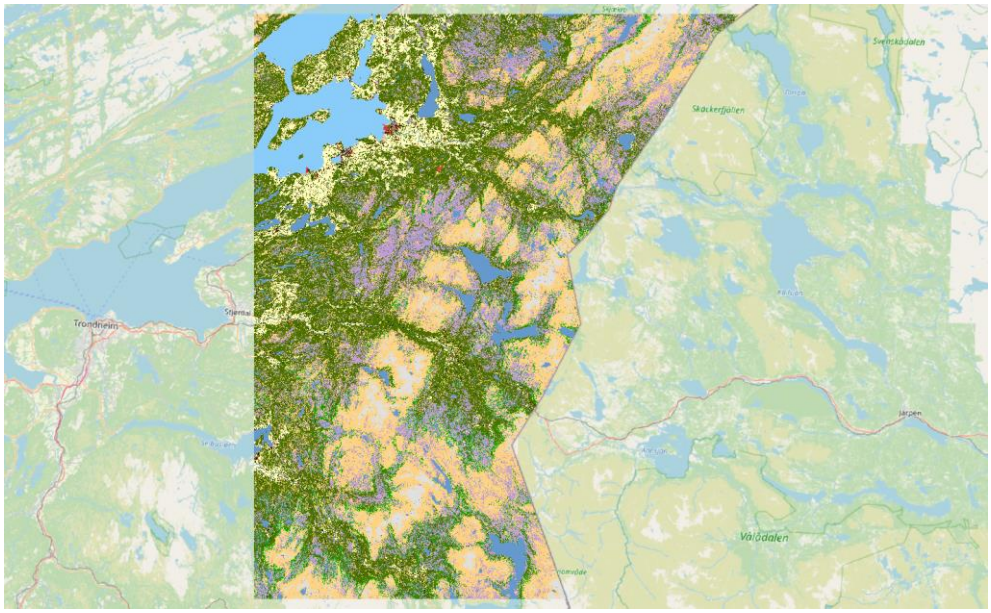
M-2574|2023

NMD TEST MAPPING IN NORWAY

Final report



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Contents

Summary

Nationella marktäckedata (NMD) is a 10x10 meter resolution land cover product covering all of Sweden that was produced by Metria AB with primary funding provided by The Swedish Environmental Protection Agency (SEPA, Swe: Naturvårdsverket) with supplemental funding by several other Swedish government agencies.

During 2022 Miljødirektoratet in Norway approached Naturvårdsverket and Metria to gauge the possibility of producing an similar map for Norway. Metria surveyed the data available for such a project and concluded that while it seemed possible to produce a Norwegian NMD-version given the infrastructure of geographical data in Norway, a test mapping should be conducted to better determine the consequences of switching data sources, which is some cases are not comparable across the national boundary.

To this end, two test areas covering a combined area of roughly 12 000 km^2 were mapped with NMD methods by Metria using available supporting data in Norway. The results of the test mapping shows that the NMD concept can indeed be transferred to Norway and produce land cover maps that on a look-and-feel basis provide good results. However, if continuing with similar mapping efforts in Norway as a whole, further method development and greater stakeholder involvement is essential to reach similar quality levels that are found in the Swedish product, which has gone through years of iterative processes to reach its current state.

Abbreviations

DEM	Digital elevation model
LiDAR	Light detection and ranging (laser measured elevation data)
NMD	Nationella marktäckedata (Eng: National land cover data)

Swedish terms used in report

Agenda för landskapet	Agenda for the landscape
Fjällnära gräns	Alpine forest boundary
Lantmäteriet	The Swedish national mapping agency
Marktäckedata	Land cover data
Naturvårdsverket	Swedish Environmental Protection Agency (SEPA)

Background

During the spring of 2022 Metria AB in Sweden was tasked by Miljødirektoratet, the Norwegian Environment Agency, to evaluate the possibility of producing a land cover map of Norway using similar methods that were developed to produce the Swedish product "Nationella marktäckedata" (Eng: National land cover data), or NMD. NMD was produced by Metria and financed by a consortium of Swedish government agencies led by Naturvårdsverket (Eng: The Swedish Environmental Protection, Agency, SEPA).

Metria performed a survey of available data sources and concluded that while a land cover mapping of Norway similar to Sweden's would be possible to perform, a test mapping of one or more selected areas should be completed to further evaluate additional data requirements and potential issues that may arise if Norway as a whole were mapped with NMD methods. A report describing the preparatory work performed as well as a more in-depth description of NMD can be found on Miljødirektoratet's website (Metria AB, 2022). Readers of this report who have not read the preparatory report are encouraged to do so first as it provides necessary context for the work described here. A technical report describing the Swedish NMD product available from Naturvårdsverket (Jönsson, Ahlkrona, Keskitalo, Häljestig, & Eriksson, 2019) also provides a comprahensive background to the NMD concept.

During the fall of 2022, Miljødirektoratet and Naturvårdsverket agreed to jointly fund the test mapping Metria had previously suggested. This was arranged as a part of the project Agenda för landskapet[1] which aims to improve and expand the Swedish version of NMD and promote cross-border cooperation for land cover mapping in Northern Europe.

The NMD concept

The philosophy behind the NMD-concept is to combine the best thematic sources available in Sweden with multispectral analysis of satellite data and elevation-derived variables collected from LiDAR-scans to generate high-quality land cover data. Reference data plays an important role in training classification models and verifying results. In the latest version of NMD, increased focus has been put on automation and machine learning.

NMD is an evolving family of products with future development targets that will improve its accuracy further and expand its content. The focus of the test mapping was to implement the NMD version that has been produced for all of Sweden; version 1.1, also called NMD 2018 in some sources, which has the reference year

[1] https://www.vinnova.se/p/agenda-for-landskapet2/

Retrieved 2022-03-31.

2018. This means that the data sources used to produce NMD 1.1 were current as close to 2018 as possible.
Version 2.0 of NMD has been produced as a test in selected areas of Sweden. Version 2.0 is slated to be the basis of the next effort to map all of Sweden, currently planned for production during 2023-24. The new version contains more thematic classes and improves the mapping accuracy by increasing the use of satellite data in time series and applying machine learning methods.

NMD version 1.1 consists of a series of data products that describe land cover and for some classes, such as arable land, land use in Sweden. The main component is the **base layer**, a raster layer with a spatial resolution of 10x10 meters that contains the main thematic classes. Creating a Norwegian version of the base layer is the focus of the test mapping.

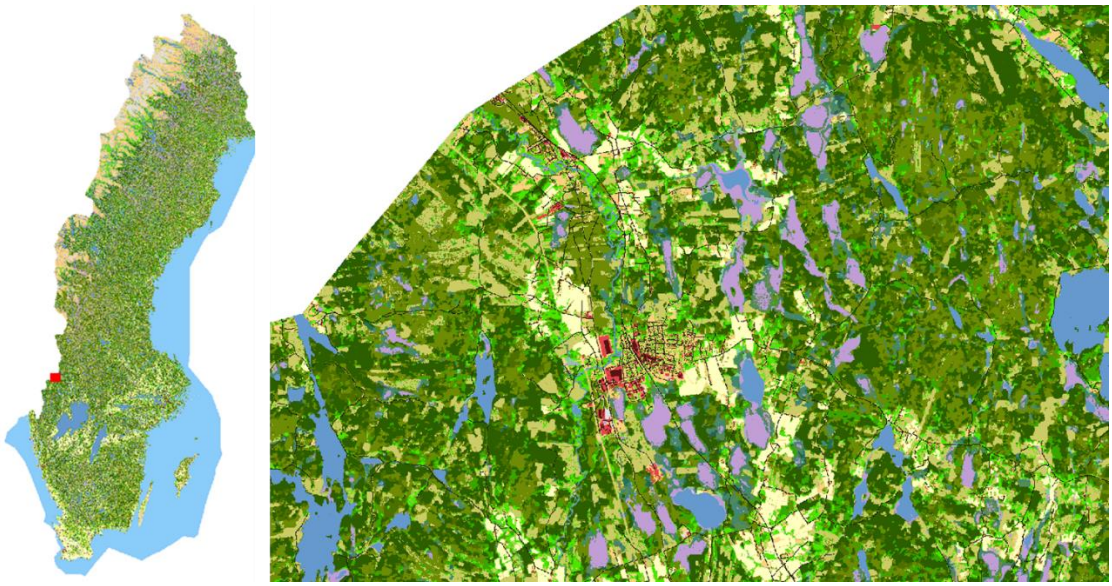

Figure 1: Base layer in raster format from version 1.1 (reference year 2018) of NMD with a zoomed in view on a part of the Swedish county Värmland next to the Norwegian border.

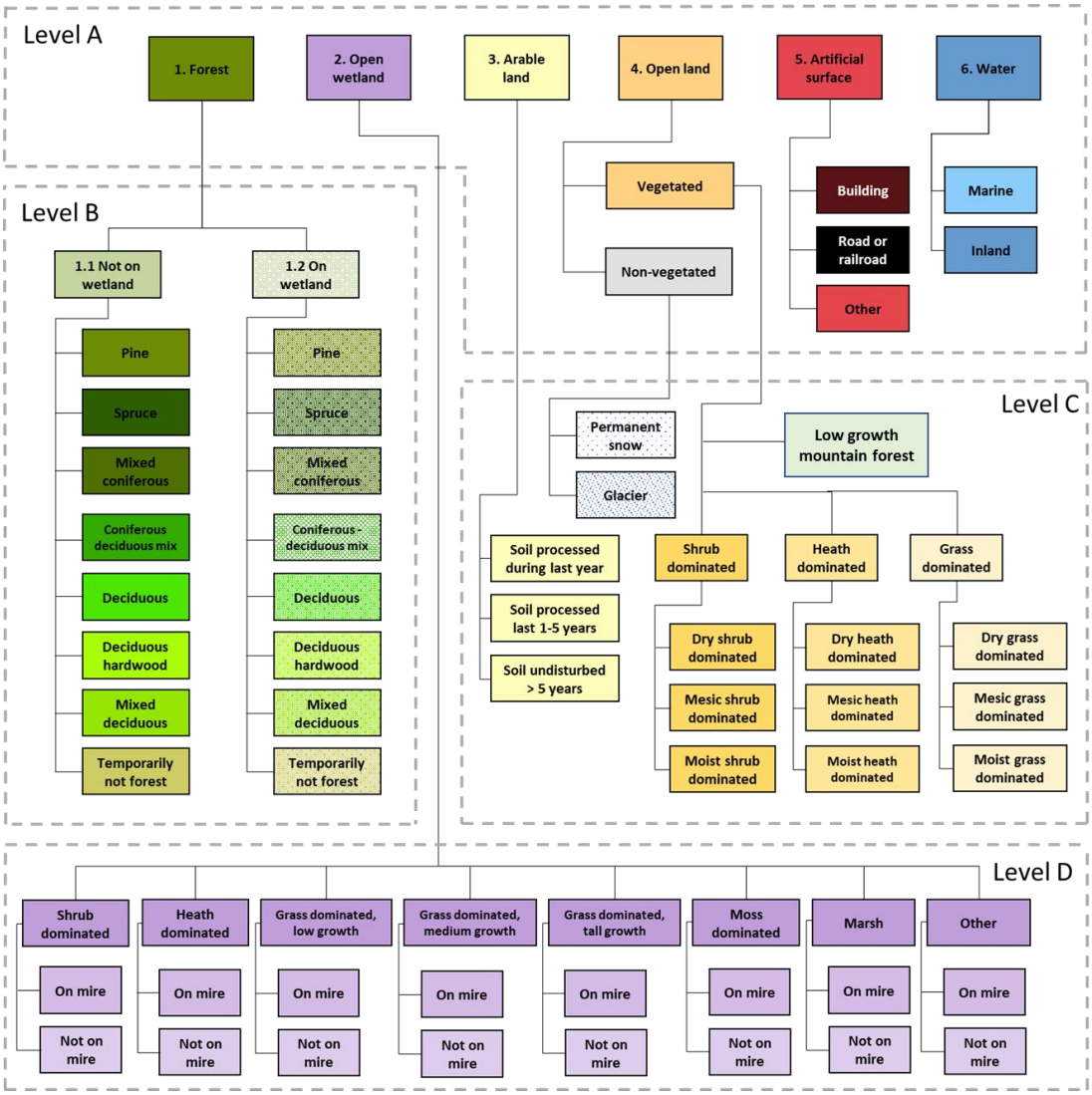

Figure 2: Illustration of the full class hierarchy in the Swedish NMD version 2.0 base layer. NMD version 1.1 consists only of levels A and B in combination. Note that NMD version 2.0 also provides for improved quality in many classes and offers additional supplemental data.

Scope

Geographic extent

In Sweden, the production of NMD is based on the tile index for the Sentinel-2 satellite constellation[2]. Two of these tiles, or granules that span across the Norwegian-Swedish border were selected for the test production: **33VUL** (southern area) and **33WWQ** (northern area). The tiles are roughly 110 by 110 kilometers in size. The selection of tiles that include both Norway and Sweden was made in order to better compare the impact of different supporting data in the two countries on the results and to gauge the possibility of creating seamless cross-border NMD information in the future.

