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The content and accuracy of the CORINE Land Cover dataset for Norway

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ABSTRACT

The CORINE Land Cover dataset for Norway for the reference year 2018 (CLC2018) was compared to detailed national land cover and land use data. This allowed us to describe the thematic composition of the CLC-polygons and aggregate the information into statistical profiles for each CLC-class. We compared the results to the class definitions found in the CLC mapping instructions, while considering the generalization and minimal mapping units required for CLC. The study showed that CLC2018 in general complied with the definitions. Non-conformities were mainly found for detailed and (in a Norwegian context) marginal classes. The classification can still be improved by complementing visual interpretation with classification based on the statistical profile of each polygon when detailed land use and land cover information is available. The use of auxiliary information at the polygon level can thus provide a better, thematically more accurate CLC dataset for use in European land monitoring.

1. Introduction

CORINE Land Cover (CLC) is the de facto standard for land use and land cover (LULC) monitoring at the pan-European level. CLC consists of a sequence of inter-annual LULC datasets of Europe, produced by national agencies and coordinated by the European Environment Agency (EEA). The datasets are produced according a common standard and represent the status for the reference years 1990, 2000, 2006, 2012 and 2018. This time-series provides a harmonized description of the development of land cover and land use in Europe over the last 30 years (Feranec, 2016).

The CORINE (Coordination of information on the environment) initiative was initiated by the European Union in 1985. The program aimed to compile a consistent environmental database for the EU (Wyatt et al., 1988). The preferred method was to aggregate the European database from existing national data, but the lack of consistent national land cover information led to the compilation of the first CLC by manual interpretation of satellite imagery (Briggs and Mounsey, 1989).

The first comprehensive CLC dataset for Europe was completed for the reference year 1990. The CORINE program has later been terminated, but CLC continues as a LULC monitoring program led by the EEA. The program is now an integral part of the pan-European component of the Copernicus Land services, implemented by EEA. The agency is using CLC and the corresponding CLC change information to estimate and report LULC changes as part of their monitoring of the European environment (Feranec et al., 2010).

The CLC nomenclature consists of 44 LULC classes (Bossard et al., 2000, Feranec et al., 2016). The classes are defined and explained in an illustrated technical guideline (Kosztra et al., 2017). The minimum mapping unit (MMU) is 25 ha (250 000 m^2) and the minimum feature width is 100 m. CLC mapping is carried out by national teams, with good knowledge of the local topography and land cover. The approach used in each country vary depending on the available technology and the access to auxiliary data. The techniques range from manual image interpretation via supervised image classification to bottom-up combination and generalization of existing national datasets (Ben-Asher et al., 2013). Notwithstanding these differences, the national teams adhere to the same nomenclature and are supervised by a European technical team, assuring that the common classification and approved technical standard is implemented by each national team.

The CLC process and datasets have been subject to criticism (Arnold et al., 2016). One frequently raised issue is the lack of distinction between land cover and land use. The CLC nomenclature is a mixture of these two concepts (Comber, 2008). This is not unusual. Land use information is often perceived as more important in intensively used areas, while land cover information is more relevant in extensively used and natural areas. CLC is a wall-to-wall dataset of Europe and covers both man-made and natural environments. The conjunction of LULC aspects is a pragmatic attempt to increase the overall relevance of the dataset as a tool for environmental monitoring.

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Further criticism is linked to the use of "mixed classes" (Feranec et al., 2016). A mixed class is a class where several types of land use and/or land cover coexist. An example is the CLC class «Land principally occupied by agriculture, with significant areas of natural vegetation». Mixed classes do not provide unambiguous information on the state of the land surface. On the other hand, the 25 ha MMU will inevitably mask out smaller patches of LULC in heterogeneous landscapes, e.g. regions with small-scale mountain agriculture or scattered settlements. The mixed class is another pragmatic approach to document the variability across Europe, possibly creating a more useful dataset than a purified approach would allow.

The purpose and justification for CLC is the need for pan-European land monitoring. The relevance at the national and sub-national level is questionable. CLC is occasionally used to describe LULC status and changes in smaller regions, like the UK (Cole et al., 2018), or to compare two or more countries (Feranec et al., 2007). The spatial resolution is, however, too coarse and the dataset usually less relevant for use at the national level. Many countries also maintain their own medium or high-resolution land use and/or land cover database with a spatial resolution and a nomenclature customized towards specific national needs. The relevance of CLC as a source for information at the national and sub-national level is, however, undeniably present when no better data source is available or accessible, as demonstrated by e.g. Popovici et al. (2013).

