1991, Myneni, Hall et. all 1995), and also to be sensitive to the content of both lichen (Nordberg and Allard 2002) and bare soil and rock. Digital topographic maps (N50 © Norge digtalt) were used to mask out areas not to be classified (forest, water, agricultural areas, glaciers, peat land and built-up land). Areas covered by clouds were also masked out and removed manually.

Classification was carried out by segmentation and subsequent classification of image segments using the Ecognition® software. The segmentation process grouped together neighbouring image pixels based on spectral similarity and a predefined maximum size of segments. The segmentation was implemented in two phases. The first phase was segmentation with strong requests for spectral similarity while allowing very small groups of pixels to form segments. The demand for spectral similarity was relaxed in the second phase where only quite large groups of pixels were allowed to form segments. The output from the first phase was a ”map” of small segments (Figure 2). The content was a large number of tiny but spectrally homogeneous segments. The output from the second phase was a map of fairly large segments containing more internal variation (Figure 3). Each of these larger segments was built by grouping together, based on spectral similarity, a number of adjoining smaller segments from phase one.

Figur 2. Satellite image with small segments from segmentation phase one. Landsat5 15.aug 1997 Besseggen Jotunheimen, Oppland County.

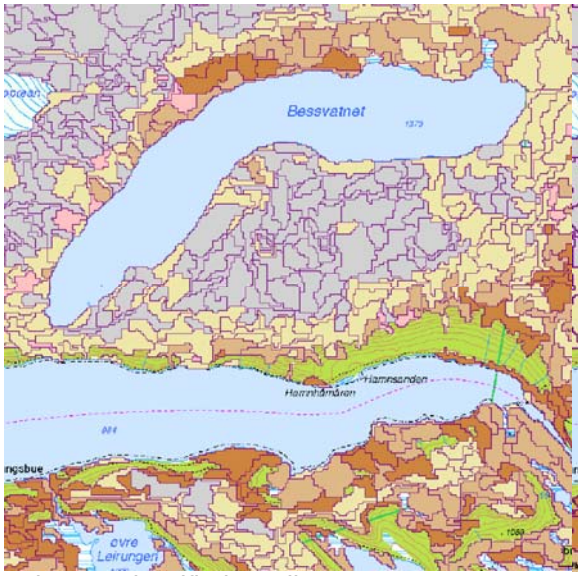


Figur 3. Satellite image with large segments from segmentation phase two. Landsat5 15.aug 1997 Besseggen Jotunheimen, Oppland County.

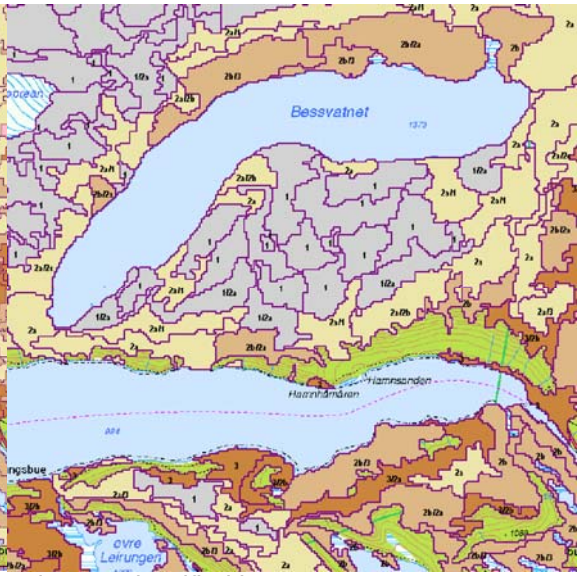
The map containing small segments was classified using training areas for each of the five AR-FJELL classes (Figure 4). Approximately 100 training areas were identified for each class in each satellite image. The result of the classification was a thematic map where the small segments

were grouped into the five classes corresponding to the five classes identified in Table 1. This map was combined with the map of large segments and a statistical description of each large segment compiled by summary of the percentage coverage of each of the five classes from the small-segment map inside the large segment. Finally, the dominating class in a large segment was encoded as the classification of that segment. Furthermore, in cases where the runner up did cover at least 20 % of the mapping unit, this class was added as a secondary class signifying a mosaic (eg. 2b/2a, Figure 5).

The large segments are the mapping units used in the AR-FJELL dataset. Each mapping unit is also encoded with mean elevation and aspect compiled from the national 25 meter digital elevation model (DEM) provided by the National Mapping Authority. Finally, mean NDVI for the mapping unit was also calculated and added as an attribute in the database. This additional information was later used in the manual correction and evaluation of the classification result (see below).



Figur 4. Classified small segments. Besseggen Jotunheimen, Oppland County.



Figur 5. Classified large segments. Besseggen Jotunheimen, Oppland County.

NDVI: Normalized Difference Vegetation Index (NDVI) is calculated using the red (R) and near-infrared reflection (NIR). NDVI = (NIR – R) / (NIR + R). NDVI is assumed to provide information related to photosynthesise activity and the density of plant coverage on the reflecting surface.

3.2 Manual correction of the results

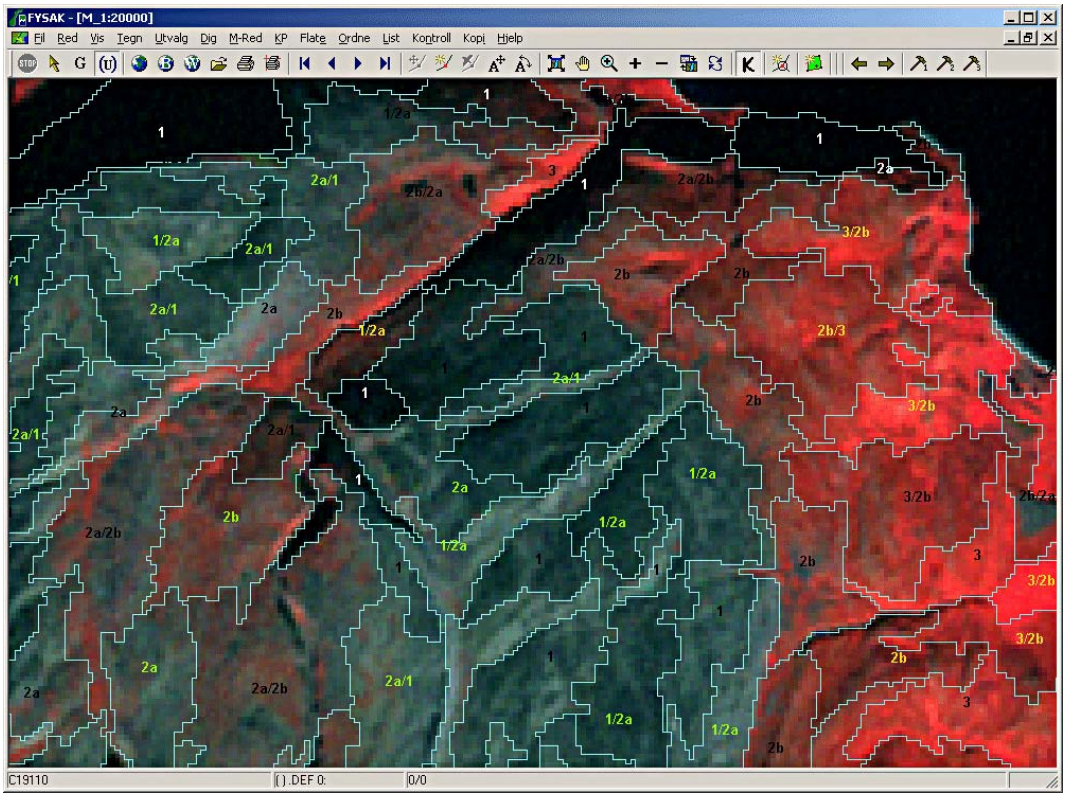
The time of acquisition, topography and weather conditions all influence the classification of vegetation using satellite images. Reflection from the vegetation will change continuously throughout the growing season. The changes affect both the strength and the composition of the reflection. Elevation and the process of snow melting are important factors, as are topography, relief and sun angle (Figure 6).

Most mapping units will cover areas with different kinds of vegetation. Classification is difficult when the land cover composition of a mapping unit is heterogeneous. It is also difficult when seasonal changes influence the spectral reflection. The amount of continuous and lush vegetation is often underestimated due to late thawing and melting of snow. On slopes well exposed to the sun, on the contrary, the continuous and lush vegetation is often overestimated.

Approximately 10% of the mapping units were selected for manual examination. The basis for the selection was the composition of the mapping unit (in terms of relative amount of each of the five classes) together with mean elevation asl, exposition and NDVI. Image analysts with field experience and local knowledge of the area under consideration carried out the manual examination and, if necessary also, correction of the classification. These analysts also had access to the satellite images, aerial photographs and topographic maps.

Visual inspection was carried out using the map editing software FYSAK (Figure 7). The analysts were working on screens using maps and images in scale 1: 30 000. The analysts did a systematic evaluation of the classification results for the mapping units.

Figur 6. Topographic relief, sun angle and snow melting can have strong influence on the appearance of vegetation in a satellite image, Landsat7 21.juli 2000 Skårasalen, Hjørundfjord, Møre og Romsdal County.



Figur 7. Screen dump from FYSAK. Uncertain classification (shown as green and orange colour) is selected for evaluation by trained image analysts with field experience. Landsat7 15.sept 1999 Oterfjellet, Syltefjord, Finnmark County.

4. THE LAND RESOURCE SURVEY AR18X18

AR18X18[2] is an area frame survey of land cover and land use based on the first generation of *Lucas* (Land use/cover area frame survey). Lucas is a European area frame survey carried out in the EU countries by Eurostat (Eurostat 2003). The *Lucas* methodology has later been changed in order to provide more accurate statistics for agricultural areas, but the sampling frame of the original survey has been retained in Norway.

The sampling units of the first generation of *Lucas* were points located on the intersections of an 18 × 18 kilometer grid mesh throughout Europe. Each of these points was the centre of a Primary Statistical Unit (PSU) of 1500 × 600 meters. Ten additional points, known as Secondary Statistical Units (SSU), were located inside each PSU (Figure 8). Measurements in *Lucas* were mostly made on an approximately 7 m^2 plot around each SSU and on a transect through the five northernmost SSUs of each PSU.

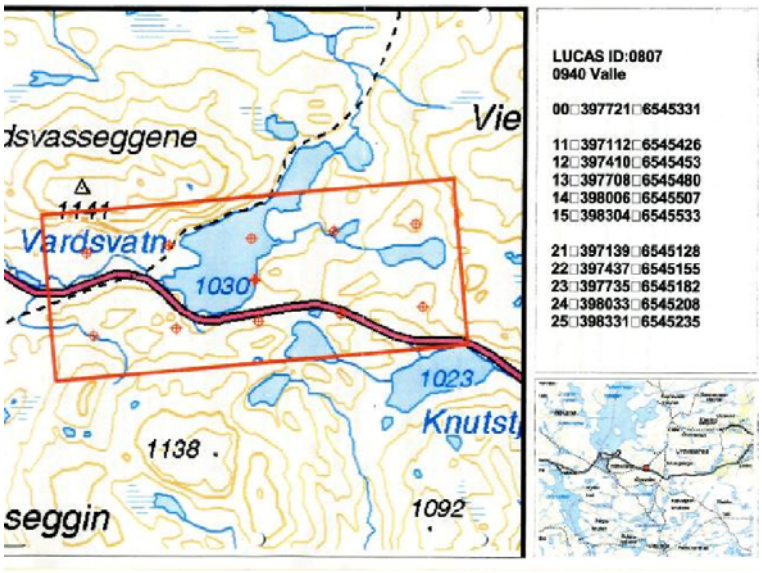
Figur 8. A *Lucas* sample site consists of a Primary Statistical Unit (PSU) shaped as a 1500 x 600 meters rectangle. Ten Secondary Statistical Unites (SSU) are located inside the PSU. The distance between the SSU's is 300 meters.

AR18X18 is using the *Lucas* concept of PSU and SSU locations. The major modification of the original Lucas methodology is that AR18X18 also collects land cover data for the rectangular PSU covering 1500 × 600 meter (0.9 km^2). The PSU provides a better coverage of the area in the data collection and improves the probability for inclusion of small and/or rare features. It also allows the survey to be treated as a single stage systematic sample instead of a two-stage sample.

A PSU is included in the survey as long as any part of it falls within Norwegian land areas (including freshwater). The estimated total number of sampling sites in the survey is 1083, but the actual number may change slightly as PSUs along the complex coastline of western- and northern Norway remains to be studied in detail. PSUs thought to contain only ocean, may turn out to actually also contain some island and vice versa.

A field map of each survey site is prepared using topographical maps provided by the Norwegian Mapping Authority (Statens kartverk). The map (Figure 9) consists of a detailed image of the PSU and its immediate surroundings (based on topographical map in scale 1:50 000) and an access map (based on topographical map in scale 1:250 000). Key information including the site identification, name of the municipality and the coordinates of the center point is also included.

[2] This chapter is an edited excerpt from Strand and Rekdal (2006)



Figur 9. Field map for AR18X18 PSU # 807 Vardsvatn, Valle (Base map: N50, © Norge digitalt).