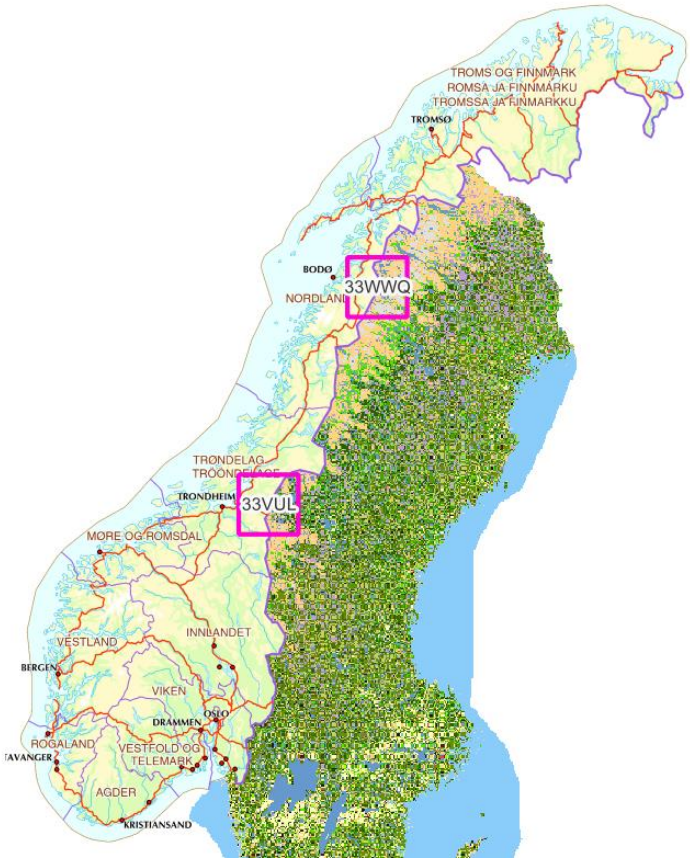

Figure 3: Location of test sites. Background maps: Toporaster 4 WMS[3] and NMD Sweden version 1.1[4]

[2] https://sentinel.esa.int/web/sentinel/missions/sentinel-2
Retrieved 2022-11-20

[3] https://kartkatalog.geonorge.no/metadata/toporaster-4-wms/430b65ec-8543-4387-bf45-dbb5ce4bf4c8
Retrieved 2022-11-20.

[4] https://metadatakatalogen.naturvardsverket.se/metadatakatalogen/GetMetaDataById?id=8853721d-a466-4c01-afcc-9eae57b17b39
Retrieved 2022-11-20.

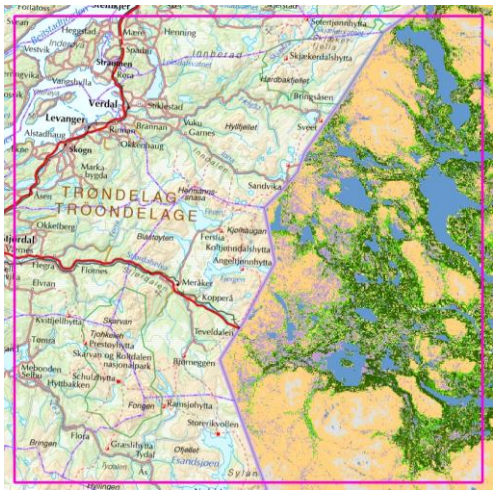

Figure 4: Zoomed in view of 33VUL (southern area). Background maps: Toporaster 4 WMS and NMD Sweden version 1.1

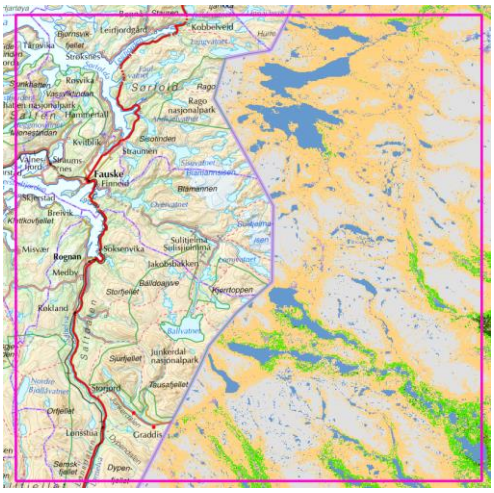

Figure 5: Zoomed in view of 33WWQ (northern area). Background maps: Toporaster 4 WMS and NMD Sweden version 1.1

Thematic content

A modified NMD classification scheme is used in the Norwegian test production, combining parts of NMD version 1.1 and 2.0 (see Figure 2). In Sweden forest is divided into different species or categories, such as pine, spruce and broadleaved deciduous forest. In Norway a simplified forest class only subdividing into forest on, or not on wetland is used but low growth mountain forest classes are also included in the main class tree, as opposed to in Sweden where low growth forest is delivered as an additional attribute in NMD.

Class definitions in the Norwegian NMD test products are outlined in Appendix 1.

Handling of low growth mountain forest

The different climate conditions in the two test sites caused issues when delineating low growth mountain forests. In Sweden a commonly accepted alpine forest boundary is used to define where low-growth forest can occur[5], but since an equivalent boundary was not available in Norway alternative methods had to be attempted.

In the southern area (33VUL), trees between 2-5 meters in height, with more than 10% coverage growing at more than 500 meters above sea level are classified as low-growth mountain forests. Depending on whether these occur on other open land or open wetland, they are divided into two classes (see Figure 6).

[5]https://www.skogsstyrelsen.se/globalassets/sjalvservice/karttjanster/geodatatjanster/produktbeskrivningar/grans-for-fjallnara-skog---produktbeskrivning.pdf

Retrieved 2022-12-15

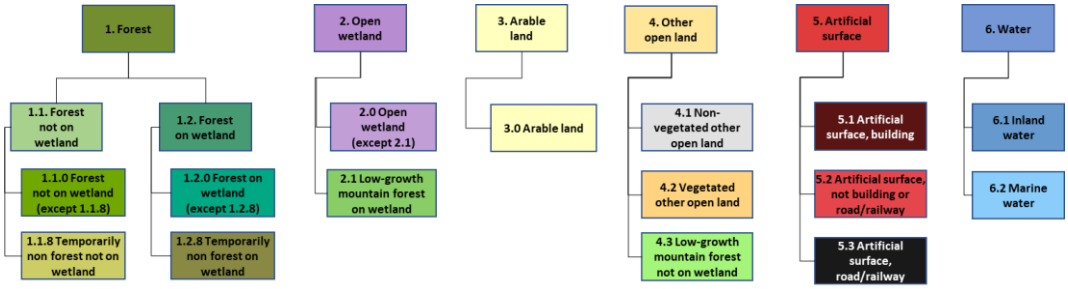

Figure 6: NMD class hierarchy used in the southern test area (33VUL).

The 500 meter elevation limit worked satisfactorily in the southern test area, but in the northern test area it caused classification artifacts, such as bands of other open land dividing forests from low-growth mountain forest areas.

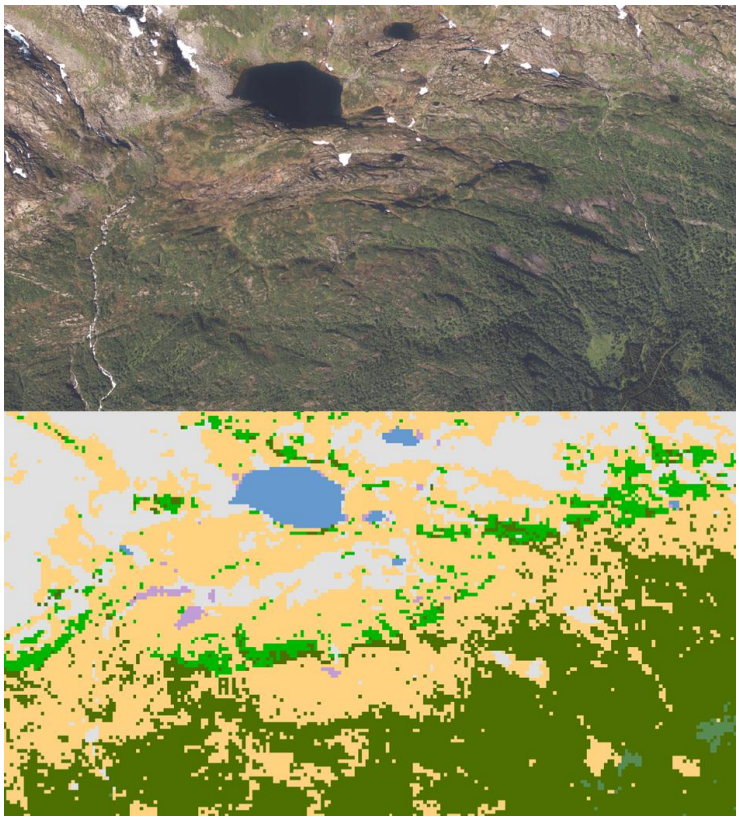

Figure 7: Example of gaps in forest cover caused by applying the 500 meter above sea level limit for low-growth mountain forests in the northern test site (33WWQ). Forest is shown in dark green, low-growth mountain forest in light green.

Further tests showed that applying any firm above-sea elevation limit in 33WWQ caused different results in different parts of the test area, which necessitated an alternative approach. Metria proposed integrating shrubland information and creating two expanded classes in the northern test site. The descriptions of these classes are available in Appendix 1.

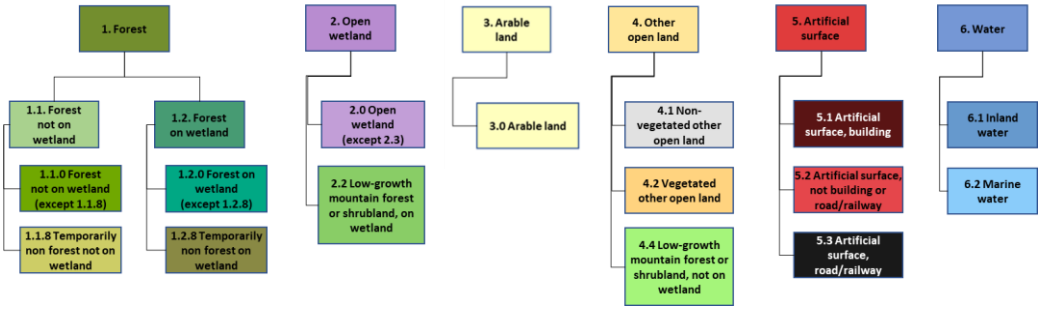

Figure 8: NMD class hierarchy used in the northern test area (33WWQ). Note the replacement of classes 21 and 43 in 33VUL with classes 22 and 44, reflecting the different handling of low growth forest in the two test areas.

The two different methods that are applied to the test areas are to be considered first proposals for how these land cover categories can be mapped in Norway. Similar discussions are ongoing in Sweden and there is currently no consensus in the Swedish NMD project concerning the handling of low-growth forests and shrubland.

Data sources

The input data used in the production of the test areas can be found in Table 1. In addition to these data, orthophotos have been used for calibration of wetland mapping, defining thresholds for alpine forest areas and for quality controls. IR orthophotos are preferable for most validation tasks. Nature type data from Blom (2022) have been used for additional evaluations of results in the southern test area (33VUL).

Table 1: Input data and sources

OBJECT TYPE	DATA SET NAME	PUBLISHER
Power lines	Kraftlinjer / Nettanlegg	NVE[6]
Contemporary satellite data	Sentinel-2	ESA[7]
Contemporary satellite data	Sentinel-1	ESA
Historic satellite data	Landsat 5	USGS[8]
LiDAR	Prepared_laserdata	Kartverket[9]
Water	N50	Kartverket[10]
Roads	Elveg 2.0	Kartverket[11]
Railroads	Jernbane - Banenettverk	Bane NOR SF[12]
Buildings	FKB-Bygning	Geovekst[13]
Arable land	FKB-AR5	Geovekst[14]
Clear-cut areas	SR16beta	NIBIO[15]
Soil map	Løsmasser	Norges geologiske undersøkelse[16]
Pasture land	FKB-AR5	Geovekst
Wetland in mountainous areas in Sweden (for calibration of wetland models)	Topografi 10 Nedladdning	Lantmäteriet (Sweden)[17]

[6] http://nedlasting.nve.no/gis/
[7] https://scihub.copernicus.eu/
[8] https://earthexplorer.usgs.gov/
[9] https://hoydedata.no/LaserInnsyn2/
[10] https://kartkatalog.geonorge.no/metadata/ea192681-d039-42ec-b1bc-f3ce04c189ac
[11] https://kartkatalog.geonorge.no/metadata/77944f7e-3d75-4f6d-ae04-c528cc72e8f6
[12] https://kartkatalog.geonorge.no/metadata/c3da3591-cded-4584-a4b1-bc61b7d1f4f2
[13] https://kartkatalog.geonorge.no/metadata/fkb-bygning/8b4304ea-4fb0-479c-a24d-fa225e2c6e97
[14] https://kartkatalog.geonorge.no/metadata/fkb-ar5/166382b4-82d6-4ea9-a68e-6fd0c87bf788
[15] Preliminary data not yet publicly available.
[16] https://kartkatalog.geonorge.no/metadata/loesmasser/3de4ddf6-d6b8-4398-8222-f5c47791a757
[17] https://www.lantmateriet.se/sv/geodata/vara-produkter/produktlista/topografi-10-nedladdning-vektor/

Links are valid as of 2022-12-20

Method

Production

The production of NMD in Norway can be divided into three main steps: **pre-classification**, **moisture mapping** and **aggregation**. In the Swedish version of NMD an additional step of **forest classification** into different species took up a significant share of the production schedule.

Pre-classification

In the initial pre-classification phase, input data are used to create rough outlines of classes into individual image segments that are modified in later steps. The main software application used in the pre-classification is eCognition by Trimble[18].

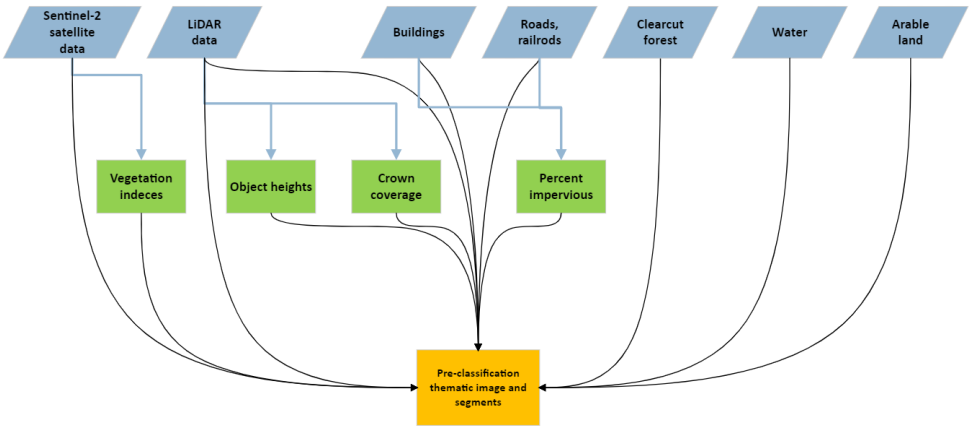

Figure 9: Overview of input data used in the pre-classification step of NMD production. Derived data are shown in green boxes.

Using a combination of height (greater than or equal to 5 meters) and crown coverage (at least 10% coverage per pixel), forest is delineated from other classes. Open land is divided into four different temporary classes, depending on presence of vegetation in index calcuations and percent imperviousness. These classes are later classified further into the final land cover classes in NMD in the aggregation step.

[18] https://geospatial.trimble.com/products-and-solutions/trimble-ecognition

Retrieved 2022-11-28

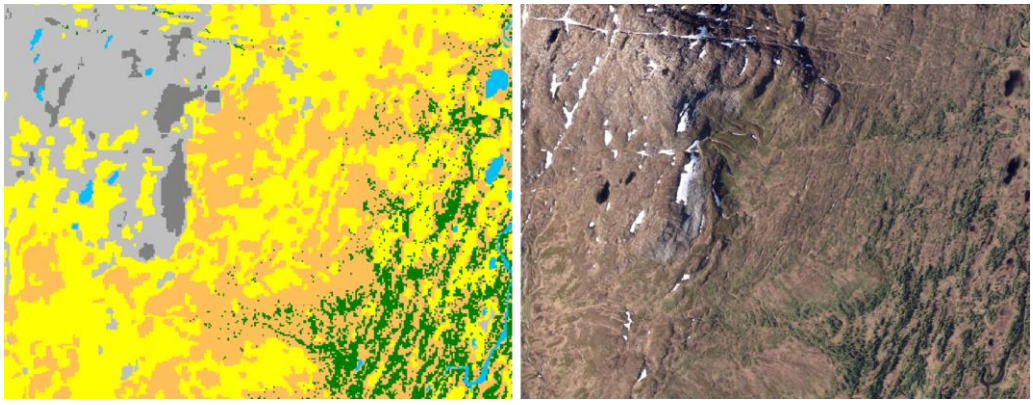

Figure 10: Example of pre-classification thematic image (left). Light and dark grays indicate possibly vegetation free open areas, green and orange possibly vegetation covered open areas. Green color indicates forest, blue indicates water.

All thematic sources that are used in the pre-classification are rasterized and use a pixel size of 10x10 meters, regardless of their original resolution or data format.

Moisture mapping

In order to deliniate the open wetland class from other NMD classes a reliable source of potential landscape moisture is required. In the Swedish version of NMD a significant amount of time was spent developing methods that accurately show the accumulation of moisture in the landscape. Elevation data is the single most important source, but soil type information is also required to achieve a high level of accuracy.

The main method for deriving open wetland areas in NMD is by classifying a wetness index image, the production of which is outlined in Figure 11.

During the production of NMD in northern parts of Sweden an underestimation of open wetland was observed, caused by the failure of the elevation data to accurately capture soil moisture present in highly sloping areas in mountain regions. To compensate for this Metria developed a method using confirmed moist areas as a reference source for a machine learning based method that utilizes satellite data from the Sentinel-1 and Sentinel-2 satellite constallations (see Figure 12). The resulting image from this analysis is a probability map with values between 0.0-1.0 that is used in the aggregation phase to threshold out additional open wetland. This method was applied to both study areas in Norway.

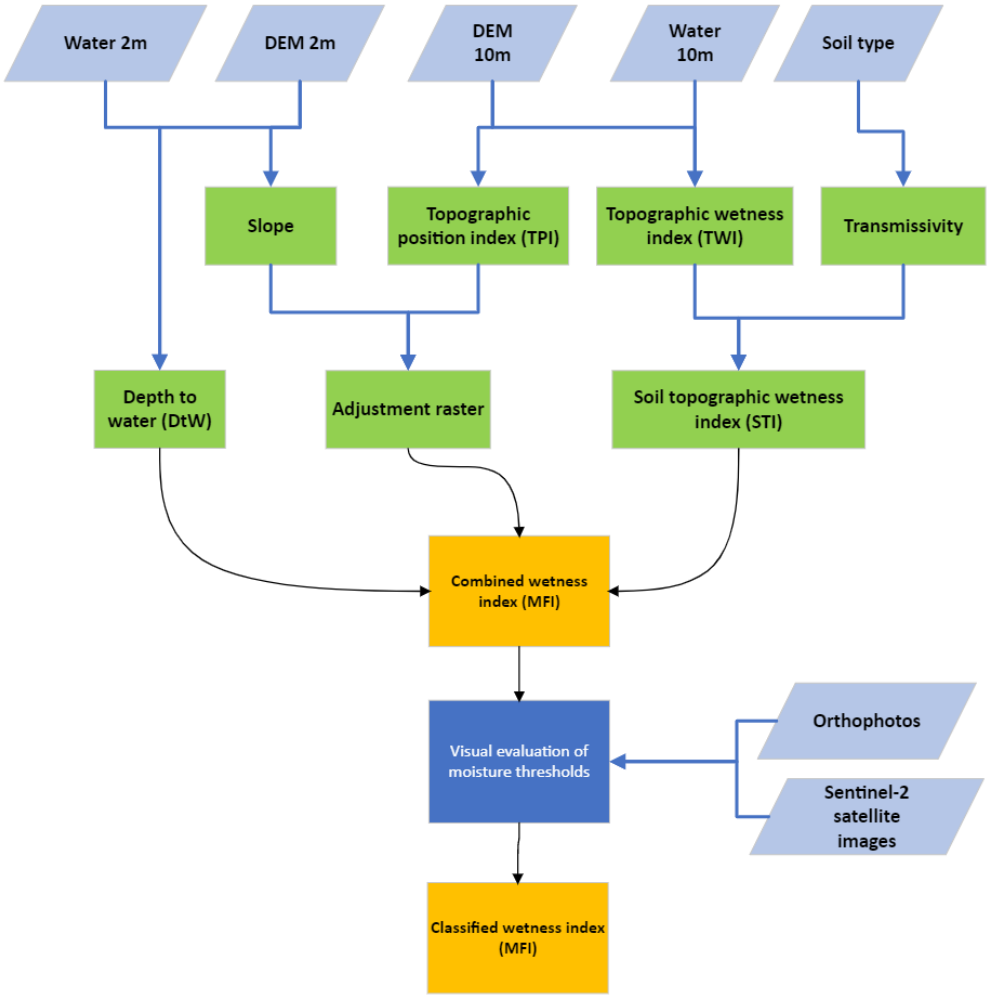

Figure 11: Overview of data and processes used to create moisture information for the test mapping.

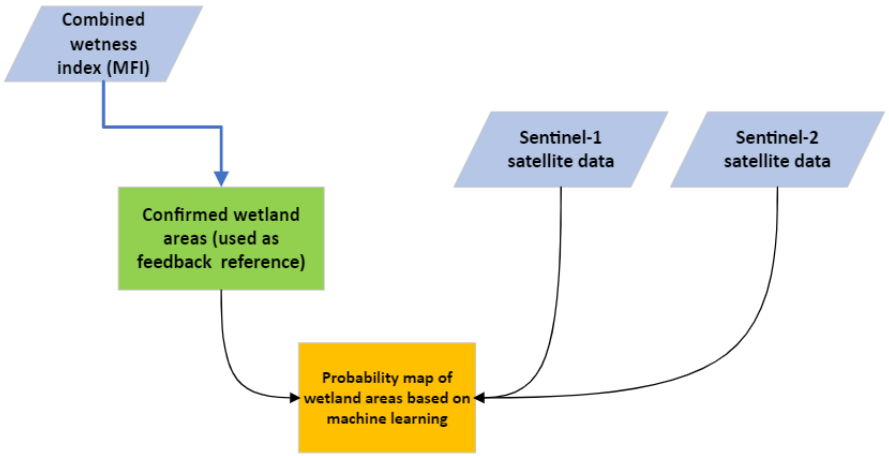

Figure 12: Overview of additional wetland mapping using a combination of moisture information and satellite data.

Aggregation

In the aggregation phase the pre-classification results are used to create the final NMD classification. This is done by utilizing a combination of input data from previous steps and other thematic sources to provide contextual information that guides the classification.

Developing the aggregation methods for Norway provided a significant challenge since the Swedish NMD version was designed with availability of certain national supporting thematic data in mind, for instance soil type data and older land cover products that have no Norwegian equivalent. The aggregation performed in the test mapping represents a first suggested method that can be refined with additional data if needed.

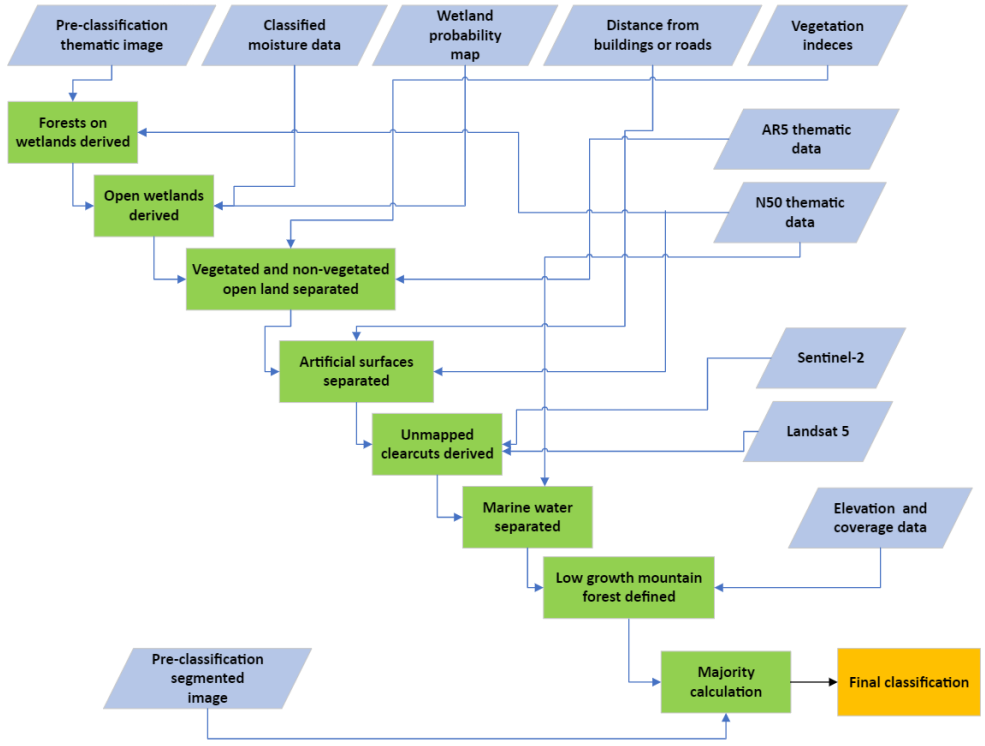

Figure 13: Generalized workflow for the aggregation phase of the production of NMD in Norway

Validation

The NMD test products for Norway were validated by Metria using a look-and-feel approach focusing on:

- General class accuracy and a more detailed survey of the transition between NMD in Norway and Sweden.
- Comparison of the largest error-prone areas in the test products against comparable data sets in Norway.

Remotely sensed data used in the look-and-feel validation included images from Sentinel-2 and IR orthophotos dated to 2021 covering the southern part of the southern test area (33VUL) and natural color ortophotos from 2016 covering the enterity of both test areas.