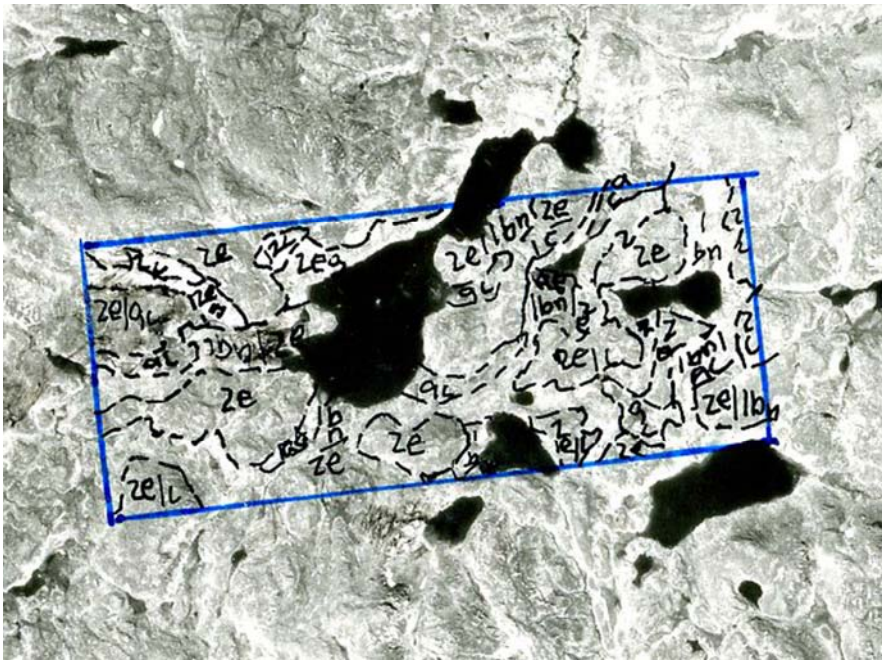
The land cover survey of the PSUs is carried out following the Norwegian Forest and Landscape Institutes system for vegetation and land cover mapping at intermediate scale (1:20 000). The system is developed through mapping projects throughout Norway over a period of 25 years (Rekdal and Larsson 2005). The system is thoroughly tested through practical use, the cost is acceptable and the results are used for quantification and assessment of many aspects of land resources.

Figur 10. Per Bjørklund drawing a land cover map on a stereo pair of aerial photographs during work in 2009. Photo: Linda Aune-Lundberg, Skog og landskap.

The basic nomenclature of the Norwegian Forest and Landscape Institutes system for vegetation and land cover mapping consists of 54 land types (45 of these are vegetation types). A number of additional registrations are also added. Examples of such additions are the coverage of lichen, willow or fern and areas with particularly rich grass cover. There is close coherence between this mapping system and a classification system often used for detailed vegetation descriptions in Norway (Fremstad 1997). The differences are mainly that the Norwegian Forest and Landscape Institute approach is less detailed for vegetation types that cover small areas or require highly specialized botanical knowledge for identification. The hierarchical sequence of key registrations in the two

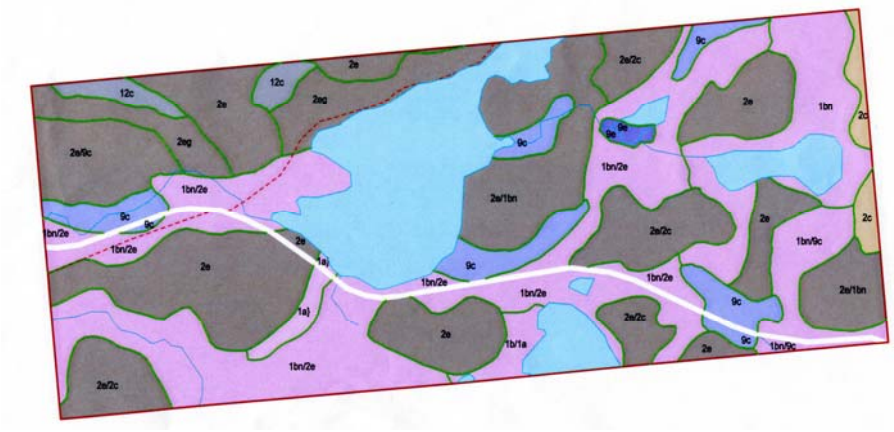
systems is also somewhat different because the Norwegian Forest and Landscape Institute system is aiming to be efficient during applied mapping in the field.

Vegetation and land cover mapping following the Norwegian Forest and Landscape Institute system is carried out in situ using aerial photographs usually at scale 1:40 000 (Figure 10). Both black and white and IR photos can be used, but IR photos are preferred if available. Vegetation polygons are drawn directly on the photos (Figure 11) and later digitized and processed using GIS software.



Figur 11. Aerial photograph with land cover interpretation of AR18X18 PSU # 807 Vardsvatn, Valle.

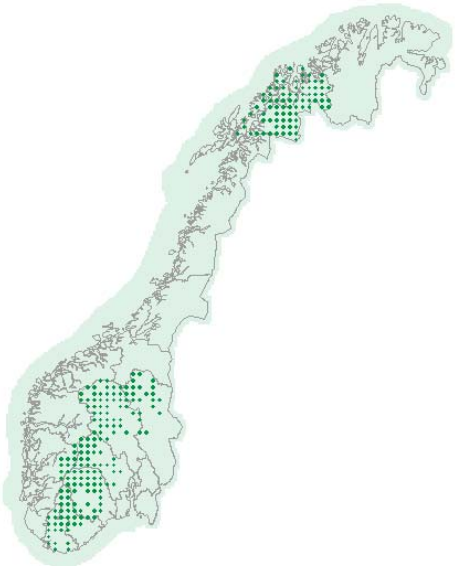
The minimum polygon size is 0.1 hectare, but a mosaic of two different vegetation types can be registered for any polygon when each type covers at least 25% of the area. The dominant vegetation type is for statistical purposes counted as covering on average 62.5% of each polygon, while the secondary vegetation type is counted for the remaining 37.5%. A simplified vegetation map based on the measurements in Figure 11 is shown in Figure 12 below.



Figur 12. Vegetation map of AR18X18 PSU # 807 Vardsvatn, Valle.

5. METHODS

5.1 Overlay between AR-FJELL and AR18X18



Figur 13. AR18X18 sample plots used in the study

The overlay (intersect) between AR-FJELL and AR18X18 was carried out using Python scripting with geoprocessing tools provided in ArcGIS®. The AR-FJELL datasets was divided into 100x100 km^2 tiles (17 in total). The overlay was carried out separately for each tile before the results of the overlays were merged together. Based on this dataset, area statistics was compiled showing the percentage distribution of vegetation types and supplementary information (following the Norwegian Forest and Landscape Institute system for vegetation and land cover mapping as described in Rekdal and Larsson 2005) for each of the five AR-FJELL classes. The vegetation types and the supplementary information found in open mountain areas are listed in the appendix. A total of 244 AR18X18 sample plots were used in the overlay. Eighty of these samples were located in Troms County in the northern part of Norway. The remaining 164 plots were located in the mountains of southern Norway.

5.2 Elevation

Elevation (meter asl) was used as ancillary information in the segmentation of satellite images leading up to AR-FJELL. The elevation data had been retained for 12 out of 23 satellite images, where the average elevation was linked to each pixel (30 meters x 30 meters). These data were used to calculate the mean height value for each polygon in those parts of AR-FJELL where the data were available. Next, the polygons were grouped into elevation classes with 100 meters intervals. Finally, statistics were compiled showing the percentage distribution of the area of the different AR-FJELL classes in the height intervals and the general height distribution of the areas covered by AR-FJELL.

5.3 Mosaics

The vegetation maps compiled in the AR18X18 survey allows for mosaic figures. A mosaic is used when two different vegetation types are present in an area, but it is impossible to separate the two cartographically due to the size of the minimal mapping unit. In order to allow the use of a mosaic, the lesser of the two vegetation types must cover at least 25% of the area. For statistical purposes, the minor vegetation type in a mosaic is assigned to 37.5 % of the area (midway between 25% and 50%) and the major vegetation type is assigned to the remaining 62.5% of the area. As an example imagine a polygon with an area of 12 000 m^2 where the vegetation is a mosaic of (2e) Dwarf shrub heath and (2c) Lichen heath (signature “2e/c”). This polygon is for statistical purposes assumed to contain (12 000 x 0.625 =) 7 500 m^2 Dwarf shrub heath and (12 000 x 0.375 =) 4 500 m^2 Lichen heath.

5.4 Supplementary information

The vegetation maps compiled in the AR18X18 survey also contains supplementary information about the land cover. This provides additional data about the land cover. Examples are significant content of non-productive areas (impediment), lichen ground cover and the presence of large areas covered with willows.

Table 2 describes how the supplementary information in the AR18X18 vegetation maps is used in the profiles of the AR-FJELL classes (chapter 6). The terms in the column "Supplementary information" is used in various graphs and tables as a label to describe the additional information found in the column "Contents".

Table 2.Description of the supplementary information used in the profiles of the different AR-FJELL classes.

Supplementary information	**Contents**
Impediment	Vegetation types with 50 – 75 % coverage of boulder field or 50 – 75 % coverage of bare rocks.
Vegetation	Unproductive areas with 10 – 25 % coverage of vegetation.
Lichen	Vegetation types with > 25 % lichen coverage. *Exeption in class 3 (chp 5.4) 2c lichen have > 50 % lichen coverage*
Shrub layer	Vegetation types with > 25 % coverage of shrub, both willows and other deciduous trees.
Tree layer	Vegetation types with trees > 3 meters, with canopy coverage 5 – 25 %. All types of wood.

The vegetation types in the AR18X18 survey can have supplementary information attached. Those items that were used in the current study are listed in Table 3. In the profiles of the AR-FJELL classes, only one of these items is used for each polygon. The choice is based on a priority table (table 3). As an example "2e&v" is the signature for dwarf shrub heath (2e) with tree layer of broad-leaved forest (&) and a bottom layer of 25 – 50 % lichen coverage (v). In this case the tree layer is prioritized and only *2e with tree layer* is shown in the graphs.

Table 3.Priority list of the supplementary information.

Priority	**Class**	**Sign**
1.	Impediment	⟠ ⩓
2.	Tree layer	& + * o $ £]
3.	Shrub layer	s o)) ⊂
4.	Lichen	v x

6. AR-FJELL CLASSES

The AR-FJELL classes are foremost spectral classes in the sense that mapping units belonging to a certain AR-FJELL class has similar spectral composition and appearance in satellite images. The classes are neither vegetation classes nor land resource classes. Still, a relationship between spectral appearance and land cover can be expected. In order to make it easier to interpret and use the AR-FJELL data set, the classes have been given names that relate to the assumed content of four main components:

- Luxuriant, green vegetation
- Meagre or dry vegetation
- Light-coloured lichen species
- Bare rock, boulders, gravel and sand

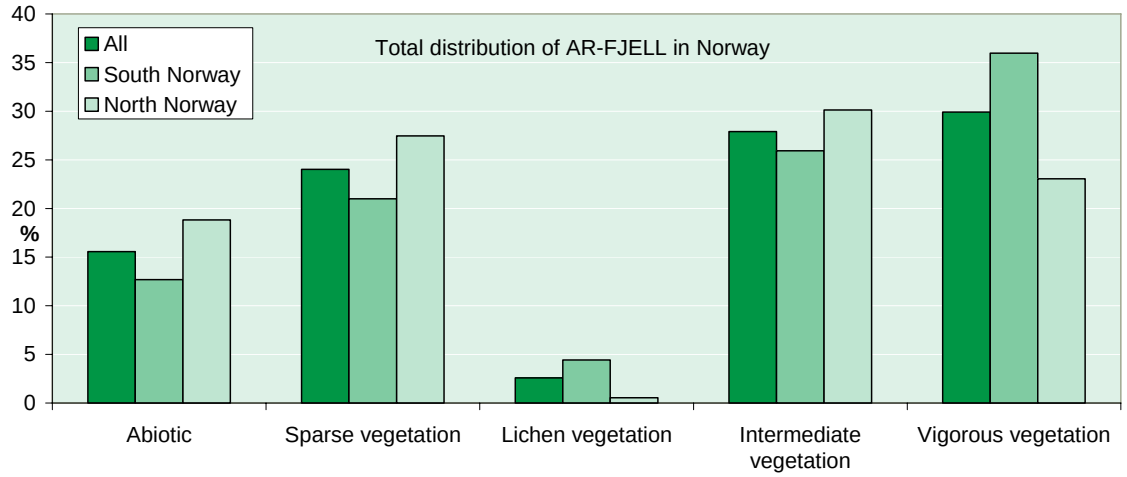
The following chapter contains a more detailed description of the actual content of each of the five major classes found in AR-FJELL. The main component of the descriptions is the results from the overlay between AR-FJELL and AR18X18. Concepts from vegetation mapping are used as descriptive references. Field experience and comparison with existing vegetation maps (scale 1:20,000) are used in the interpretation of the classes. Many vegetation types are present in several of the AR-FJELL classes (see details in the chapters below), often reflecting differences between dry or moist conditions, or high or low nutrition level. Variation in the content of non-vegetated ground within instances of a vegetation type can also result in those instances being assigned to different AR-FJELL classes. The objective of this chapter is thus to document both the content of, and the variation within the AR-FJELL classes. The purpose is to assist the user of AR-FJELL data to better understand and interpret the information contained in the dataset.