The Norwegian thematic data sets used in the validation were N50 for both test areas, and a mapping of part of the mountainous areas in the southern test area (33VUL) by Blom Norway (2022).

It is important to clarify that the validation method was based on targeting perceived possible errors of the NMD Norway product. Thus, the validation results do not reflect the accuracy of the products. Metria recommends that a comprahensive evaluation of the the accuracy and usefulness of the test products be performed by Norwegian partners and users in the future.

Results

Thematic classes

Southern area (33VUL)

The Norwegian part of 33VUL covers a total of 69 311 325 pixels, representing an area of roughly 6 930 km^2 or 693 000 hectares.

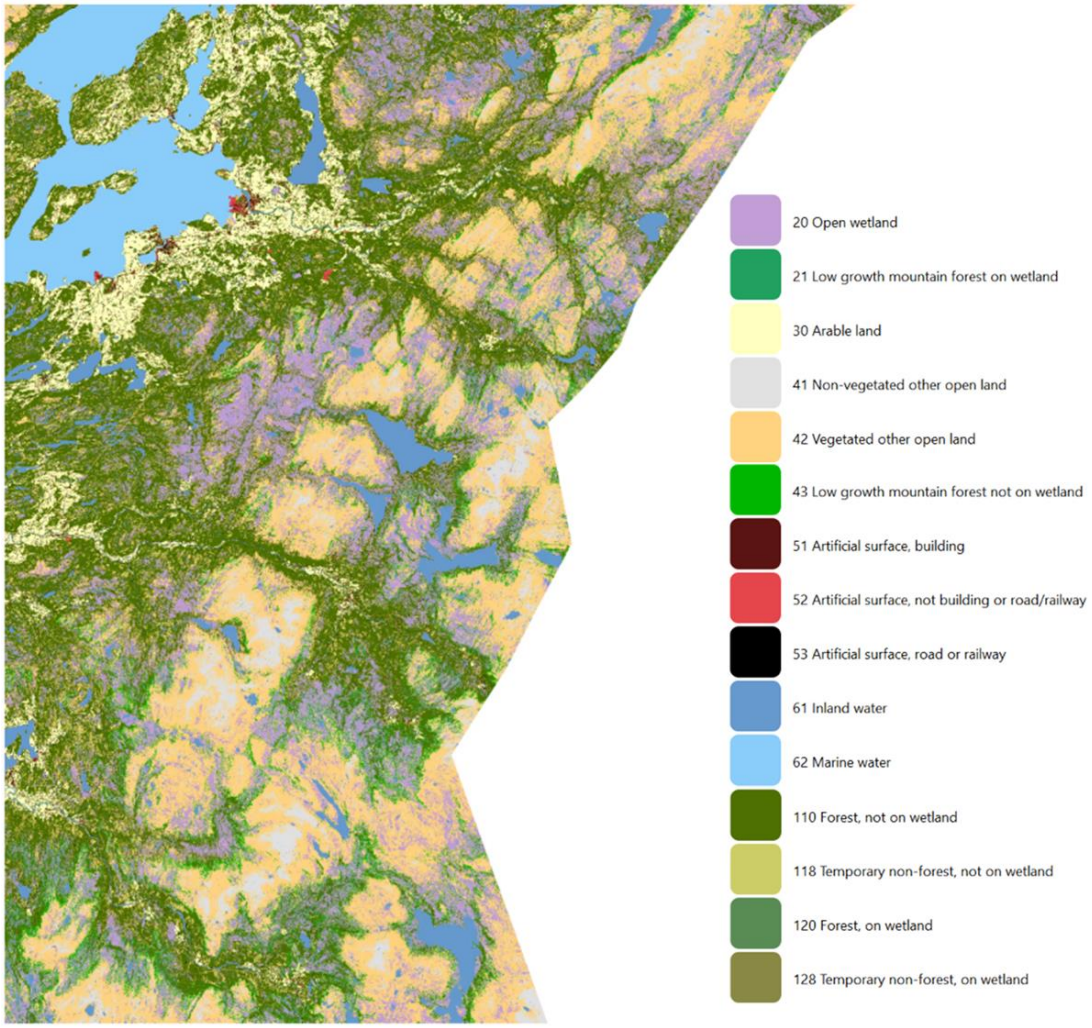

Figure 14: Results of NMD Norway test mapping in 33VUL

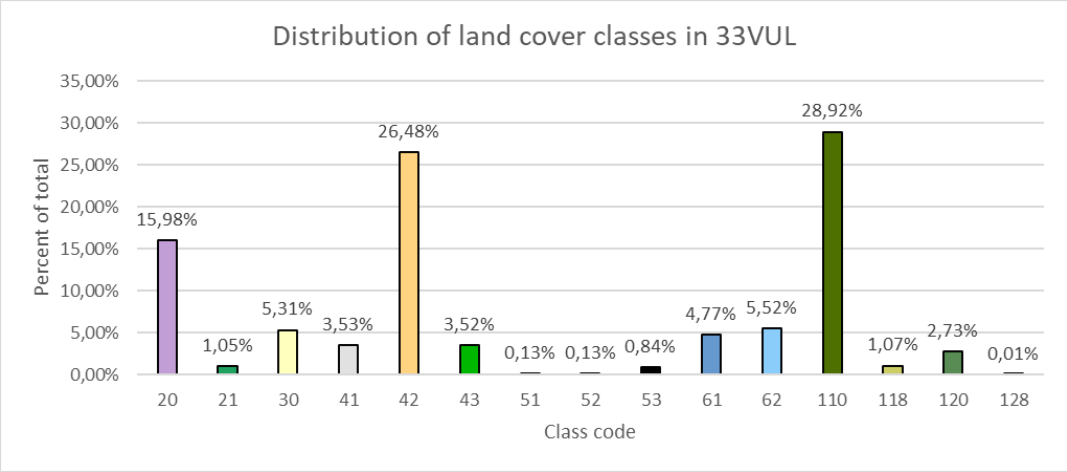

Figure 15: Distribution of NMD land cover classes in 33VUL.

Northern area (33WWQ)

The Norwegian part of 33VUL covers a total of 55 094 428 pixels, representing an area of roughly 5 510 km^2 or 551 000 hectares.

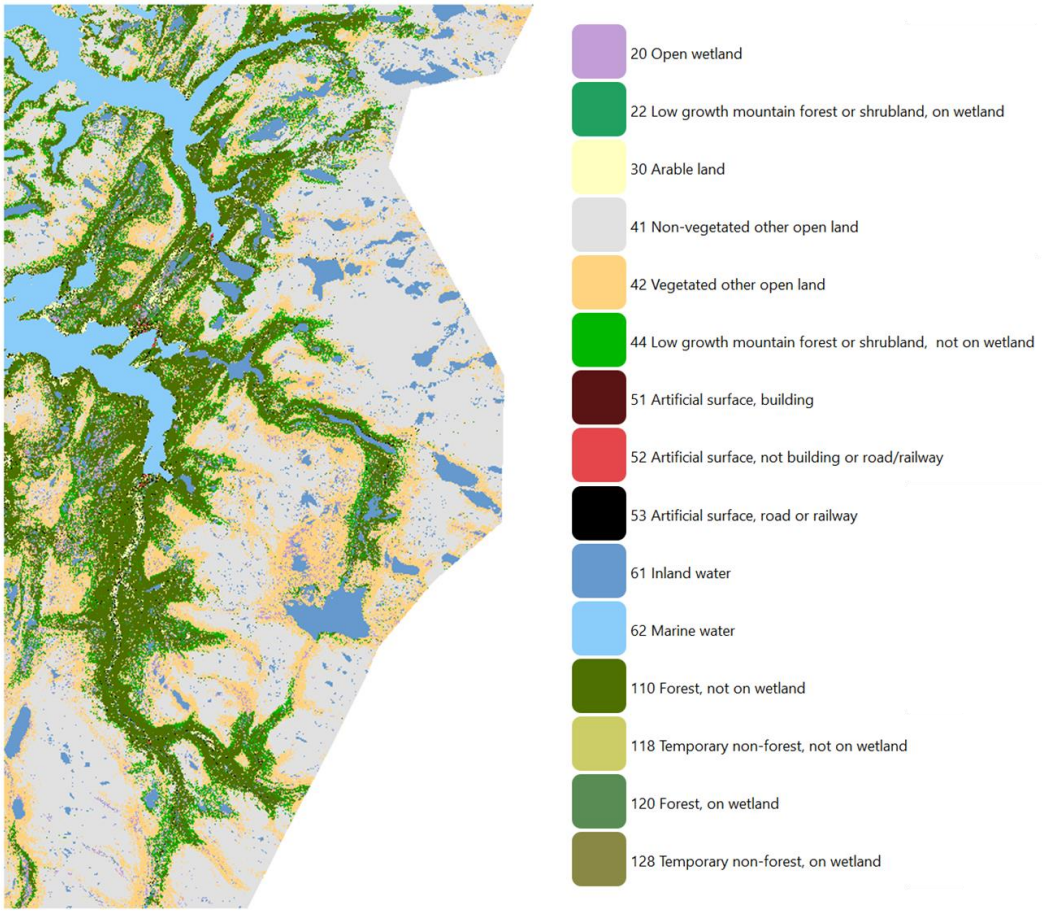

Figure 16:Results of NMD Norway test mapping in 33WWQ

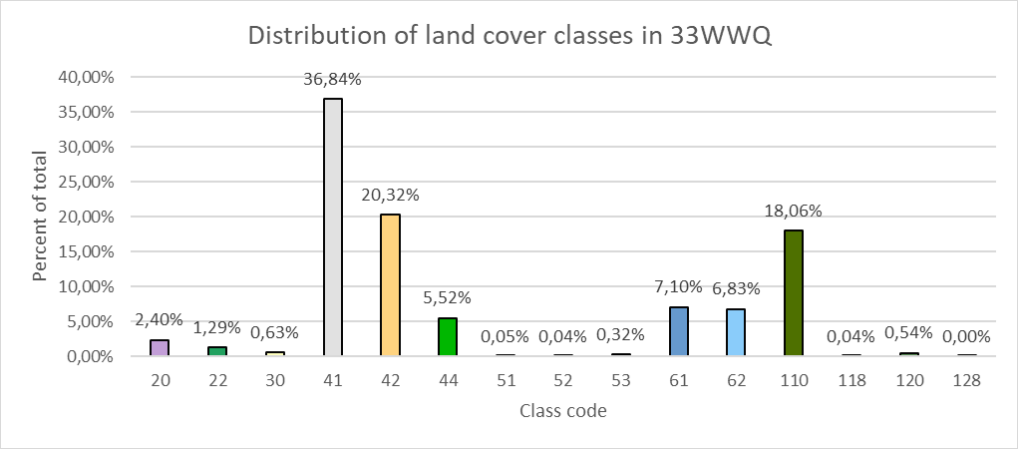

Figure 17: Distribution of NMD land cover classes in 33WWQ.

Validation

Southern area (33VUL)

Overview and comparison with Swedish NMD

The quality of the NMD test mapping in 33VUL is regarded as good based on screening of the area and comparing the classes in the final product against Sentinel-2 and orthophotos.

A commonly occurring error is that clear-cuts (Temporary non-forest) can be misclassified as Vegetated other open land (Figure 18). Relatively recent clear-cuts are mapped accurately but clear-cuts with growing young forest (trees lower than 5 meters) are often omitted. The temporary non-forest class has a high level of accuracy in the Swedish version of NMD as additional thematic data from government sources are also used as a reference, the equivalent of which were not available when mapping Norway.

Certain class borders are difficult to interpret in the orthophotos, especially the border between wetland (Open wetland) and wet land (Vegetated other open land). An impression is that Open wetland is of rather good quality but in some areas slightly overestimated and in other areas slightly underestimated.

The border between Norway and Sweden the NMD can be regarded as seamless and harmonized (Figure 19). The only minor difference is that the class wetland is slightly more prevalent on the Swedish side the border which sometimes is visible as a stripe.

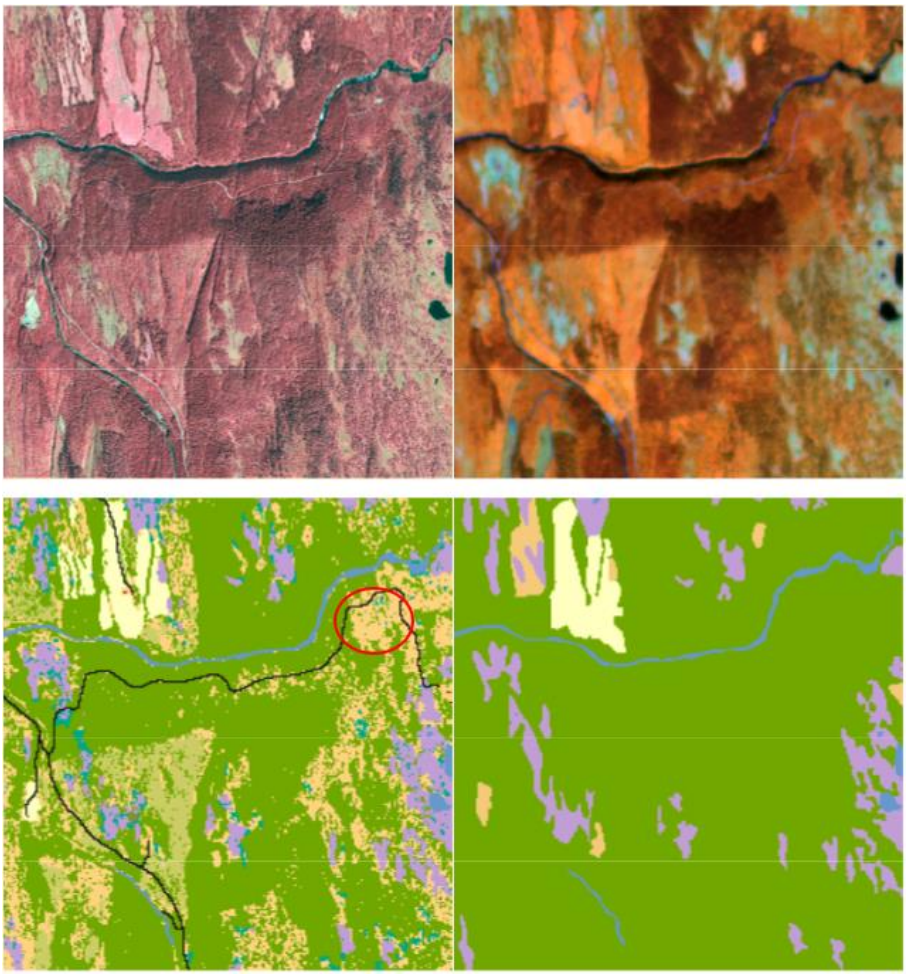

Figure 18: Illustration of an area where young forest (i.e., < 5 m) can be classified as Other open land with vegetation (42), orange coloured, instead of Temporary non-forest (118/128), olive coloured.
Upper left: Infrared IR orthophoto, 2021
Upper right: Sentinel-2, 5th of July 2018.
Lower left: NMD Norway test product.
Lower right: N50

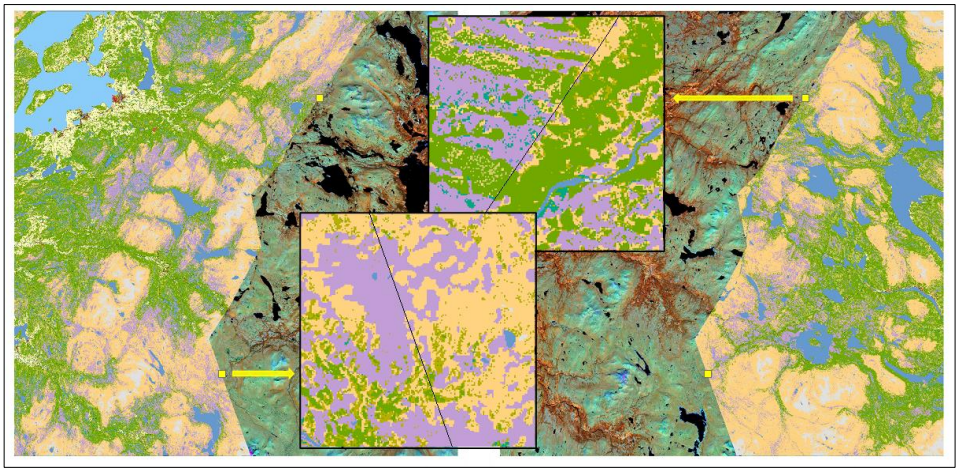

Figure 19: The border between Norway and Sweden in test area 33VUL and two examples of enlarged areas.

Error prone areas compared to N50

The selections of error prone areas were made from classes with likely similar definitions in both datasets, forest and open wetland. The 10 largest error prone areas per class combination were selected and interpreted in satellite data and, if available, orthophotos. The total area of these classes is presented in Table 2.

The result of the interpretation of the largest error prone areas is presented in Table 3. In overall, NMD Norway test product in 33VUL is considered by Metria to be of good quality.

- ***Open wetland/Myr***
  It is rather difficult to interpret in orthophotos if an area is open wetland or open wet land. Many of the error prone areas were regarded as a mix.
- ***Forest/Skog.***
  The error prone area is rather large, and it is likely that differences in definition of forest, between NMD Norway and N50, play a part. NMD Norway is based on the FAO definition; > 10 % crown cover and > 5 m in height. Most of these areas is covered by the class Low-growth mountain forest, defined as > 10 % crown cover and between 2-5 m in height.

Table 2: Total area (hectares) of possibly comparable classes Forest and Open wetland in NMD Norway and N50 in test area 33VUL. The NMD Norway class Low-growth mountain forest is not strictly a forest class according to FAO.

Class	NMD Norway (ha)	N50 (ha)
Forest	226 854	291 417
Open wetland	118 082	108 248
Low-growth mountain forest	31 682	

Table 3: The 10 largest error-prone areas between NMD Norway test product and N50 related to the possibly comparable classes of forest and wetland. The quality of NMD Norway is graded in three classes: 1 = good, 2 = acceptable, 3 = insufficient. samples per category was possible to interpret.

NMD Norway	Possible commission	Hectares	1	2	3	Comment
Open wetland	ÅpentOmråde	13 094	1	9		The 9 samples relate to uncertainty if it is wetland or wet land
Open wetland	Skog	14 190	6		4	The 4 samples are interpreted as wet land
Vegetated other open land	Myr	6 659	2	7		The 7 samples relate to uncertainty if it is wetland or wet land
Vegetated other open land	Skog	63 777	1	9		In NMD Norway the 9 samples are mainly low-growth mountain forest which is not regarded as forest according to FAO
Forest outside wetland	ÅpentOmråde	3 631	7	1	1	
Forest outside wetland	DyrketMark	2 353	1		5	The 5 samples may relate to a “crop” > 5 m in height (energy crop, Christmas tree)
Forest outside wetland	Myr	3 704	6	3		
Forest on wetland	Myr	6 849	7	3		

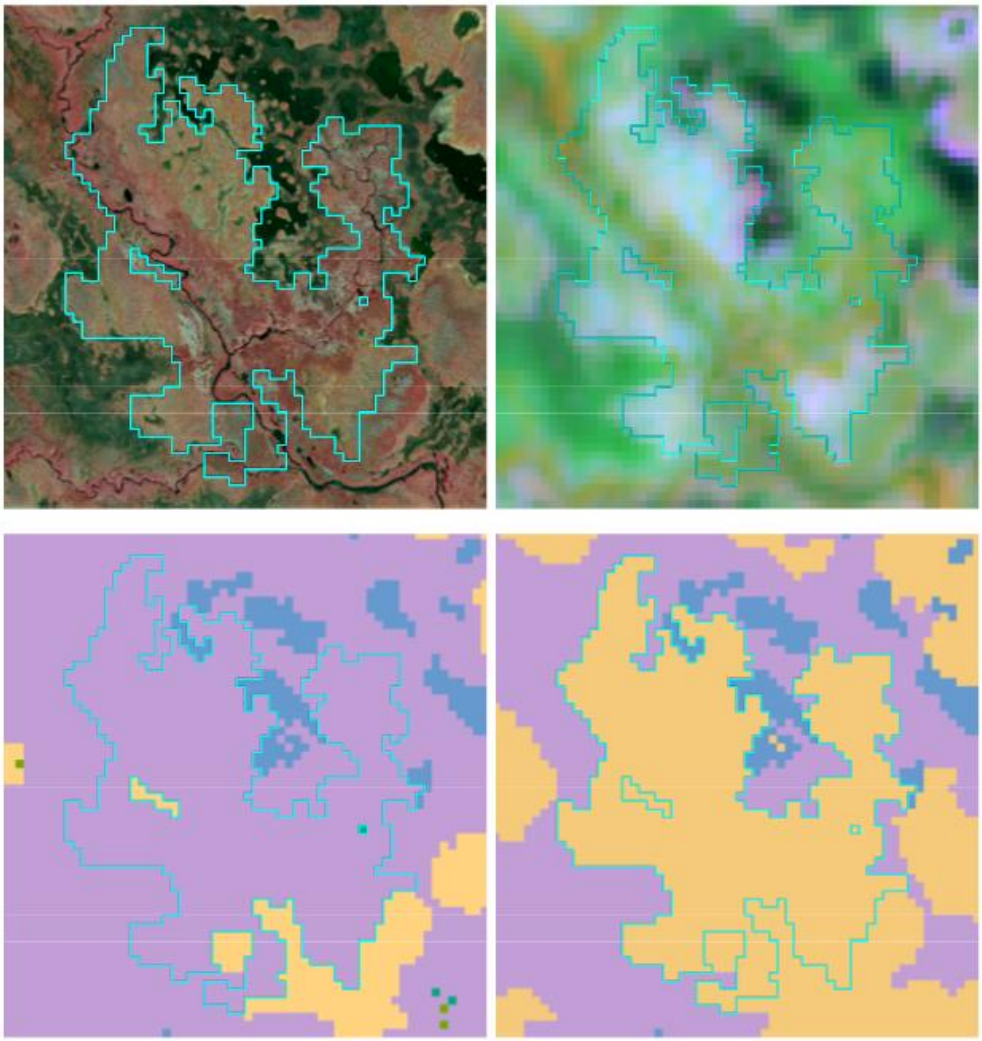

Figure 20: Illustration of an error prone area classified as "Open wetland" in NMD Norway (lower left) and "Åpent Område" in N50 (lower right). IR-orthophoto and Sentlinel-2 images on the upper row.

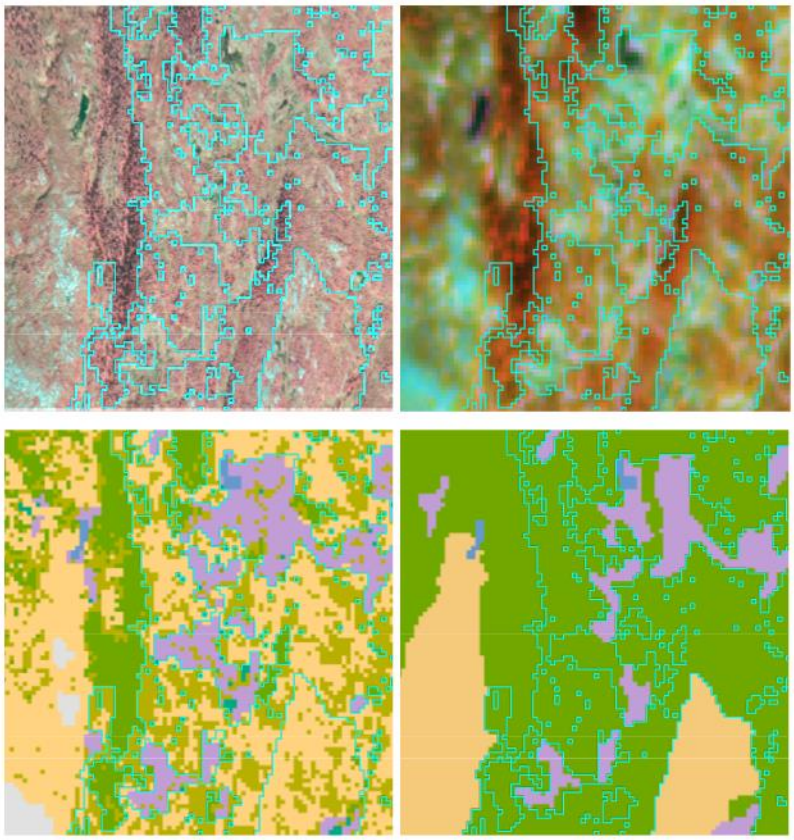

Figure 21: Illustration of an error prone area classified as "Vegetated other open land" with or without "Low-growth mountain forest" in NMD Norway (lower left) and "Skog" in N50 (lower right). IR-orthophoto and Sentinel-2 images on the upper row.

Error prone areas compared to Blom Norway mapping

Blom Norway has performed a detailed mapping of parts of the mountainous area. The number of classes are many and detailed in the mapping by Blom Norway (2022). Classes which possibly have similar definition between the map by Blom and NMD Norway were selected for error prone areas. For the comparison the data from Blom were converted to a raster layer with 10x10 m pixels.

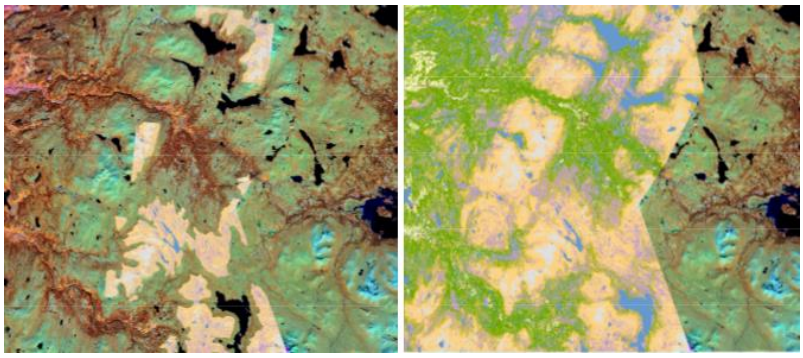

Figure 22: Mapping by Blom (left) and NMD Norway test product (right).