6.1 Overall distribution of AR-FJELL classes

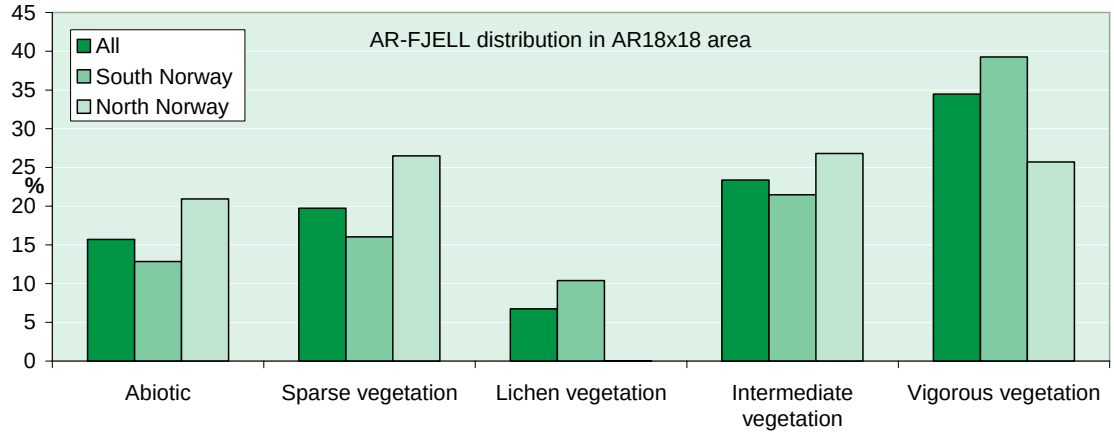
Vigorous vegetation is the most frequent class in terms of areal coverage at the national level (Figure 14). When northern and southern Norway is treated separately, Vigorous vegetation is also the most frequent in southern Norway while Intermediate vegetation is the most frequent in northern Norway. As a whole, southern Norway contains more Vigorous vegetation than the national average, while the region is below the national average with respect to Abiotic areas (bare rock, sand and gravel), and Sparse and Intermediate vegetation. The situation in northern Norway is the opposite. The class Lichen vegetation is found mainly in southern Norway.

The distribution of the AR-FJELL classes within the AR18X18 sample plots is not identical with the overall distribution of AR-FJELL classes. This is to be expected, partly because AR18X18 is a sample (and does not cover the entire area) but mainly because AR18X18 was unavailable for several mountain areas when this study was carried out[3] (the two datasets were not coherent), as explained above. The Lichen vegetation of southern Norway is overrepresented in the sample (because AR18X18 is complete in the southeastern mountains where the class is most frequent). Vigorous vegetation is overrepresented in the sample from northern Norway. Visual comparison of Figure 14 and Figure 15 shows the relationship between the overall AR-FJELL dataset and the subset of AR-FJELL intersecting AR18X18 sample plots.

[3] A complete national coverage of AR18X18 is expected in 2015

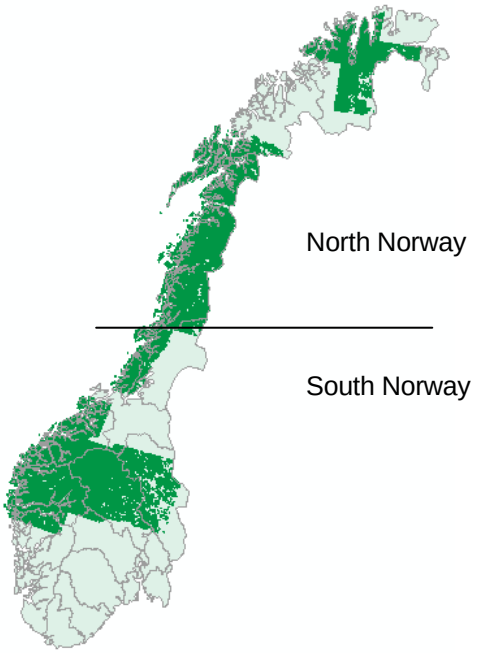


Figur 14. Total distribution of AR-FJELL classes in Norway.



Figur 15. The distribution of the different AR-FJELL classes in the AR18X18 area.

6.2 AR-FJELL classes and elevation



Figur 16. Coverage of height data for AR-FJELL

Examination of elevation data revealed a distinct difference between southern Norway and northern Norway. The mountain areas of southern Norway are generally at higher altitudes than the mountain areas of northern Norway (Figure 17). The analysis and the presentation of results were therefore stratified accordingly. The Counties south of Nordland were defined as *South Norway* and the three northernmost counties (Nordland, Troms and Finnmark) were defined as *North Norway* (Figure 16).

The variation in the altitude of the timberline is related to latitude and to the costal-continental gradient (Moen 1998). Mountains in North Norway are located at higher latitudes and are generally closer to the coast than the mountains of South Norway. The timberline is therefore found at lower altitudes in the north. It is not surprising that many land cover classes also are found at lower altitudes in the north than in the south.

The difference in altitude between mountains in South and North Norway in the study is noteworthy, with a peak in South Norway around 1000 – 1100 meters above the sea and a peak in North Norway around 400 – 500 meters above sea level. Now, recall that elevation data only is present for part of the dataset and not available for the more alpine northern areas in Troms County. A similar examination of a complete Digital Elevation Model (DEM) for all mountain areas may change the results. Still, Nordland County has a long coastline and Finnmark County has generally low altitude mountains and a climatically determined sub-arctic timberline.

Open areas with a mountain-like appearance along the coastline constitutes a large proportion of the AR-FJELL areas in the elevation class 0-100 meters asl. Areas with altitude between 100-200 meters asl will mostly be forested. The small peak in South Norway for altitudes in the range 300-500 meters represents low altitude coastal mountains.

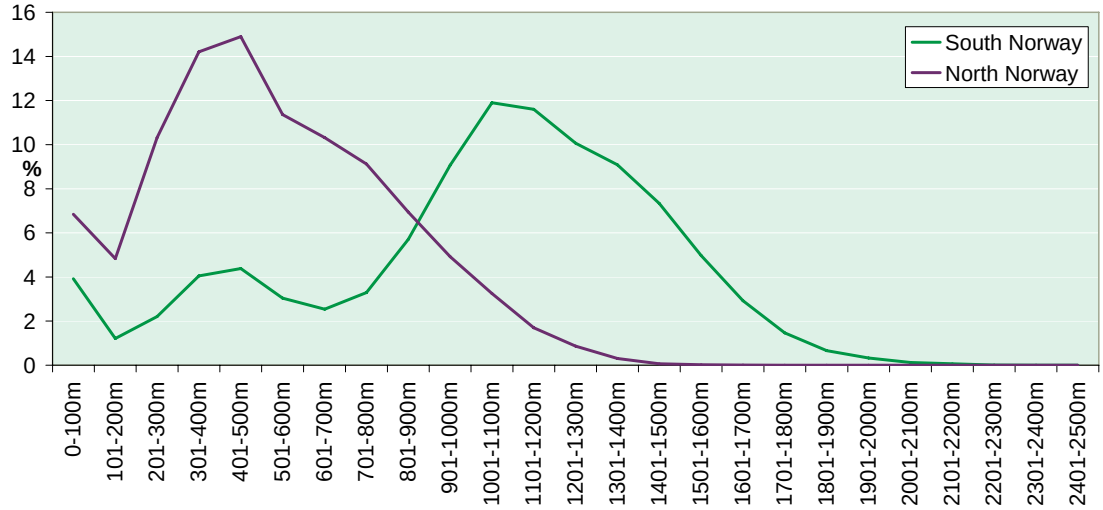
The timberline in the continental part of South Norway is found at relatively high altitude, reflected as a smaller amount of open areas in the range 500 – 800 meters.

The differences in altitude of the individual AR-FJELL classes exhibit similar pattern in North and South Norway, although at lower altitudes in the north than in the south. Abiotic land (bare rock, gravel etc) is mainly found at the highest altitudes. A belt of sparse vegetation is found below the abiotic areas, followed by intermediate and finally vigorous vegetation. The lower altitudes in South Norway are dominated by intermediate (rather than vigorous) vegetation and sparse vegetation, probably reflecting the exposed, coastal character of these areas. The low-laying areas in North Norway exhibit a pattern with vigorous vegetation dominating at low altitudes.

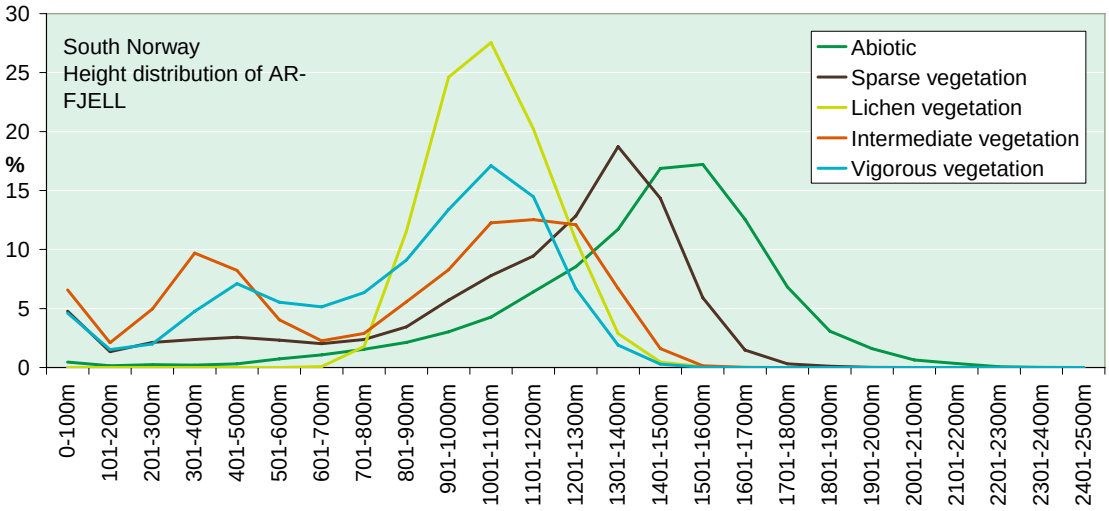
This pattern is approximately the pattern that would be expected from real vegetation classes corresponding to the names used to label the AR-FJELL classes. This observation strengthens the assumption that the AR-FJELL classes are related to the luxuriance of the vegetation in the mountain areas and on bare land elsewhere.

The AR-FJELL class Lichen has a distribution independent of the other four classes. In North as well as in South Norway, lichen is dominating at mid altitudes, around 400 meters asl in the north

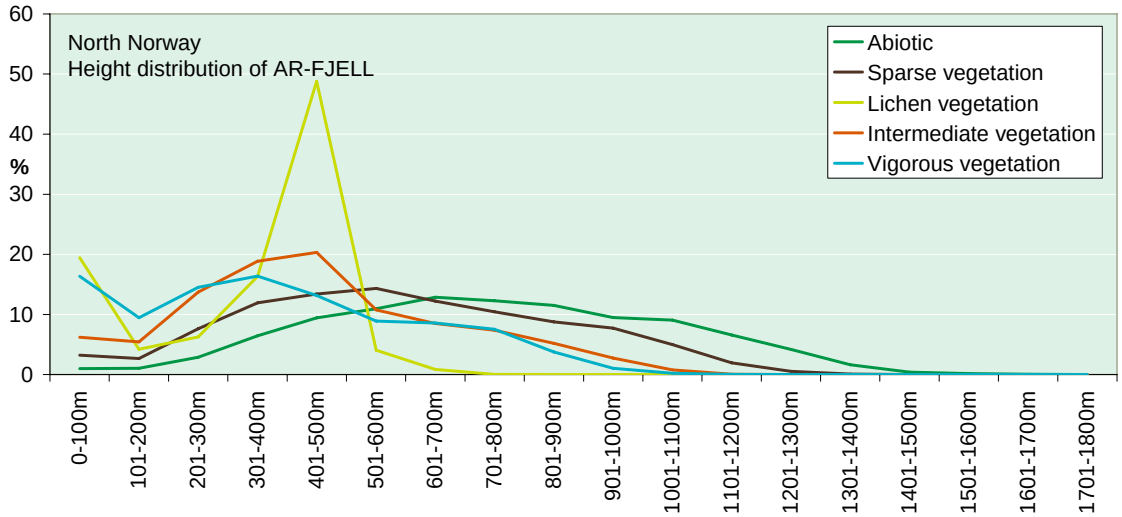
and 1000 meters asl in the south. Lichen is not found at the highest altitudes and in the south neither at low altitudes.



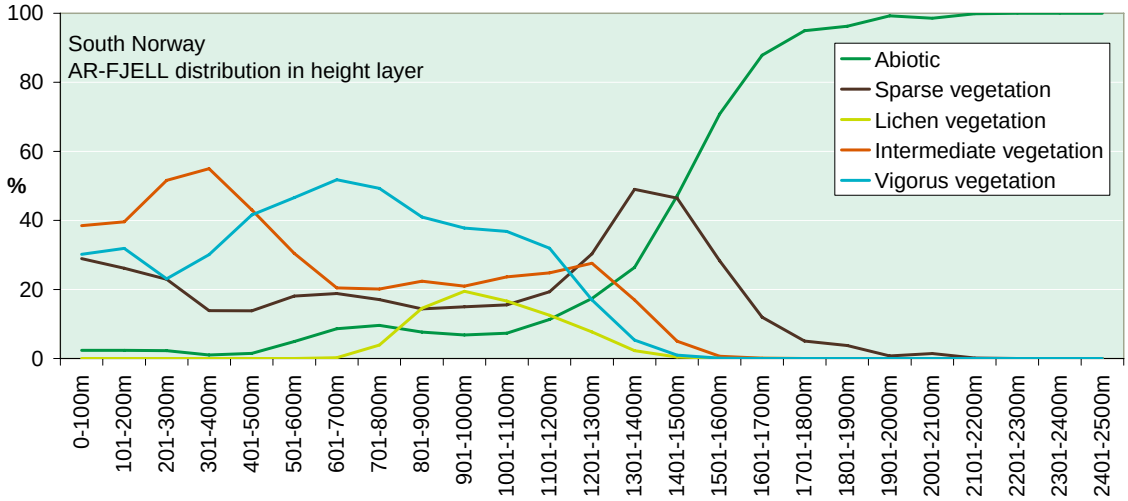
Figur 17. Distribution of land area across elevations.



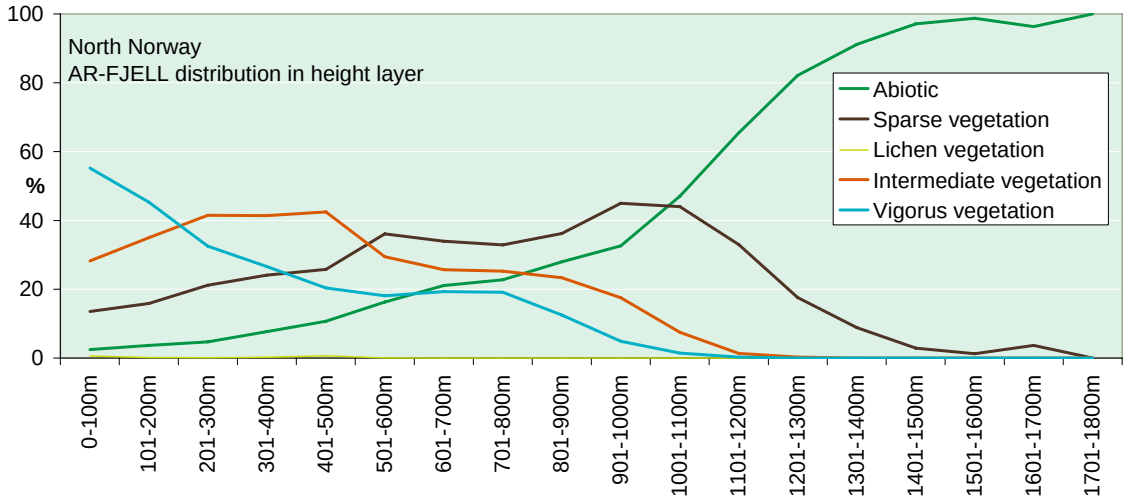
Figur 18. Distribution of the area of different AR-FJELL classes across elevations in South Norway.



Figur 19. Distribution of the area of different AR-FJELL classes across elevations in North Norway.



Figur 20. Relative distribution of AR-FJELL classes at dfifferent elevations in South Norway.



Figur 21. Relative distribution of AR-FJELL classes at dfifferent elevations in North Norway.

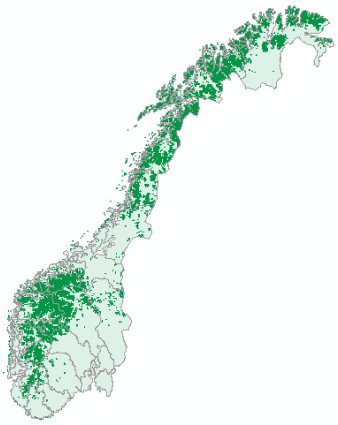
7. STRUCTURE OF THE CLASS DESCRIPTIONS

The five AR-FJELL are treated in detail below. Each sub-chapter is started with a framed text called “Expected land cover”. This is a description of the land cover composition expected by the analysts when the classes were defined and used as a reference frame for the image analyses and subsequent corrections. The text can be interpreted as an elaborate legend, and the subject of this study was to examine how well this legend was matched by ground truth.

The framed text is accompanied by a thumbnail map showing the geographical distribution of the class. The results from the GIS overlay is described and also illustrated using histograms, and informative photographs appended in order to assist the user who may be less familiar with the Norwegian mountain environment.

8. CLASS 1: ABIOTIC

Expected land cover: Areas with more than 75 % abiotic surface. The abiotic component may be bare rock, boulders, stones, gravel and sand. The vegetation is scant, but small areas of vegetation can be present. The productivity of this vegetation can be highly variable and very productive areas can be present, but the productivity is usually low.

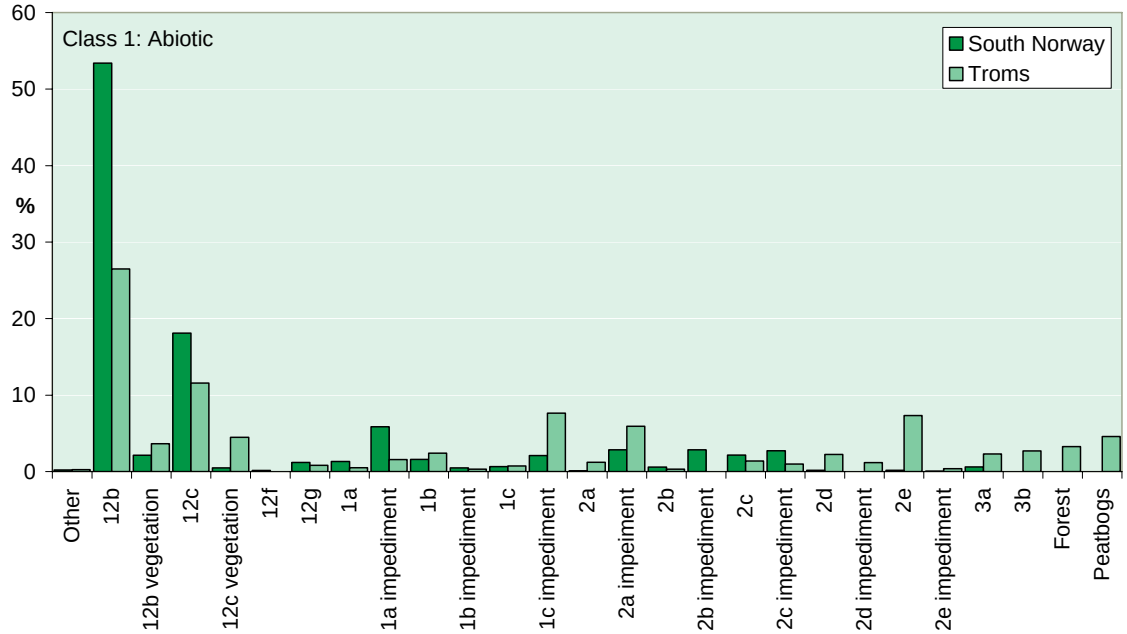


Figur 22. National coverage of the AR-FJELL class 1, Abiotic.

This class constitutes 16 % of the AR-FJELL area (13 % in South Norway and 19 % in North Norway). In South Norway, this class mainly consists of boulder fields, exposed bedrock or different vegetation types with impediment (50 – 75 % boulder field or bare rocks) as a significant element. In South Norway the definition of this class (i.e. more than 75 % exposed bedrock, boulder field, bare soul and gravel) fits well with the actual content. Where 74 % of the area is boulder field and exposed bedrocks, and 17 % are various vegetation types but with 50 – 75 % boulder field and bare rocks included. Adding up these Figures, 91 % of the area in this AR-FJELL class is dominated by impediment in South Norway.

Biotic land cover types are, however, also present in this AR-FJELL class. They are in South Norway distinguished by having low vegetation layer and are often characterized by scattered and barren vegetation. Most often is the productivity in these vegetation types low.

The content of the abiotic AR-FJELL class in Troms County is 42 % of the area, and composed of pure boulder fields and exposed bedrock. Another 23 % of the area is covered by different vegetation types with a significant element of impediment. Adding up these Figures, 64 % of the class is dominated by impediment in Troms County. This is less than the expected 75 % and much less than the 91 % observed in South Norway.



Figur 23. Vegetation distribution in the AR-FJELL class 1: Abiotic.

In Troms County, almost 25 % of the area in this class is composed of luxuriant vegetation types. The explanation is twofold. One is the natural mosaic of vegetation types in Troms County where patches of rich vegetation are common, but too small to be mapped in AR-FJELL. However, when these patches are added together they constitute a significant amount of rich vegetation mixed with land dominated by abiotic land cover.

The second explanation is technical and related to the use of satellite images in fiord topography at high latitudes, where the growing season is short and shadows are pronounced. Areas with shadows, low reflection in the satellite image, were automatically assigned to class 1 independent of the actual (unknown) content of the area. Improved interpretation requires the use of digital ortophoto (allowing better vision where the image is obstructed by shadows) as well as more field inventory.

This class is most common in the high mountain areas (Figure 18 to 21), but can also occur in the lowland where the growing conditions for vegetation are too poor to allow for a continuous vegetation layer. Abiotic areas (class 1) exhibit a gradual transformation towards areas with sparse but more continuous vegetation (class 2).

Figur 24. Bare rocks. Sirdal, Vest-Agder County. Photo: Johnny Hofsten

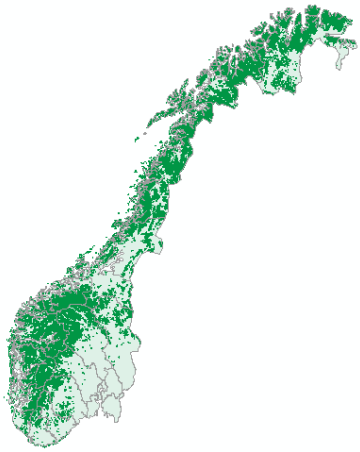
Figur 25. Boulder field (foreground) at Vega, Nordland County. Photo: Michael Angeloff

Figur 26. Boulder field of anortositt. Voss, Hordaland County. Photo: Michael Angeloff

Figur 27. Bare rocks and boulder fields in Grønnliskardet. Sunndal, Møre og Romsdal County. Photo: Yngve Rekdal

9. CLASS 2: SPARSE VEGETATION

Expected land cover: Areas with scanty vegetation, either as scattered patches or as a continuous but meagre vegetation cover. More than 25% of the area is covered with vegetation. Meagre vegetation types with little green foliage and low productivity dominate in areas belonging to this class: Lichen heath with scanty lichen coverage, Dry grass heath, Mid-Alpine heath or snow beds in mosaic with rock outcrops or uncompacted material. Snow beds melting late in summer are also found in this class.



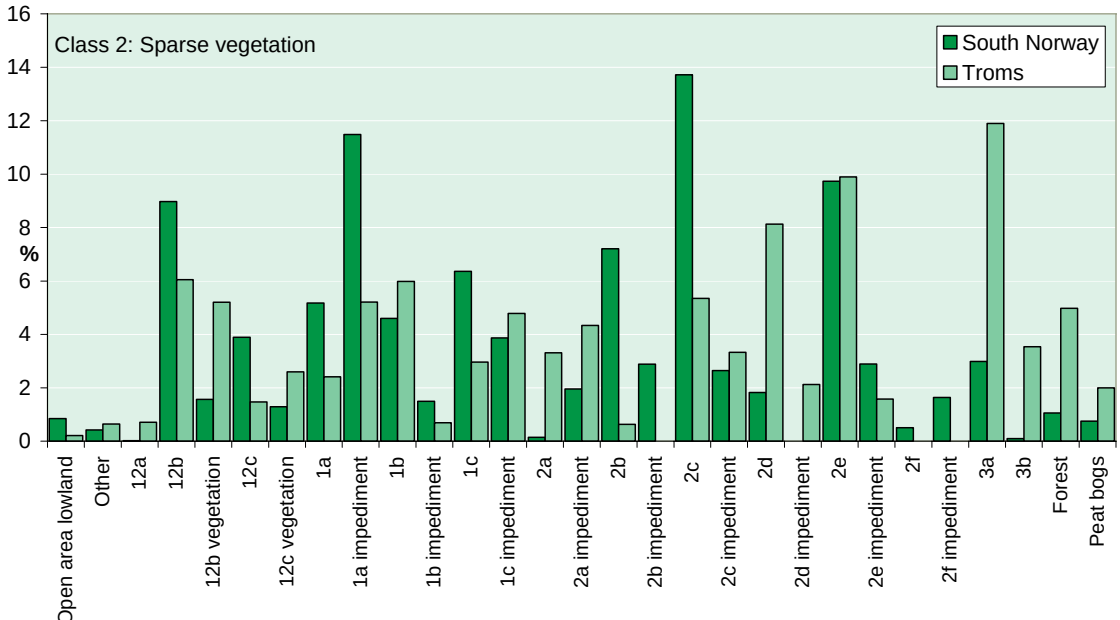
Figur 28. National Coverage of the AR-FJELL class 2, Sparsely vegetated.