The results of the comparison, listed in Table 4 consists of samples (> 1 hectare error-prone areas) where the classification of NMD (left-most column) differs from the Blom's mapping (second column). The comparison shows, for example that two samples classified as "Non-vegetated other open land" in NMD, were found to be inaccurate as these samples were regarded as vegetated according to interpretation of aerial orthophotos and Sentinel-2 data.

Important to mention is that the selected classes are probably not completely comparable between the two products. The thematic detail is higher in the mapping by Blom however, the NMD Norway test product in 33VUL is regarded as rather good also in comparison to this more detailed mapping. Possible improvements of the test product are related to the border between wetland and wet land (se example in Figure 23).

Table 4: Error-prone area, > 1 hectare, between NMD Norway test product and mapping by Blom. The quality of NMD Norway is graded in three class: 1 = good, 2 = acceptable, 3 = insufficient.

NMD Norway	Mapping by Blom	1	2	3	Comment
Non-vegetated other open land	V1: Åpen jordvannsmyr			2	Mainly vegetation, wetland or wet land with vegetation in the orthophotos.
Vegetated other open land	T14: Rabbe	1	4		Mix vegetation and non-vegetated
Vegetated other open land	T1: Nakent berg		1		Mix vegetation and non-vegetated
Vegetated other open land	T13: Rasmark		1		Mix vegetation and non-vegetated
Open wetland	T7: snöleie	4	6		Mix wetland and wet land
Open wetland	T3: Fjellhei, leside og tundra	3	3	4	Mix wetland and wet land. In four samples interpreted as not wetland.

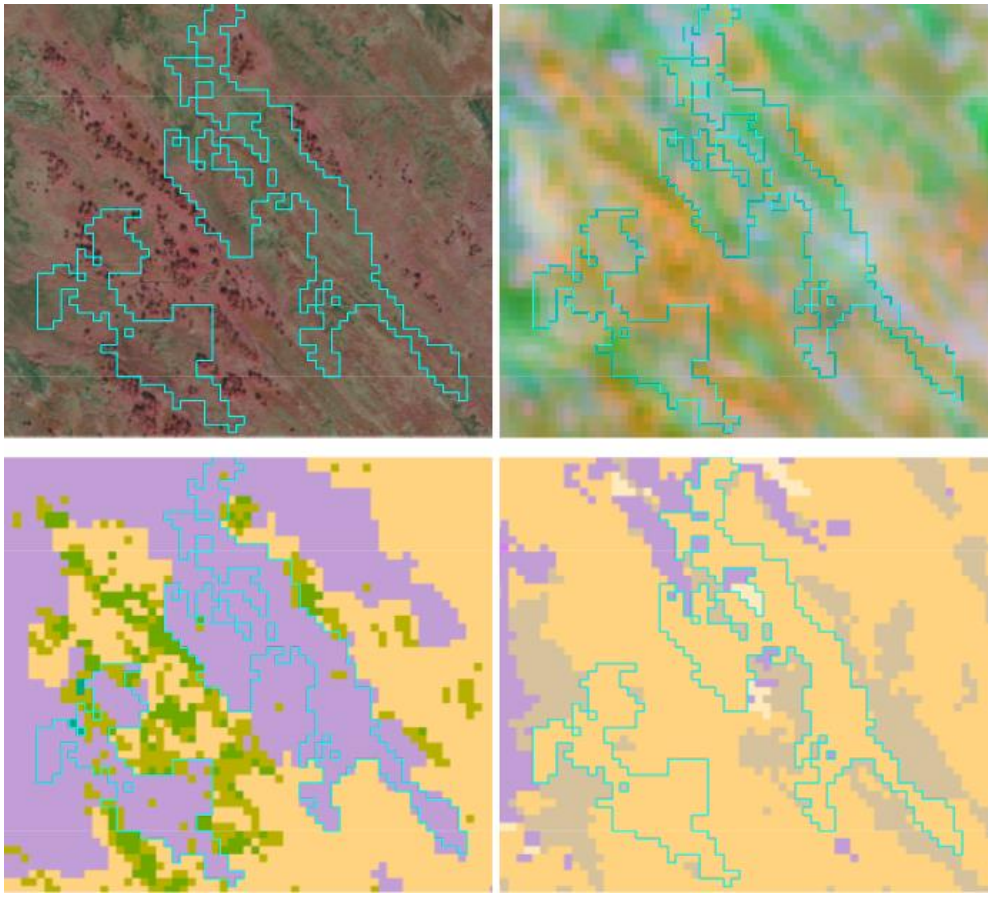

Figure 23: Illustration of an error prone area classified as "Open wetland" in NMD Norway (lower left) and "T3: Fjellhei, leside og tundra" in the mapping by Blom (lower right). The mapping by Blom has more detailed classes than illustrated in the figure. IR-orthophoto and Sentlinel-2 images on the upper row.

Northern area (33WWQ)

Overview and comparison with Swedish NMD

The quality of the NMD product is regarded as good based on screening of the area and comparing the NMD Norway product with Sentinel-2 data and orthophotos.

A notable commission error, though small in total area, is that stripes of forest appear in north facing steep slopes (Figure 24). Most likely these areas are not forest and are caused by erroneously high vegetation index values in permanently shaded pixels in Sentinel-2 data.

Along the border between Norway and Sweden the NMD is regarded as seamless and harmonized (Figure 25). In principle only classes 41 and 42 are, however, crossing the border.

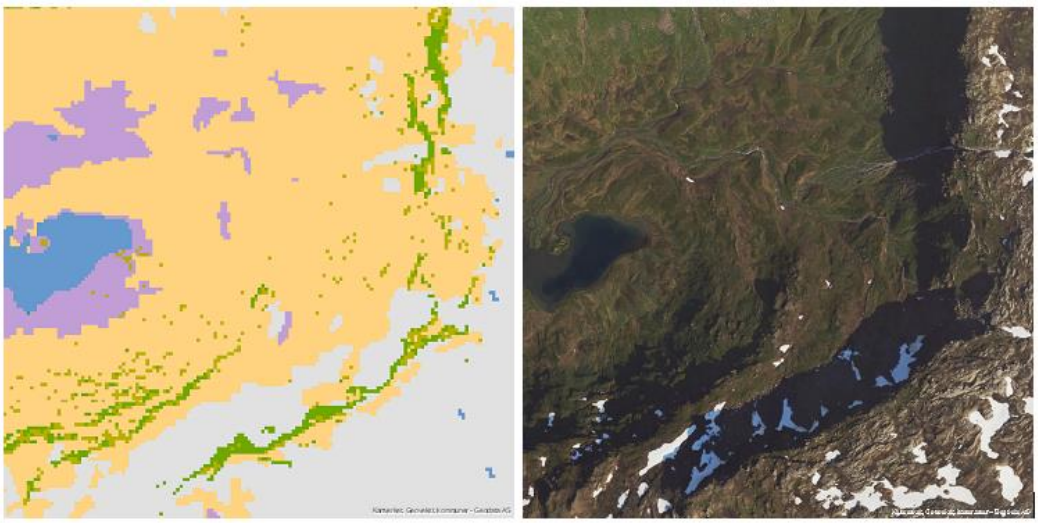

Figure 24: Example of forest commission errors on north-facing slopes

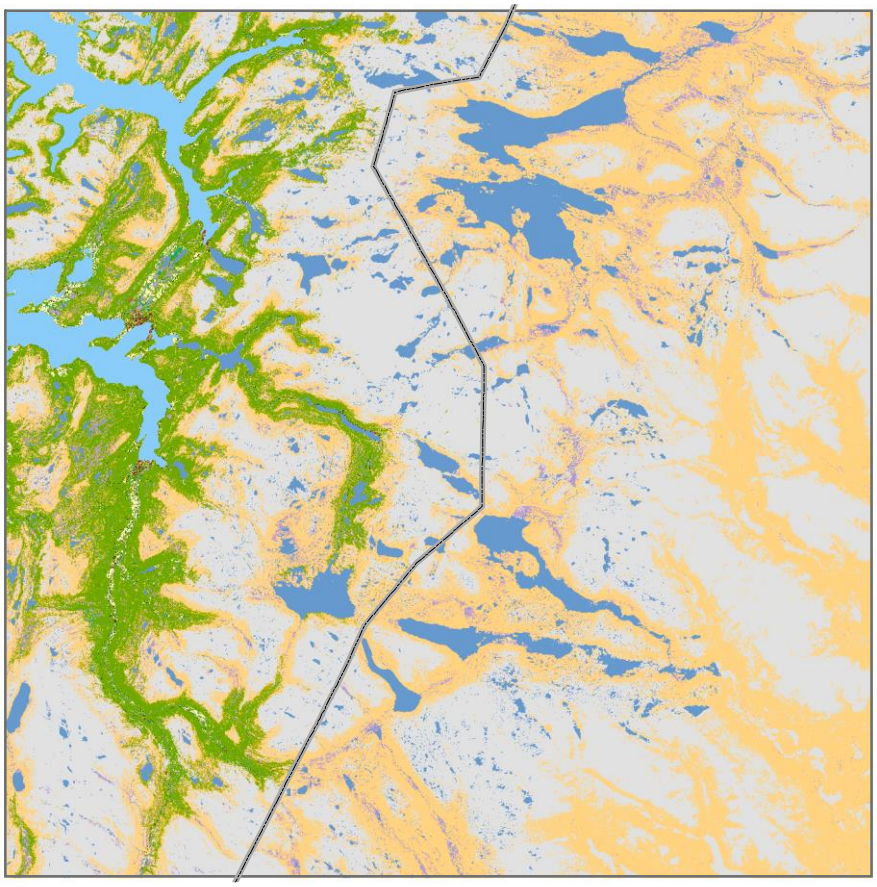

Figure 25: Norwegian and Swedish NMD maps in 33WWQ side by side

Error prone areas NMD Norway and N50

The selection of error prone areas is made from classes with likely similar definitions in both datasets, i.e., forest and wetland. The 10 largest error prone areas (> 1 ha) per class combination were selected and interpreted in satellite data and orthophoto. The total area of these classes is presented in Table 5.

The result of the interpretation of the largest error prone areas is presented in Table 6. Overall, the NMD Norway test product is regarded as of good quality.

- Open wetland/Myr
  It is rather difficult to interpret in orthophotos if an area is open wetland or open wet land. Many of the error prone areas were regarded as a mix, see example in Figure 23. An impression is, however, that wetland is slightly overclassified in NMD Norway.
- Forest/Skog.
  Most possible error prone samples are interpreted as correct in NMD Norway. Steep north facing slopes casting shadows is obviously problematic in NMD. Parts of these areas is not seldom classified as forest, sometimes incorrect but also sometimes correct (Figure 24).

Table 5: Total area (hectares) of possibly comparable classes Forest and Open wetland in NMD Norway and N50 in granule 33WWQL. The NMD Norway class Low-growth mountain forest is not strictly a forest class according to FAO.

Class	NMD Norway (ha)	N50 (ha)
Forest	102 695	138 469
Open wetland	13 214	13 496
Low-growth forest or shrubland	37 565	-

Table 6: The 10 largest error-prone area (if > 1 ha) between NMD Norway test product and N50 related to the possibly comparable classes of forest and wetland. The quality of NMD Norway is graded in three class: 1 = good, 2 = acceptable, 3 = insufficient. Not all samples per category was possible to interpret.

NMD Norway	Possible commission	Total hectare	No. areas validated	1	2	3	Not possible to interpret	Comment
Open wetland	Åpent Område	4 793	10		6	2	3	Difficult to interpret if wetland or wet land.
Open wetland	Skog	795	6	5	1			
Vegetated other open land	Myr	1 054	1		1			
Vegetated other open land	Skog	15 536	10	8	1			
Forest outside wetland	Åpent Område	3 635	10	5	1		4	The 4 samples are in complete shadow
Forest outside wetland	Dyrket Mark	346	0					
Forest outside wetland	Myr	659	1	1				
Forest on wetland	Myr	493	0					

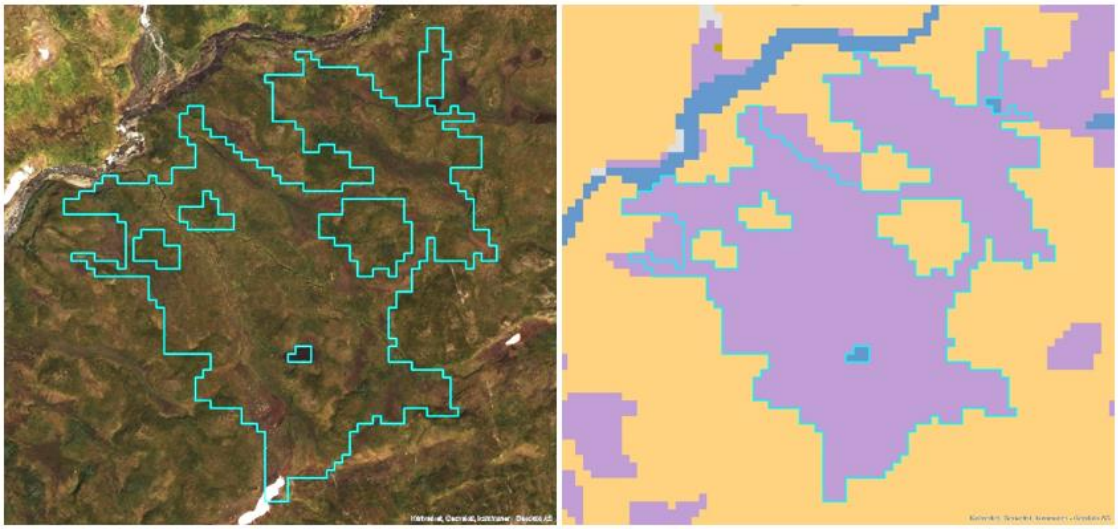

Figure 26: Possible commission error for wetland in NMD Norway where N50 is open land. The sample is interpreted as a mix between wetland and wet land. Orthophoto to the left and NMD Norway to the right.