This class covers 24 % of the total AR-FJELL area. The coverage is 21 % in South Norway and 28 % in North Norway.

Alpine heath communities are the dominant vegetation group (45 %), and lichen heath is the largest individual vegetation type (14 %) in this AR-FJELL class in South Norway. Snow-bed vegetation (33 %) is also a frequent group. Impediment covers 16 % of the area while another 32 % contains significant amounts of bare rocks and boulder field.

Alpine heath communities are also the largest vegetation group in this class in Troms County, covering 39 % of the area. Snow-bed vegetation covers another 22 % and impediment 16 %. Alpine meadow communities, forest and peat bogs (all vegetation types not expected in this AR-FJELL class) covers 22 % of the area in Troms County.

The rich vegetation type Low herb meadow is the largest individual vegetation type classified as Sparse vegetation in Troms County, covering 12 % of the area. The high amount of low herb meadows may be related to the fact that this type has a low vegetation layer and represents low absolute amounts of chlorophyll. These areas do therefore not stand out from less vegetated land in satellite images.



Figur 29. Vegetation distribution in the AR-FJELL class 2: Sparse vegetation.

Approximately 21 % of the low herb meadow found inside the Sparse vegetation class has more than 50 % coverage of bare rocks or boulder field. Land cover with significant amount of impediment covers 30 % of the area classified as Sparse vegetation in Troms County.

In South Norway, 63 % of the area in this class is covered by vegetation types usually characterised by a short herbivorous vegetation layer. Several of these types are also commonly found with a scattered and barren vegetation cover. The productivity is often low, but can vary. The coverage of these vegetation types in class 2 in Troms County is 39 %. Here, the class contains more vigorous vegetation types than expected for this class.

The expectation for this AR-FJELL class was that more than 25 % of the area should be covered by vegetation. In South Norway, around 55 % of the area is covered with vegetation. In Troms County, the coverage is 60 %. Furthermore, the expectation was to find meagre vegetation types with little green foliage and low productivity in this class. This is the case in South Norway, but the class contains more productive vegetation in Troms County.

This class is most common in a zone between the continuous vegetation cover in the low mountain areas and the non-vegetated higher altitudes. The class is often found as a mosaic with the abiotic class. The class is also found in the lowlands, usually in places where local growing conditions are marginal with respect to plant production.

Figur 30. Stone polygon land. Folldal Hedmark County. Photo: Yngve Rekdal.

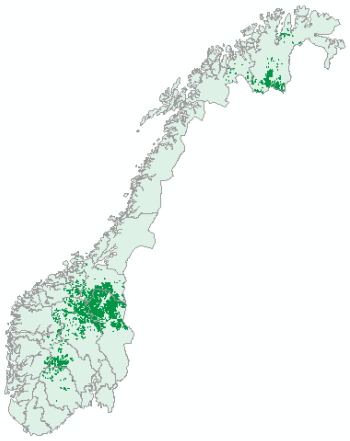
Figur 31. Sparse vegetation in mosaic with bare rocks. Forsand, Rogaland County. Photo: Yngve Rekdal.

Figur 32. Mid-Alpine heath. Bardu, Troms County. Photo: Michael Angeloff

Figur 33. Dry grass heath rich in boulder fields. Photo: Michael Angeloff.

10. CLASS 3: LICHEN HEATH

Expected land cover: Areas with thin snow cover and low productivity dominated by light coloured lichen species. The most important lichen species is *Flavocetraria nivalis*, *Cladonia stellaris* and *Cladonia* species. A thick layer of lichen covers at least 50% of the surface. Occurrences of bare rock and boulder fields can in some places be considerable. The dominating vegetation type is lichen heath, but meagre heather heath and dry grass heath with a considerable content of lichen at the ground layer are also found in this class.

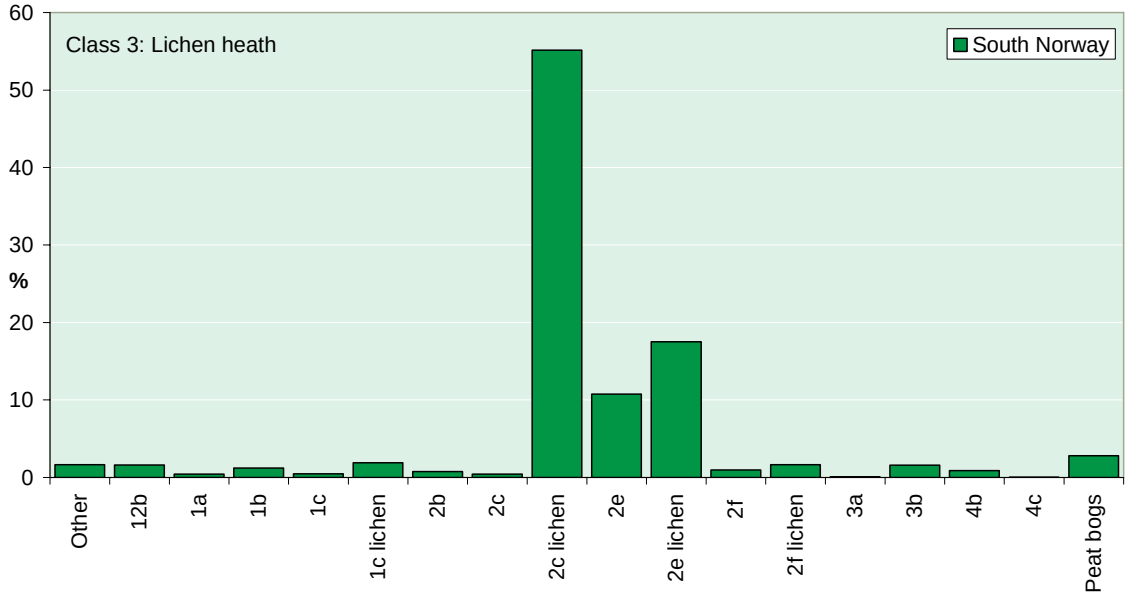


Figur 34. National coverage of the AR-FJELL class 3, Lichen heath.

This class covers 3 % of the total area in AR-FJELL (4 % of the area in south Norway and 1 % of the area in North Norway). The class is dominated by lichen heath vegetation with lichen coverage above 50 % in South Norway. More than 20 % of the other vegetation types represented in this AR-FJELL class have lichen coverage over 25 %. The frequency of the lichen vegetation class in the area used in this analysis in South Norway is much higher (10 %) than the average for South Norway.

The class is marginal in North Norway and the content of the class in Troms County is totally dominated by alpine meadow communities, forest and peat bogs. The lichen coverage is generally small in Troms County and the fact that AR18X18 only was available for this county in North Norway makes it impossible to evaluate the class for North Norway.

Lichen heath is mainly found in dry, low-alpine continental mountain areas, around 800 to 1200 meters above sea level in South Norway. The lichen cover usually gets thinner in mid-alpine zone and the class is less frequent in these areas. Lichen heath is important winter grazing areas for reindeer. Destruction of the lichen cover in areas with high pressure from reindeer grazing can change these areas from AR-FJELL class 3 to AR-FJELL class 2 Sparse vegetation or class 4 Intermediate vegetation.



Figur 35. Vegetation distribution of the AR-FJELL class 3: Lichen vegetation

Figur 36. Lichen rich dwarf shrub heath near Mårvatn. Vinje, Telemark County. Photo: Michael Angeloff.

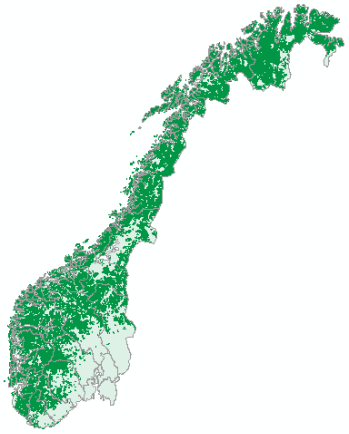
Figur 37. *Cladonia stellaris* dominated alpine calluna heath. Rendalen. Hedmark County. Photo: Michael Angeloff.

Figur 38. Lichen heath. Rendalen Hedmark County. Photo: Yngve Rekdal.

Figur 39. Large areas with lichen heath. Tolga, Hedmark County. Photo: M. Angeloff.

11. CLASS 4: INTERMEDIATE VEGETATION

Expected land cover: Areas with continuous plant cover and low or moderate biomass production. The plant cover is continuous but the green foliage still sparse. The class includes dry heather- and grass-heaths as snow beds with low productivity. The content of rocks and boulder fields is below 25% of the area. In low-alpine mountain areas as well below the tree line, the class also contains dry heather heaths, coastal heaths, Calluna heath and *Trichoporum cespitosum-damp* dominated damp heath. At higher altitudes, the class contains dry grass heath and snow-beds.

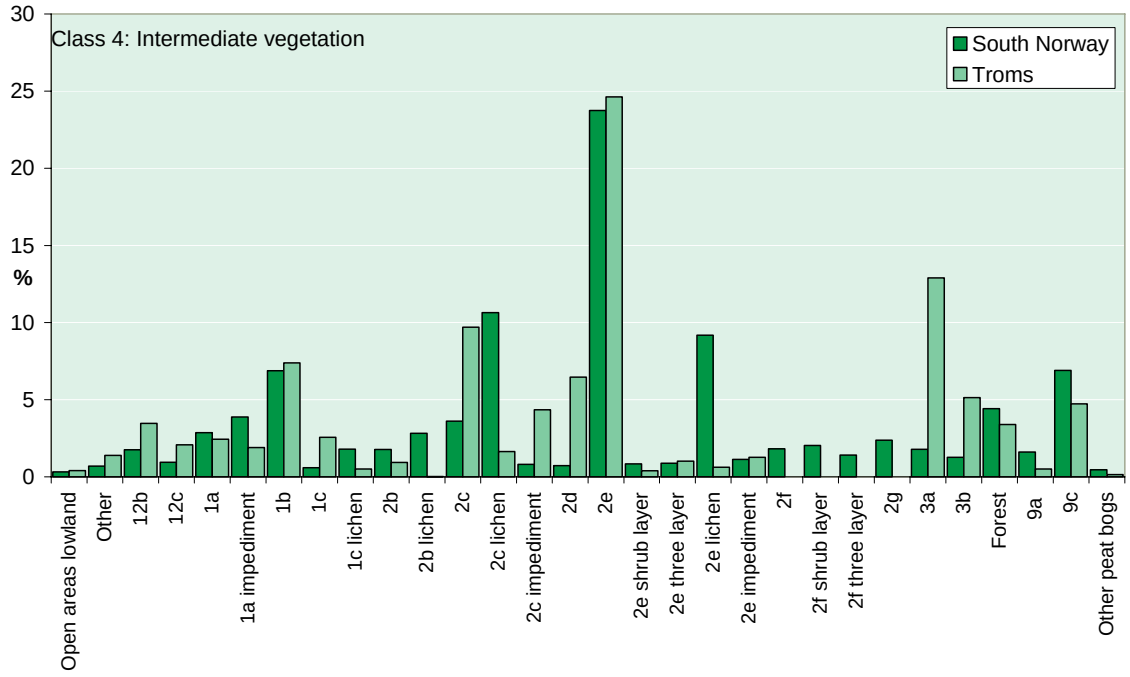


Figur 40. Distribution of the AR-FJELL class 4, Intermediate vegetation.

This class covers 30 % of the AR-FJELL area, 26 % in South Norway and 30 % in North Norway. In South Norway, the class is dominated by alpine heath communities (65 %). Different types of dwarf shrub heat (36 %) and lichen heath (15 %) are most common. The main vegetation types represented in this AR-FJELL class in South Norway has continuous vegetation coverage, with low to moderate productivity of plant material. Vegetation types with more than 50 % impediment cover 9 % of the area, and vegetation types with more than 25 % coverage of light lichen spices cover 25 % of the class in South Norway.

A similar pattern is present for this class in Troms County. Here, around 50 % of the area is covered by alpine heath communities. The alpine meadow communities cover another 18 % and 13 % of the area is populated with various vegetation types with more than 50 % impediment. The lichen coverage is generally low.

The intermediate vegetation class is most common in the low mountain areas, but is also frequent in the mid-alpine areas.



Figur 41. Vegetation distribution of AR-FJELL class 4: Intermediate vegetation.

Figur 42. Dry drwarf shrub heath. Målselv. Troms County. Photo: Per Bjørklund.

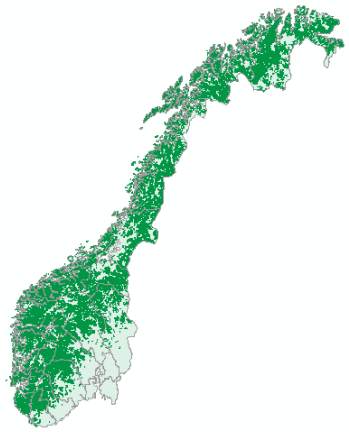
Figur 43. Dry grass heath. Sel, Oppland County. Photo: Yngve Rekdal.

Figur 44. Costal heath. Tranøy. Troms County. Photo: Finn-Arne Haugen.

Figur 45. Alpine calluna heath. Vinje, Telemark County. Photo: Johnny Hofsten.

12. CLASS 5: VIGOROUS VEGETATION

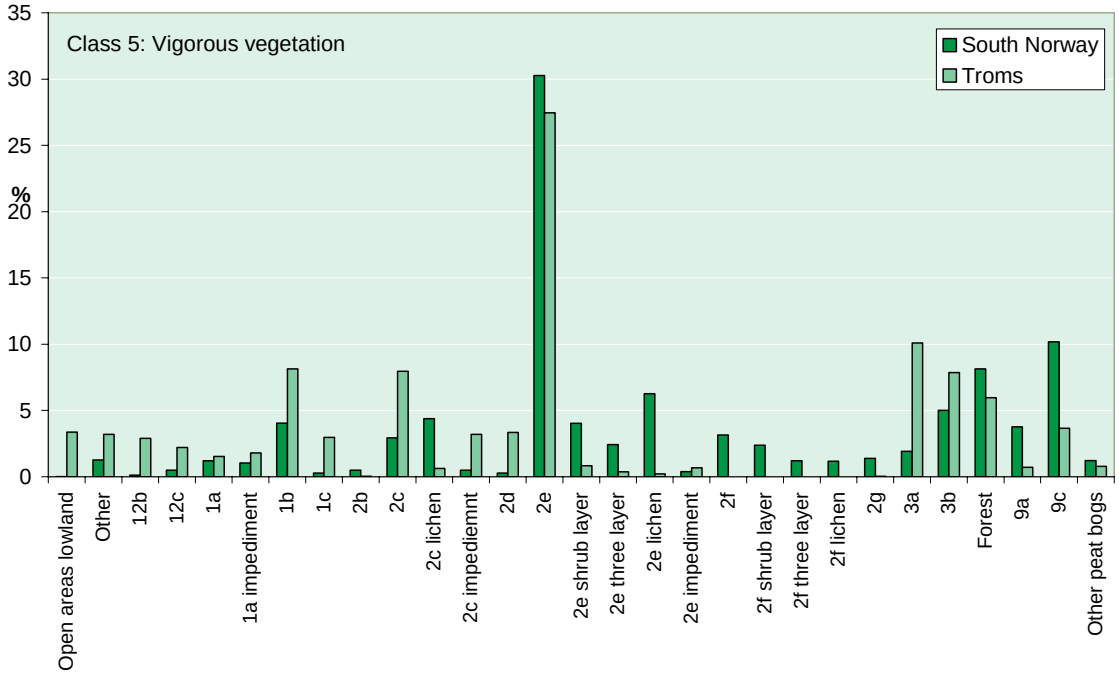
Expected land cover: Productive areas with natural vegetation, but without tree cover. The vegetation is continuous and the areas have lush, vigorous green foliage. Typical species are *Phyllodoce*, dwarf birch, grass, herbs and frondage. Areas with tree coverage of birch can also be found in this class even though the undercover is meagre. The content of rocks and boulder fields is low, but increases with altitude, and can reach 25%.



Figur 46. National distribution of the AR-FJELL class 5, Vigorous vegetation.

This class covers 30 % of the AR-FJELL area and is the dominant class in the south (36 % in South Norway and 23 % in North Norway). Dwarf shrub heath is the most common vegetation type, covering 43 % of the area in South Norway and 30 % in Troms County. The vegetation types in this class have continuous vegetation coverage and relatively high productivity. Vegetation types with shrub or scattered tree layers covers 10 % of the class area in South Norway (Troms County 1%). The vigorous vegetation types, such as the alpine meadow communities, forest and fens cover up 30 % of the area in this class in South Norway and 29 % in Troms County. Vegetation types with more than 50 % bare rocks and boulder field form only a small amount of the area in South Norway (3 %).

This class is most common in the low mountain areas and open areas in the lowland. Lush snow beds may be included at higher altitudes. The class is expected to appear in mosaic with class 4.



Figur 47. Vegetation distribution of the AR-FJELL class 5: Vigorous vegetation.

Figur 48. Dwarf shrub heath along Stakkedalen, Byggland, Aust-Agder County. Photo: Yngve Rekdal.

Figur 49. Fresh Dwarf shrub heath, Kvænangen, Troms County. Photo: Finn-Arne Haugen.

Figur 50. Tall herb meadow with Salix shrub. Nore Uvdalm, Buskerrud County. Photo: Michael Angeloff.

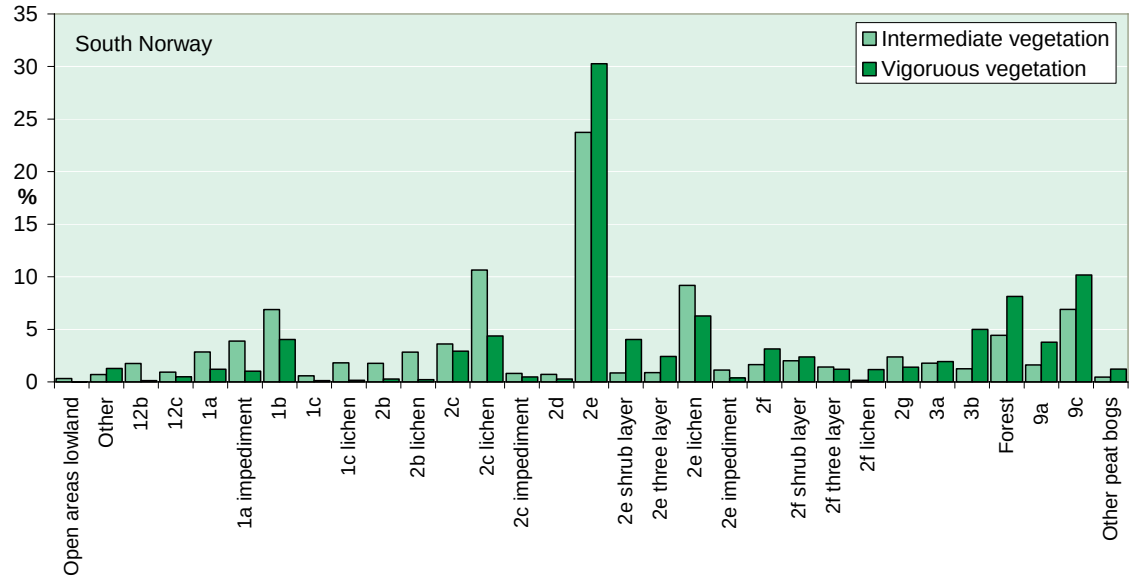
Figur 51. Strongly grazed tall herb meadow, Ullensvang, Hordaland County. Photo: Johnny Hofsten.

13. AR-FJELL CLASS 4 VS. AR-FJELL CLASS 5

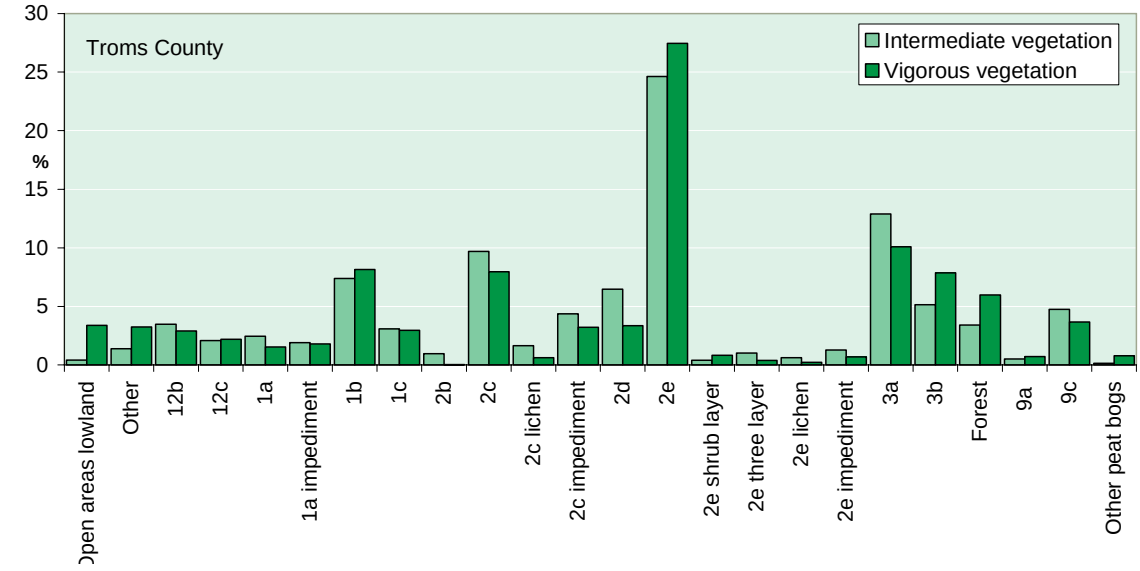
Comparison of the AR-FJELL class 4 (Intermediate vegetation) and 5 (Vigorous vegetation) in South Norway shows that the intermediate vegetation class has a higher content of vegetation types with lichen coverage above 25 %, more snow-bed vegetation and less alpine meadow communities and forest than the Vigorous vegetation class (Figure 53). The vigorous vegetation class has a higher content of dwarf shrub heath and alpine Calluna heath with shrub and tree layers than the intermediate class. The vegetation distribution seen in Figures 53 and 54 is as expected (in line with ELC), given the methods used in the AR-FJELL productions.

Figur 52. Mosaic of dwarf shrub heath and grazing land in Bjarkøy, Troms County. This area was classified as Vigoruos vegetation in AR-FJELL. Photo: Finn-Arne Haugen.

The difference between the intermediate vegetation class and the vigorous vegetation class with respect to land cover content is not as distinct in Troms County as in South Norway (Figure 54). There is a tendency for vegetation types with short plants in the Intermediate vegetation class (class 4: 45 %, class 5: 41 %) and for vegetation types with taller plants in the Vigorous vegetation class (class 4: 55 %, class 5: 59 %). The difference between the Intermediate and the Vigorous vegetation in Troms County in terms of vegetation content is, however, far from clear and should be examined in further detail.



Figur 53. Vegetation distribution of class 4 and class 5 in South Norway.

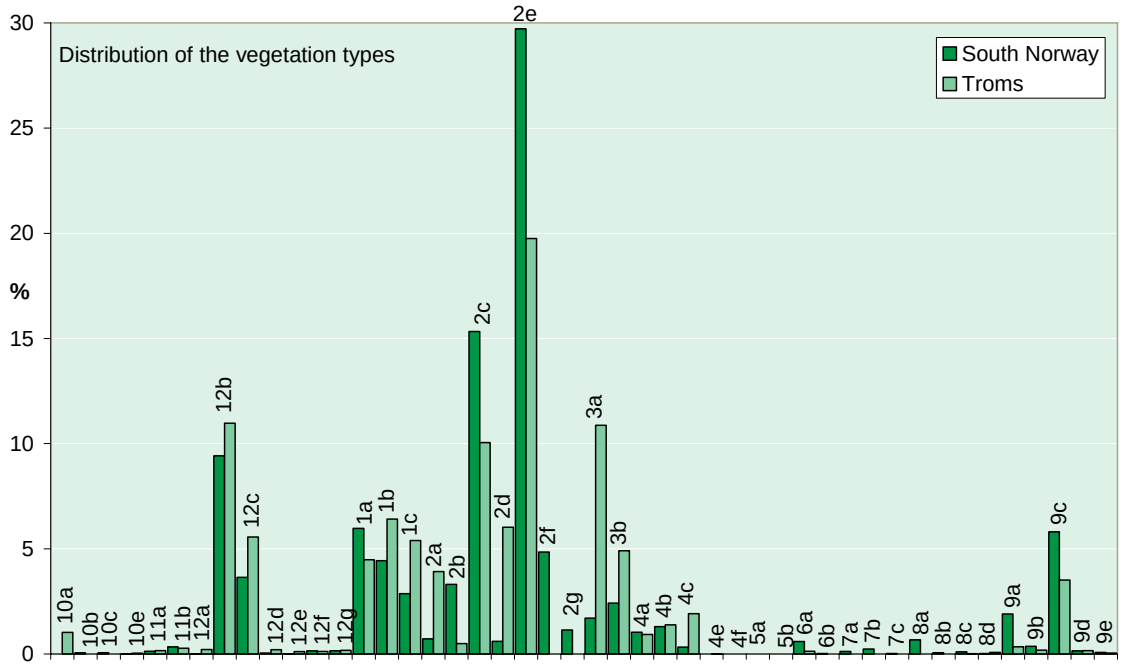


Figur 54. Vegetation distribution of class 4 and class 5 in Troms.