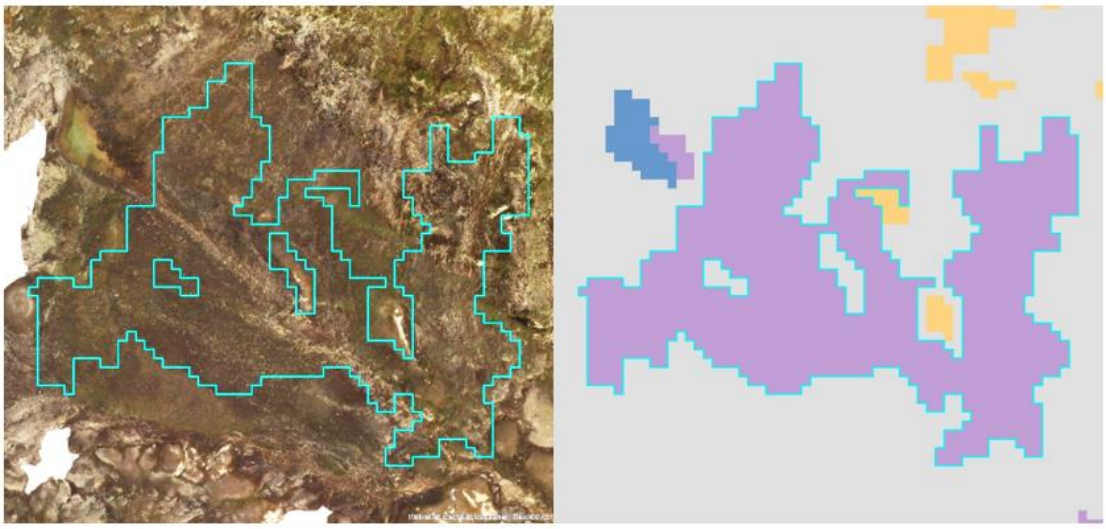

Figure 27. Possible commission error for wetland in NMD Norway where N50 is open land. The sample is interpreted as mainly not wetland. Orthophoto to the left and NMD Norway to the right.

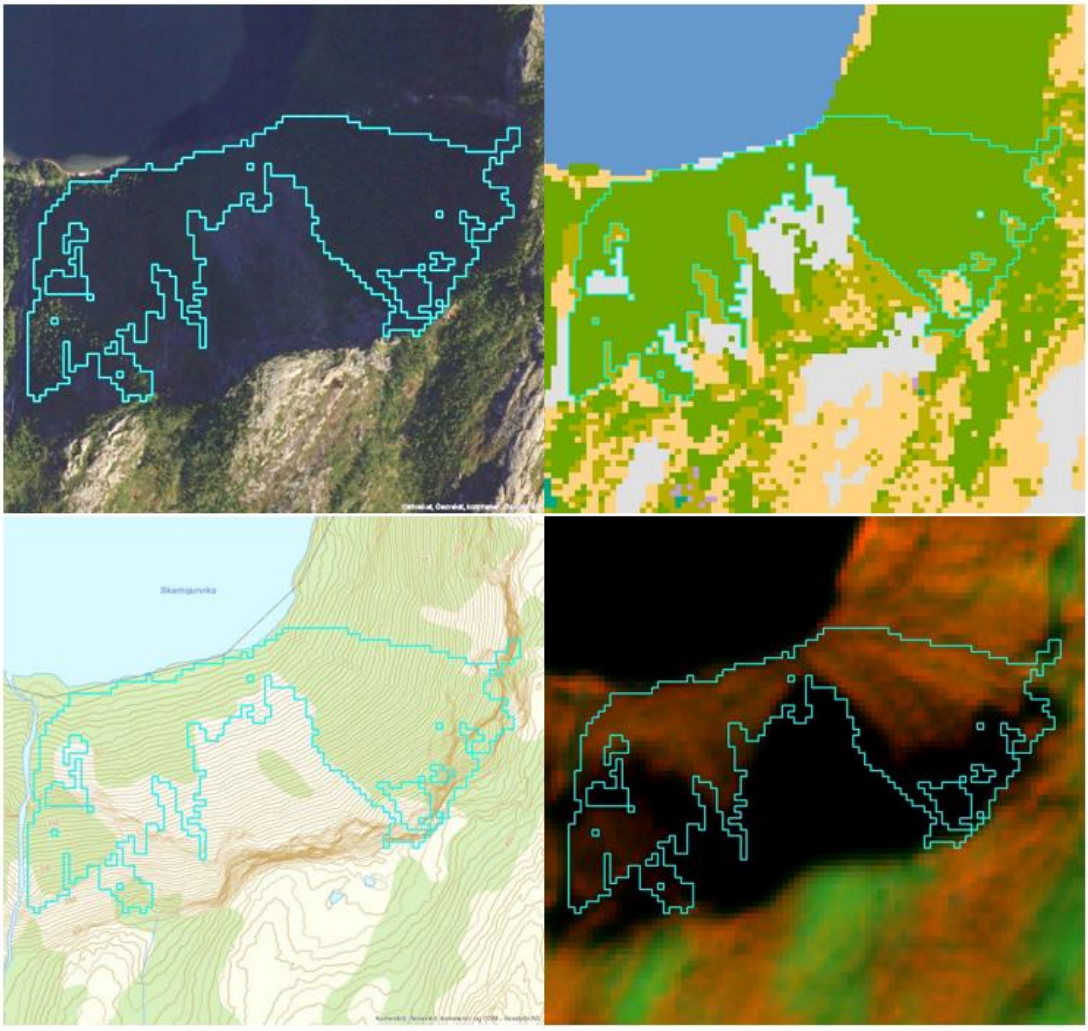

Figure 28. Possible commission error for forest in NMD Norway where N50 is open land. Most area of the possible commission error for forest are in shadow and are therefore not possible to interpret. This area is an exception and interpreted as correct in NMD Norway. Upper left: orthophoto, upper right: NMD Norway, lower left: map from Geodata AS (GeocacheBasis) lower right; Sentinel-2.

Discussion

While the look-and-feel evaluation showed an overall good result in the Norwegian test areas, there are several issues that have affected the quality of the NMD product in Norway. Some of these problems are difficult to solve given the input data available in Norway (such as problem of the lack of road width attributes outlined below), some can be solved or mitigated by modifying the mapping methods used (for example the problem of accurately mapping clear-cut forests or preventing over-estimation of open wetlands).

Sources of quality errors

Forest mapping and LiDAR data

A key difference between the Norwegian and Swedish LiDAR data sources is that the Swedish LiDAR data gathering has been executed in a uniform way with the same point density and a nationally supervised schedule. In Norway LiDAR scans have been performed with varying point densities and in different areas at different times, but always with a point density higher or equal to the national LiDAR scan in Sweden. In Norway, differences in point density can in some cases cause visible edges between different collection areas. Flight line metadata is not entirely standardized in Norway which makes the preparation more time consuming than on the Swedish side.

In the two test sites the the overall quality of the LiDAR data was varying and artefacts in the tree cover has been discovered due to this. One area within the 33WWQ test area had to be discarded because of quality problems and could not be used in the analysis (Figure 29). In this test production, LiDAR is only used for deriving forest and since the entire area was at an altitude of 600 meters or more, the likelyhood of encountering trees taller than 5 meters in this area is low. It will however affect the low-growth mountain forest mapping in parts of that area.

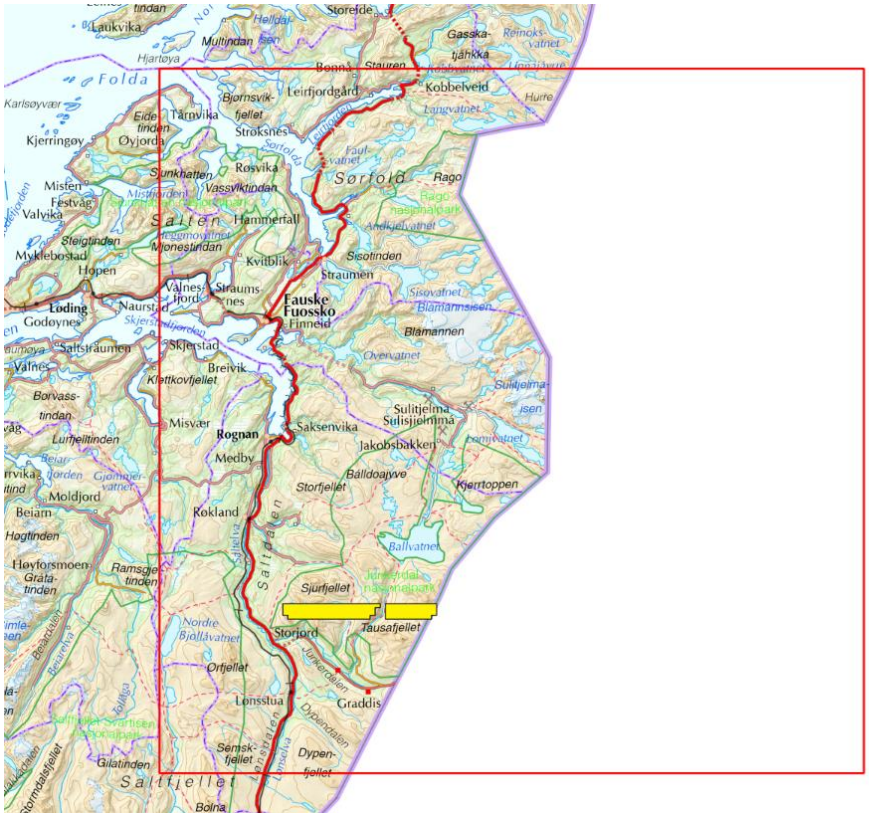

Figure 29: LiDAR data discarded in 33WWQ test area for quality reasons, shown in yellow. Background map: Toporaster 4 WMS.

Soil data and wetland mapping

As shown in the method section of this report a large part of the NMD production is concerned with creating a wetness index for delineation of wetlands. This process is in part based on soil properties: hydraulic conductivity and depth of the soil layers. In Norway there was no available soil depth map, so a common 1 meter depth was assumed. Based on the soil map and the different soil type infiltration potential attributes, assumptions were also made about the hydraulic connectivity. In some cases, no hydraulic connectivity could be assumed.

Due to the uncertainties, the resulting wetness index for the Norwegian test areas do not rely on soil information to a high degree. The soil map used in the Swedish NMD production lacks in geographic precision, but still reduces the overall assumptions regarding hydraulic conductivity and soil depth needed.

The slight over-estimation of wetland in parts of the study areas can possibly be mitigated by changing thresholds in the machine-learning based wetland probability maps that were genereated (Figure 12).

Road data and vegetation thresholding

The road data set used in the Norwegian test areas does not contain any information about road width. While all roads in the final NMD are rasterized to 10x10 meters, road width is essential when calculating the percentage of imperviousness in any given pixel and when calibrating the threshold between

vegetated and non-vegetated areas in index calculations. Since no exact road width data was available, the thresholds ultimately had to be semi-manually calibrated for each test area, causing increased production time and evaluation.

In the test production road widths were set to 10 meters (one pixel) for standard roads and 20 meters (2 pixels) for highways.

Clear-cut areas data

In the NMD production, data showing clear-cuts are an important supporting information source that can correct pixels that can otherwise be misclassified as open land. The available data showing clear-cut areas in the SR16beta data set are based on the automatic satellite monitoring system Global Forest Watch (https://www.globalforestwatch.org/) but were found to cause both over- and underestimations of actual clearcuts when compared to current Sentinel-2 data (Figure 30).

Efforts were made to correct this in primarily 33VUL where a combination of older Landsat 5 and current Sentinel-2 satellite images were used to analyze clearcut forest areas. This is something that may be necessary to repeat for additional areas in Norway if they are mapped with NMD methods in the future.