14. DISTRIBUTION OF VEGETATION TYPES IN THE AR18X18 SAMPLE

Figure 55 shows the distribution of the vegetation types in the available AR18X18 samples inside the AR-FJELL area, in those parts of Norway where AR18X18 were available (see Figure 13).

Dwarf shrub heath (2e[4]) is the most frequent vegetation types in these mountain areas. This is the case both in South Norway (30 %) and Troms County (20 %). Alpine heath (2a-2g) is the most frequent vegetation community (South Norway: 56 % and Troms County: 40 %). Alpine meadow communities (3a-3b) are much more common in Troms County than in South Norway (South Norway: 4 % and Troms County: 16 %). Lichen heath (2c) and dwarf shrub heath (2e) are more frequent in South Norway, while mountain avens heath (2d) and low herb meadow (3a) are most frequent in Troms County.



Figur 55. Distribution of the vegetation types in the AR18X18 samples in the AR-FJELL area.

The distribution of AR-FJELL classes within each of the vegetation types is shown in Figures 56 to 58. Only vegetation types with coverage of more than 1 % are represented in the Figures and all the different vegetation types describing forest are merged into a single class. The overall picture is that impediment and snow-bed vegetation (Figure 56) in most cases are mapped as Abiotic and Sparsely vegetated areas in AR-FJELL. Alpine heath communities (Figure 57) are distributed across all the different AR-FJELL classes and the alpine meadow, forest and peat bogs (Figure 58) are mapped as Intermediate and Vigorous vegetation in AR-FJELL.

Bare rock (12b) and boulder fields (12c) are mostly mapped as Abiotic areas in AR-FJELL. Moss snow-bed (1a) is mostly found as Abiotic areas and Sparse vegetation in AR-FJELL, but the amount of snow-beds falling in the Intermediate and Vigorous vegetation class is still higher than

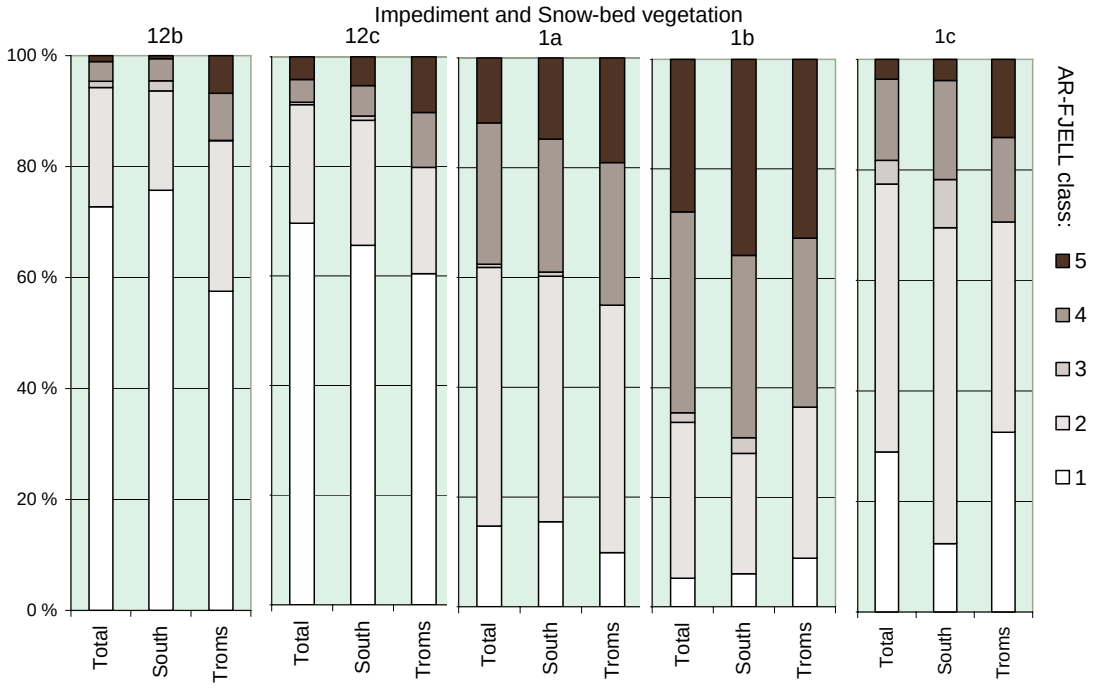
[4] Classification codes used in the AR18X18 field survey are used in the Figures and inserted in the text for reference

expected (see multiple comments above). The sedge and grass snow-bed (1b) is one of the most vigorous vegetation types at mid- and high altitudes. Much of this area is mapped as Intermediate and Vigorous vegetation in AR-FJELL.

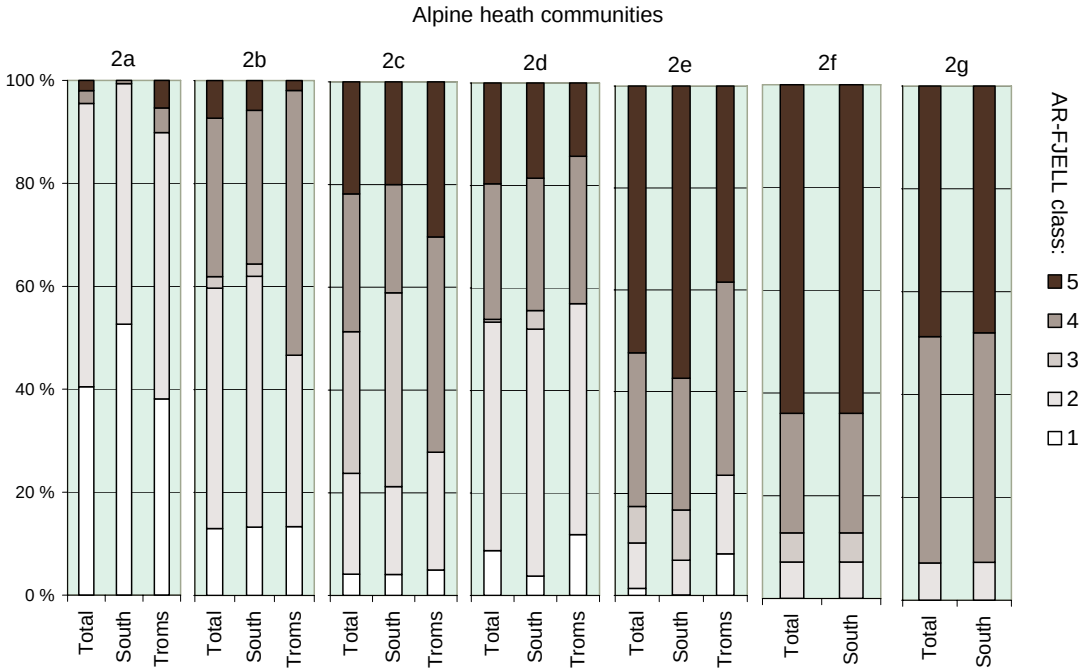
To find the lichen heath (2c) in Troms County mapped as Intermediate and Vigorous vegetation was unexpected, but the class is marginal in Troms County. A meaningful assessment of lichen heath in North Norway can only be carried out when AR18X18 is available for Finnmark County.

The vegetation types in the categories alpine meadow communities, forest and peat bogs are reasonably mapped as Vigorous or Intermediate vegetation in AR-FJELL. The low herb meadow (3a) is a vegetation type containing herbs with high demand for nutrition, but the vegetation layer is short. The herbs growing in this vegetation type are rich in the sense that they have high demand for nutrition, but the chlorophyll saturation is not necessarily high in the plant community as such. It is also difficult to get an optimal time window for acquisition of satellite images to intercept the low herb meadow class. Satellite images acquired too early in the season results in problems with snow coverage in the mountains. Images taken too late in the season presents problems with shadows in valleys and other steep slopes, together with the fact that the growing season is over and the chlorophyll saturation is lower than earlier in the season. Considerable areas with low herb meadows are found inside the class Sparse vegetation in AR-FJELL.

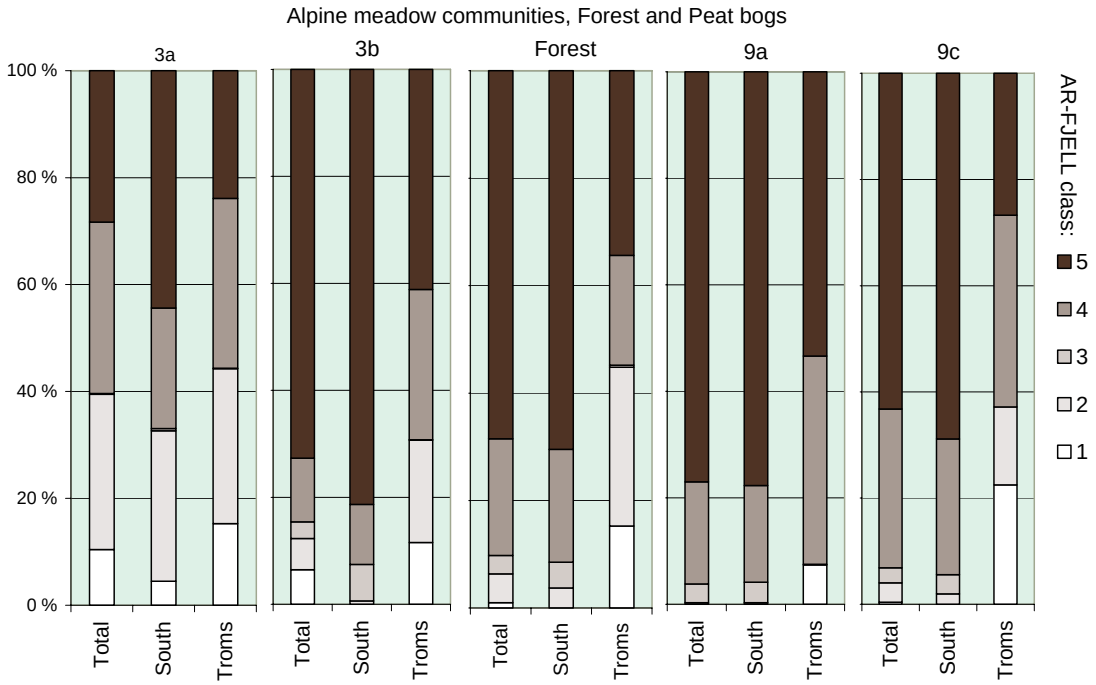
Areas covered by shadows in the satellite image were automatically assigned to AR-FJELL class Abiotic. The effect is high in Troms County where mountains are alpine and the sun-angle is low because the region is located at high latitudes. The areas mapped as Abiotic in AR-FJELL therefore constitute a high percentage of several vegetation types in Troms County. But the shadow effect is not the only explanation of the unexpected results for Troms County since Tall herb meadow (3b) as well as forest types also frequently are found in the Sparse vegetation class (Figure 58).



Figur 56. Distribution of AR-FJELL classes in the vegetation types impediment and snow-bed vegetation.



Figur 57. Distribution of AR-FJELL classes in the vegetation types in alpine heath communities.



Figur 58. Distribution of AR-FJELL classes in the vegetation types in alpine meadow communities, forest and peat bogs.

15. CONCLUSION

Several factors (eg elevation, geology, soil, climate, distance to the sea, latitude) determine the distribution of the vegetation types in the Norwegian mountains (Moen 1998). Changes are frequent and boundaries between different types of land cover are often elusive. Land cover mapping is therefore an abstraction showing a generalised and simplified picture of a complex reality. This is even more so when the land cover map is made from interpretation of satellite images. Satellite images can not be used to observe and determine plant species. Neither can they be used to delineate and map plant communities or vegetation classes.

Satellite images can, however, be used to map areas with similar spectral appearance. Areas with similar spectral appearance can be expected to exhibit some degree of homogeneity in terms of land cover. Our aim is therefore not to map a priori defined vegetation classes from satellite images, but rather to make a map of classified spectral values and subsequently to describe and understand these classes in terms of land cover content.

AR-FJELL is, as described in chapter 2, based on semi-automatic satellite image interpretation, were pixels, in the satellite images, with similar “colour” are merged together into polygons. Each polygon is then assigned to one out of five classes based on the spectral signature. This assignment of the polygons into classes is neither “correct” nor “incorrect”. It is just a fact. The problem of “correctness” occurs when the classes are labelled with descriptive names, eg Abiotic, Sparse vegetation etc.

Still, this labelling does have justifications. The classification of each polygon is based on spectral values reported by many scientists as correlated to the photosynthetic activity (e.g. Sellers 1986, Eidenshink 1992). Based on the experience of field surveyors Class 1 was labelled Abiotic and Class 5 was labelled Vigorous vegetation. Along the gradient between these extremities, Class 2 was labelled Sparsely vegetated and Class 4 Intermediate vegetation. The remaining Class 3 was labelled Lichen. These labels are used only for convenience and do not imply any precise mapping of land cover classes.

The overlay with AR18X18 has shown that the content of each of the AR-FJELL classes is heterogeneous. Each AR-FJELL class does contain many different vegetation types, and the composisition varies geographically. It is the composition and variation within the AR-FJELL class, and not the short label, that is the factual definition of the class.

The AR-FJELL dataset evaluated in this report is the first complete land resource map for the mountain areas in Norway. The methodology used for the production of the map was developed during the production period following a tight time schedule. The classes are essentially groups of spectral values, but these are thought to be related to ground vegetation cover and the classes are labelled accordingly.

The study has shown that the AR-FJELL classes are related to vegetation as indicated by the class labels. But the labels are clearly general and the result is not in any respect a precise vegetation or land cover map. The study has also shown that the vegetation profiles for Troms County are more heterogeneous than the profiles for South Norway. This complicates the use of the chosen labels. A revision of AR-FJELL is required in areas with poor satellite coverage. There is also a need for evaluation of the remaining areas of AR-FJELL when more AR18X18 surveys are available. There are still challenges associated with altitude, shadows and areas with high precipitation in the coastal areas.

16. REFERENCES

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17. APPENDIX I: AR-FJELL CLASS LABELS

AR-FJELL calls code, labels and short description ("Expected land cover" – ELC)

Class	Code	Name	Contents
1	1	Abiotic	Areas with more than 75 % abiotic surface. The abiotic component may be bare rock, boulders, stones, gravel and sand. The vegetation is scant, but small areas of vegetation can be present. The productivity of this vegetation can be highly variable and very productive areas can be present, but the productivity is usually low.
2	2a	Sparse vegetation	Areas with scanty vegetation, either as scattered patches or as a continuous but meagre vegetation cover. More than 25% of the area is covered with vegetation. Meagre vegetation types with little green foliage and low productivity dominate in areas belonging to this class: Lichen heath with scanty lichen coverage, Dry grass heath, Mid-Alpine heath or snow beds in mosaic with rock outcrops or uncompacted material. Snow beds melting late in summer are also found in this class.
3	2c	Lichen	Areas with thin snow cover and low productivity dominated by light coloured lichen species. The most important lichen species is *Flavocetraria nivalis*, *Cladonia stellaris* and *Cladonia* species. A thick layer of lichen covers at least 50% of the surface. Occurrences of bare rock and boulder fields can in some places be considerable. The dominating vegetation type is lichen heath, but meagre heather heath and dry grass heath with a considerable content of lichen at the ground layer are also found in this class.
4	2b	Intermediate vegetation	Areas with continuous plant cover and low or moderate biomass production. The plant cover is continuous but the green foliage still sparse. The class include dry heather- and grass-heaths as snow beds with low productivity. The content of rocks and boulder fields is below 25% of the area. In low-alpine mountain areas as well below the tree line, the class also contain dry heather heaths, coastal heaths, Calluna heath and *Trichoporum cespitosumdamp* dominated damp heath. At higher altitudes, the class contains dry grass heath and snowbeds.
5	3	Vigorous vegetation	Productive areas with natural vegetation, but without tree cover. The vegetation is continuous and the areas have lush, vigorous green foliage. Typical species are *Phyllodoce*, dwarf birch, grass, herbs and frondage. Areas with tree coverage of birch can also be found in this class even though the undercover is meagre. The content of rocks and boulder fields is low, but increases with altitude, and can reach 25%.

18. APPENDIX II: NFLI VEGETATION TYPES

Short description of selected vegetation types from the Norwegian Forest and Landscape Institute system for vegetation and land cover mapping (Rekdal and Larsson 2005). The system consists of 54 land cover classes (45 of these are vegetation types). Only classes used in the present examination of AR-FJELL are included here.

Snow-bed vegetation	
1a	Moss snow-bed
	Found on wind-protected places and in depressions with extreme snow conditions, often at high altitudes. Snow covered until August. Short growing season allows only very few plant species to survive. Moss-species and dwarf willow are the dominating species. The plant cover is interrupted by gravel, stones and blocks.
1b	Sedge and grass snow-bed
	Found on places with a low to medium content of nutrition in the soil and less extreme snow condition than the preceding type. The snow may melt in July. This vegetation type consists of several formations where stiff sedge, mat grass, wavy hair grass and sweet vernal grass may dominate depending on the growing conditions. The cover of dwarf willow may be substantial.
1c	Stone polygone land
	Mid-alpine vegetation on places with high frost activity. Stone polygon formation and areas with solifluction are common. The snow cover is sparse, but melts late in the summer due to the high altitude. The vegetation is sparse and scattered. Plant species from snow-beds and barren ridges will meet in this vegetation type.
Alpine heath communities	
2a	Mid-alpine heath
	Mid-alpine vegetation on exposed areas. The ground is strongly influenced of frost and the snow cover is sparse. The vegetation coverage is scattered and sparse. Species from barren ridges and snow-beds are meeting under harsh conditions in this vegetation type.
2b	Dry grass heath
	Heath community on mountain plateaus in the mid-alpine zone with little to medium snow cover. The vegetation cover consists of hardy species of grasses and sedges, often with a bottom layer of lichen species. A specific formation with good water supplies for parts of the growing season is given the additional symbol m. Stiff sedge completely dominates the field layer in this formation, together with a dense moss-cover in the bottom layer. Species indicating favourable nutritive and calcimorph conditions may occur.
2c	Lichen heath
	Found on barren ridges and other exposed areas with shallow soil, poor in plant nutrition. The snow cover is thin during the winter. The vegetation consists of low growing hardy species resistant to frost and wind, mostly heather species and chionofobic lichens.
2d	Mountain avens heath
	Community corresponding to the lichen heath but found on calcimorph soil. May also occur on areas with better snow cover than the lichen heath. In addition to species from the lichen heath, many demanding low herbs and sedges can be found here.
2e	Dwarf shrub heath
	Common vegetation type in the mountains, infrequent on open areas under the timberline.

	Occur in leesides with moderate plant nutrition, and places with better snow cover than the lichen heath. The vegetation is dominated of bilberry, crowberry, wavy hairgrass and dwarf birch.
2f	Alpine calluna heath
	Occurs on barren ridges and other well drained places in the low alpine zone, normally in areas with high precipitation. The soil is poor in nutrition and often shallow. The common species is heather while grasses and herbs occur less frequently.
2g	Alpine damp heath
	Occurs in places with high precipitation. The vegetation types appear on shallow top soil influenced by soil water or oligotrophic soil with thick raw humus. The vegetation consists of bog- and solid ground species.
Alpine meadow communities	
3a	Low herb meadow
	Meadow-like vegetation type, with short herbs (approx. 15 cm). Usually some kind of snow-beds. The plant cover shows great diversity with many demanding species of herbs, grasses and sedges. Most common on calcareous rocks.
3b	Tall herb meadow
	Luxuriant plant community with great diversity, appearing along rivers and brooks, hillsides and depressions with trickling oxygen-rich water. Willows, tall forbs, ferns and grasses are dominating.
Deciduous forest	
4a	Lichen- and heather birch forest
	Birch forest with low productivity and low species diversity, appearing on shallow soil or coarse deposit. Sparse tree layer with multiple, bent trunks. Lichen and drought.
4b	Bilberry birch forest
	Birch forest with intermediate productivity. Bilberry dominate in the field layer, besides other heather species, less demanding herbs and grasses can be found with dense moss carpet. Small ferns dominate in areas with ample water supply.
4c	Meadow birch forest
	Birch forest with the highest productivity and high plant species diversity. Found as two sub types: 1. Low herb forest: in fields rich in nutrition and limited water supply. Includes plant species demanding nutrition and warm local climate. 2. Tall forb forest: in hillsides and depression with trickling oxygen rich water. Includes tall forbs, ferns and grasses.
Peat bogs	
9a	Bog
	Oligotrophic bog, with retarded plant decay. Tussocking is common. Vegetation dominated by dwarf birch, cotton grass, cloudberry, heather species and sphagnum.
9b	Deer-gras fen
	Fen dominated by deer grass and otherwise poor on species diversity. The top layer is firm and made up by peat mosses. Common in regions with high precipitation.
9c	Fen
	Fen influenced by soil water. The composition of plant species and production will rely on the content of nutrition in the water. Grasses and sedges together with brown coloured mosses of peat mosses dominate.

Non productive areas	
12a	Barren land
	Area composed of gravel, sand and exposed soil. Vegetation coverage less than 25 %.
12b	Boulder field
	Area dominated of gravel, rocks and boulders. Less than 25 % vegetation coverage.
12c	Exposed bedrock
	Area dominated of bare rock. Vegetation coverage less than 25 %.

Supplementary information observed in the AR18X18 sample and used in the AR-FJELL class profiles (chapter 5.2 to 5.6):

Impediment	
⟠	50-75% rocks and boulders
⩓	50-75% bare ground
Vegetation	
~	Unproductive areas (12a, b, c) with 10-25% cover of vegetation
Lichen	
v	25-50% cover of lichens
x	More than 50% cover of lichens
Shrub layer	
⊂	25-50% cover of Salix sp.
s	More than 50% cover of *Salix* sp.
o))	Shrub, underbush of deciduous trees, more than 50 % coverage
Tree layer	
*	Norway spruce
+	Scots pine
o)	Deciduous forest, mainly mountain birch
$	*Salix* sp. in the forest layer
£	Coat willow in tree layer
o	Grey alder in tree layer
]	25-50% cover of trees

19. APPENDIX III: SATELLITE IMAGES

Satellite images used in the segmentation and manual interpretation of AR-FJELL.

Usage	Priority	County	Satellite	Year	Month	Scene
Segmentation	1	Troms	L7	2000	7	L7195_11_27juli2000
Segmentation	1	Hordaland	L5	2003	8	L5_199_018_09aug03
Segmentation	2	Troms	S4	2006	8	S4_46-207_20aug2006
Segmentation	2	Agder	L5	2003	8	L5199_19_9aug2003
Segmentation	3	Troms	L7	2001	8	L7198_11_20aug2001
Segmentation	3	Oppland	L7	1999	7	L7_198_017_NOR2_30jul99
Segmentation	4	Nordland	L7	2001	6	L7_199_012_NOR3_24jun01
Segmentation	4	Oppland	L5	1997	8	L5_200_017_15aug97
Segmentation	5	Troms	L7	1999	8	L7_198_012_15aug99
Segmentation	5	Sogn og Fjordane	S4	2006	7	S4_34-225_19juli2006
Segmentation	6	Nordland	L7	1999	9	L7_199_013_NOR3_07sep99
Segmentation	6	Sogn og Fjordane	S4	2007	8	S4_33-224_22aug2007
Segmentation	7	Hordaland	L7	1999	8	L7_201_018_NOR2_04aug99
Segmentation	7	Nordland	L7	2002	9	L7_198_014_NOR3_08sept02
Segmentation	8	Finnmark	L7	2000	7	L7193_11_29juli2000
Segmentation	8	Sør-Trøndelag	L7	1999	8	L7199_16_6aug1999
Segmentation	9	Finnmark	L7	2000	7	L7_195_010_NOR5_27jul00
Segmentation	9	Sør-Trøndelag	L5	1998	8	L5_199_015_11aug98
Segmentation	10	Finnmark	L7	1999	9	L7_191_10_15sep99
Segmentation	10	Sør-Trøndelag	L7	2002	8	L7198_16_23aug2002
Segmentation	11	Finnmark	L7	1999	9	L7_191_11_15sep99
Segmentation	11	Møre og Romsdal	L7	2000	7	L7_201_016_NOR2_21jul00
Segmentation	12	Sogn og Fjordane	L7	2000	7	L7_201_017_NOR2_21jul00
InterpretUTM32		Møre og Romsdal	L7	2001	6	L7_201_015_NOR2_22jun01
InterpretUTM32		Rogaland	L7	2000	8	L7b_200_019_29aug00
InterpretUTM33		Nordland	L5	1994	7	L519912_31juli1994
InterpretUTM33		Nordland	S4	2006	8	S4_42-211_20aug06
InterpretUTM33		Nordland	S4	2006	8	S4_42-208_15aug06
InterpretUTM33		Nordland	IRS	2005	7	IRS_1020_19jul2005
InterpretUTM33		Troms	L7	2000	7	L7_197_012_NOR3_25jul00

InterpretUTM33		Troms	L7	1999	9	L7_197_12_25sept1999
InterpretUTM33		Troms	L7	1999	9	L7_197_11_25sept1999
InterpretUTM33		Troms	L7	1999	9	L7_197_11_9sept1999
InterpretUTM34		Finnmark	IRS	2005	7	IRS1006_01jul2005
InterpretUTM34		Troms	S4	2006	8	S4_42-207_15aug06
InterpretUTM35		Finnmark	L7	2000	9	L7_193_010_NOR5_15sep00
InterpretUTM35		Finnmark	L7	2000	7	L7_193_012_NOR5_29jul00
InterpretUTM35		Finnmark	IRS	2005	7	IRS1017_06juli2005
InterpretUTM35		Finnmark	IRS	2005	7	IRS1009_02jul2005