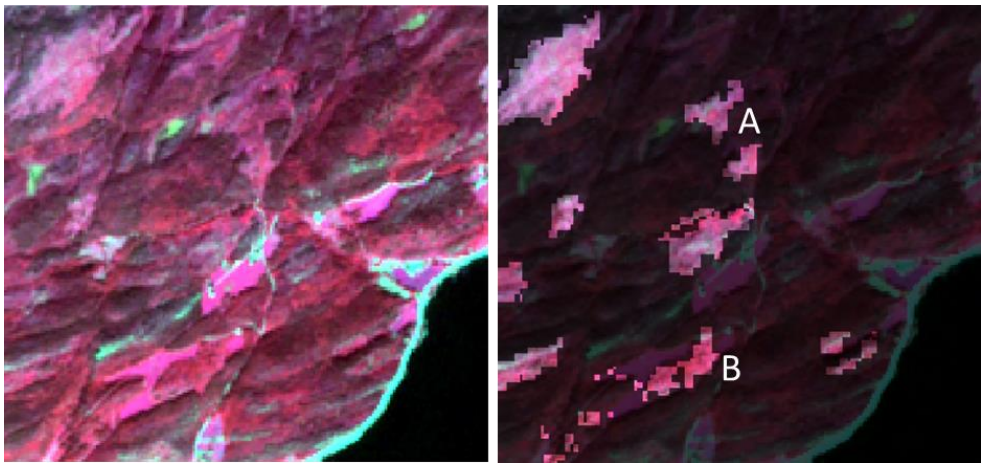

Figure 30: Example of quality issues in available clearcut data (SR16beta). Area A represents an under-mapped clearcut, Area B appears to contain deciduous trees. Example taken from 33VUL, Sentinel-2 image from 2022-07-29

Missing input data

Certain data sources that are crucial to the production of NMD in Sweden are not available in Norway, which means that modified methods were needed to achieve acceptable results in the test mapping.

Alpine forest boundary

Low-growth mountain forest in NMD is defined as areas that have object heights between 2-5 meters and that are determined to be open vegetated land or open wetland within an area that can be defined as belonging to an alpine climate zone.

In Sweden there is an official vectorized boundary decided by the Forestry Act that the Swedish Forest Agency is responsible for creating and maintaining. The boundary decides what areas can be considered alpine/low-growth mountain forest that would otherwise be defined as shrubland or bushes.

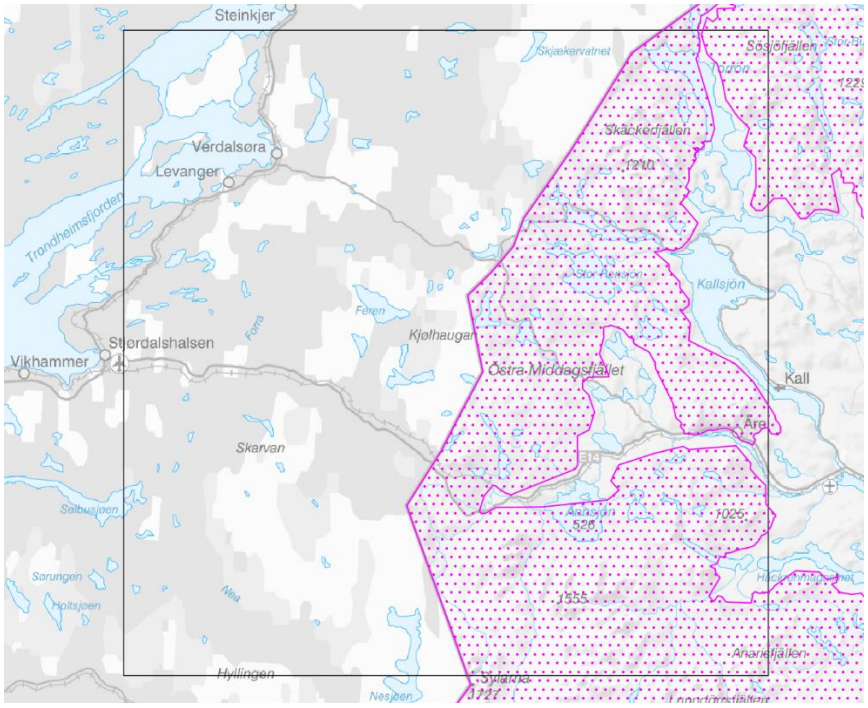

Figure 31: Example of the Swedish alpine boundary in 33VUL, shown in magenta shades. Background image © Lantmäteriet.

The alpine forest boundary is based on the areas' significance for reindeer herding or for nature and culture environment conservation purposes. In practice the boundary is mainly decided by altitude at different latitudes. This relationship cannot be directly translated to Norwegian conditions due to differing climatic conditions.

Since an official alpine forest boundary in Norway was not available, alternative methods were attempted and validated through visual inspection in orthophotos and comparing with the occurrence of low-growth forest with that on the Swedish side of the border. However, it is not entirely feasible to differentiate between alpine forest and bushes only by visually interpreting available remote sensing data since the difference is in part administrative or cultural. An official boundary in Norway would improve the overall accuracy for the low-growth mountain forest classes.

Field data for wetness index calibration

In the final steps of the analysis of the wetness index it is classified based on field inventory data that were not available in Norway. Instead, the analysis was based on IR orthophotos with the aim to harmonize the classes with NMD on the Swedish side.

Feasibility of NMD-concept for Norway

The results of the test mapping confirms that it is possible to adapt the NMD concept for use in the two test areas in Norway. However, additional method development and surveys or creation of more supporting data will be required in order to guarantee that quality standards that are used in the Swedish NMD production are reached in Norway as well.

The test production in Norway shows that different climate conditions can cause problems when mapping similar classes. This was particularly evident when attempting to map low-growth mountain forests in the northern test site. In a national production of NMD-classes in Norway it is likely that new challenges not seen in Sweden are found.

The lack of certain high-quality data, such as clear-cut forests in Norway will have an overall negative effect on the quality of a Norwegian NMD-product, but these types of data can be produced using sources such as older satellite data. Issues with the quality and homogeneity of the LiDAR-data available in Norway were also identifed.

Despite the issues with climate zones and data quality encountered, the test production also demonstrates the flexibility of the NMD concept and its ability to use new data sources to produce results that, on a look-and-feel basis approach the level of quality found in the equivalent Swedish products. It is important to note that the published Swedish NMD product has gone through several years of method development, evaluation and versions to reach its current state. A similar iterative process is necessary in Norway in order to reach high quality goals.

Any future attempt to map all of Norway with NMD-methods would also benefit from the creation of a diverse network of Norwegian stakeholders that can provide feedback and evaluation of all classes in the final products. This has been one of the key assets in the equivalent Swedish production.

Sources

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Appendices

Appendix 1. NMD Norway class definitions

Forest (Class group 1)

Definition: Land with trees higher than 5 meters and a crown cover of more than 10 percent, or trees able to reach these thresholds in situ.
Clarification: The definition is according to FAO forest definition - Global Forest Resources Assessments 2010 (FRA2010). However, unlike FRA2010, NMD will classify forest in agricultural and urban areas as well, according to the same criteria.

Forest not on wetland (except class 1.1.8) (1.1.0)

Definition: Tree-covered areas outside of wetland with a total crown cover of >10% and a tree height of >5 meters.

Temporarily non-forest not on wetland (1.1.8)

Definition: Open and re-growing areas outside of wetland that have been clear-felled the last 15-20 years, with a maximum tree height of 5 meters.
The class may also include storm-felled areas and burnt areas.

Forest on wetland (except 1.2.8) (1.2.0)

Definition: Tree-covered areas on wetlands with a total crown cover of >10% and a tree height of >5 meters.

Temporarily non-forest on wetland (1.2.8)

Definition: Open and re-growing areas on wetland that have been clear-felled the last 15-20 years, with a maximum tree height of 5 meters.
The class may also include storm-felled areas and burnt areas

Open Wetlands (Class group 2)

Definition: Open land where water, for much of the year, is close to or slightly above ground-level.
Clarification: Wetland is a general term for a wide range of habitats that are very wet. In most cases the type of vegetation can be used to determine if it is wetland or not. At least half of the vegetation cover should be hydrophilic, i.e., moisture-dependent.
Most wetlands are swamps (bogs and fens) and swamp forests (i.e., Forest on wetland, 1.2.0). Mire is a collective name for peat-forming soil. Ponds/dams in forest and agricultural landscape are also classified as wetlands. Meadows along freshwater bodies, oceans and buffer zones along waterways are also often included here as well.
Possible tree and bush cover shall not be able to reach 5 meters in height. Scattered trees (> 5 meter and less than 10 % cover) may occur.

Open wetland (2.0)

Definition: Open land where water, for much of the year, is close to or slightly over ground.

Clarification: This class excludes “Low-growth mountain forest on wetland”. Possible tree and bush cover shall not be able to reach 5 meters in height. Scattered trees (> 5 meter and less than 10 % cover) may occur.

Low-growth mountain forest, on wetland (2.1)
Definition: Low-growth forest (2-5 m in height and > 10 % cover) in mountain areas on land where water, for much of the year, is close to or slightly over ground with.
Clarification: The low-growth forest is a climax state. The differentiation between mountain and non-mountain low-growth forest has in Norway been an approximation based on the altitude as a geographical limit is lacking in comparison to Sweden. This class is only present in the 33VUL test area.

Low-growth mountain forest or shrubland, on wetland (2.2)
Definition: Low-growth forest (2-5 m in height and > 10 % cover) on land where water, for much of the year, is close to or slightly over ground with.
Clarification: The low-growth forest is a climax state. The differentiation between mountain and non-mountain low-growth forest has in Norway been an approximation based on the altitude as a geographical limit is lacking in comparison to Sweden. This class is only present in the 33WWQ test area.

Arable land (Class group 3)

Arable land (3.0)

Definition: Agricultural land used for plant cultivation or kept in such a condition that it can be used for plant cultivation. The land should be able to be used without any special preparatory action other than the use of conventional farming methods and agricultural machinery. The soil shall be possible to be used for plant cultivation every year. Exceptions can be made for an individual year if special circumstances exist.
Clarification: includes fruit trees, berry plantations and energy forest. Also includes permanent grassland (arable land with forage crop or fallow at least 5 years in a row.)

Other open land (Class group 4)

Definition: Other open land which is not wetland, arable land or an artificial non-vegetated surface.
Clarification Possible tree and bush cover shall not be able to reach 5 meters in height. Scattered trees (> 5 meter and less than 10 % cover) may occur.

Non-vegetated other open land (4.1)

Definition: Other open land that is not wetland, arable land or an artificial non-vegetated surface and has less than 10% vegetation cover during the current vegetation period. The ground can be covered by moss and lichen.

Vegetated other open land (4.2)
Definition: Other open land that is not wetland, arable land or exploited vegetation-free surfaces and has more than 10% vegetation cover during the current vegetation period.
Clarification: includes man-made surfaces such as lawns, natural areas such as grassland, meadows and thickets and semi-natural areas such as pastured grasslands.
This class excludes "Low-growth mountain forest on other open land". Possible tree and bush cover shall not be able to reach 5 meters in height. Scattered trees (> 5 meter and less than 10 % cover) may occur.
Low-growth mountain forest, not on wetland (4.3)
Definition: Low-growth forest (2-5 m in height and > 10 % cover) in mountain areas not on wetlands.
Clarification: The low-growth forest is a climax state. The differentiation between mountain and non-mountain low-growth forest has in Norway been an approximation based on the altitude as a geographical limit is lacking in comparison to Sweden. This class is only present in the 33VUL test area.
Low-growth mountain forest or shrubland, not on wetland (4.4)
Definition: Low-growth forest (2-5 m in height and > 50 % cover) not on wetlands.
Clarification: The low-growth forest is a climax state. The differentiation between mountain and non-mountain low-growth forest has in Norway been an approximation based on the altitude as a geographical limit is lacking in comparison to Sweden. This class is only present in the 33WWQ test area.

Artificial non-vegetated surfaces (Class group 5)

Definition: Artificial and non-vegetated surfaces man-made surfaces, often impervious.
Artificial surface, building (5.1)
Definition: A durable construction consisting of roofs or roofs and walls, and which is permanently placed on the ground or partly or wholly below ground or is permanently placed in a certain place in water and is intended to be designed so that people can stay in it.
Artificial surface, not building or road/railway (5.2)
Definition: Artificial open and vegetation-free surfaces that are not building or road/railway.
Clarification: Includes man-made surfaces such as sand and gravel pits.
Artificial surface, road/railway (5.3)
Definition: road or railway.

Water (Class group 6)

Inland waters (6.1)
Definition: Lake and water courses.
Marine waters (6.2)
Definition: Seas and oceans, estuaries and coastal lagoons.

Appendix 2: Delivery metadata

Test area 33VUL

Filename	NMD_Norge_test_product_33VUL_v01.tif
File format	Tagged image file format (TIFF)
Compresssion algoritm	Deflate
Bit depth	8-bit unsigned integer
Pixel size	10x10 meters
NoData value	255
Columns	10970
Rows	10966
Bands	1
Colormap	Yes
Projected coordinate system	ETRS 1989 UTM Zone 33N
Geographic coordinate system	ETRS 1989
QGIS layer style file	NMD_Norge_test_product_33VUL_v01.qlr
ArcGIS layer style file	NMD_Norge_test_product_33VUL_v01.lyr

Test area 33WWQ

Filename	NMD_Norge_test_product_33WWQ_v01.tif
File format	Tagged image file format (TIFF)
Compresssion algoritm	Deflate
Bit depth	8-bit unsigned integer
Pixel size	10x10 meters
NoData value	255
Columns	10980
Rows	10979
Bands	1
Colormap	Yes
Projected coordinate system	ETRS 1989 UTM Zone 33N
Geographic coordinate system	ETRS 1989
QGIS layer style file	NMD_Norge_test_product_33WWQ_v01.qlr
ArcGIS layer style file	NMD_Norge_test_product_33WWQ_v01.lyr