CLC has been used as auxiliary data in several studies that required access to standardized land cover data from several countries. Examples include the detrending of air pollution observations to prepare them for geostatistical interpolation (Janssen et al., 2008); dasymetric disaggregation of population data (Gallego et al., 2011); and stratification for upscaling carbon stock data to the national level (Cruickshank et al., 2000).

CLC covers the immediate needs of the EEA, and the shortcomings identified in the program are obviously also acceptable to many other users. The involvement of national institutions in the production of CLC has furthermore become a vehicle for an emerging collaboration in land monitoring below the pan-European level (Ben-Asher et al., 2013, Arnold et al., 2016). This cooperation requires thorough understanding of the content and variability of the CLC product to ensure correct interpretation and facilitate communication between the many users of the dataset.

Notwithstanding the success of CLC as a tool for pan-European monitoring and the widespread use of the dataset, there have been few attempts to examine the composition and accuracy of the CLC classes. The main work in this respect is an assessment of the thematic accuracy of CLC for the reference year 2000 (CLC2000) commissioned by EEA (Büttner and Maucha, 2006). The study used data from the LUCAS project (European Land Use/Cover Area Frame Statistical Survey) implemented by Eurostat (Eurostat, 2003). LUCAS is a point survey providing more detailed information than CLC (Gallego and Bamps, 2008). The study found that the total reliability of CLC2000 was 87.0 ± 0.8%, implying that the 85% accuracy requirement specified for CLC2000 was fulfilled. The accuracy for individual classes was highly variable, ranging from 95% down to below 70%. Some classes could not be assessed due to incompatibility between the specifications of the CLC and LUCAS nomenclatures. The main sources of mistakes included erroneous labeling (commission errors) and omitted details. Geometrical inaccuracies were less important (Büttner and Maucha, 2006).

Several pan-European and global land cover products (GlobCover, MODIS land cover (MODISLC), GLC2000 and CORINE) were compared in a study using detailed, national LULC data as the reference. When the inherent generalization and thematic uncertainty resulting from the partial overlap in legend definitions and lack of homogeneity within reference and classification were considered, the study concluded that CLC had the highest accuracy among these products (Pérez-Hoyos et al., 2014).

The accuracy of CLC has also been the topic of several regional studies. A study of the Iberian coast used point sampling from Google Maps as reference data. The results showed that CLC can be a good choice to illustrate LULC patterns at small cartographic scales, but also that the measurements and statistics for local areas are insufficient (Grullón et al., 2009). Another study, carried out in Northern Finland, found that the estimation errors of land cover variables based on CLC2000 were reasonably small in this region (Törmä and Härmä, 2004). On the other hand, a comparison between four vegetation classes in CLC2000 and the Forestry Map of Spain concluded that the concurrence between the two datasets was low (Felicísimo and Sánchez-Gago, 2002).

National verification projects have been carried out in Portugal and Norway. CLC2000 for Portugal was compared to reference data derived from visual interpretation of aerial photography for selected sample areas. The results revealed an overall thematic accuracy of 82.8%, with a confidence interval of 80.5–85.2 (i.e. lower than the result reported by Büttner and Maucha, 2006). The majority of the CLC classes were mapped with high accuracy (Caetano et al., 2006). A study of CLC2006 for Norway used the detailed Norwegian land resource map (scale 1: 5 000) to provide a statistical description of the content of the CLC classes. The study demonstrated good overall correspondence between the definitions and the actual content of the CLC classes (Aune-Lundberg and Strand 2010).

The objective of the present paper is to study the content of the CLC classes and thereby examine the thematic accuracy of the CLC dataset. The study compared CLC for the reference year 2018 (CLC2018) for Norway to several more detailed national LULC datasets. The aim was to describe the LULC composition of the CLC classes and evaluate the results against the definition provided in the CLC technical guidelines.

The study has three parts. The first part is addressing the overall content of the CLC classes. The second part is a more detailed study of mires (fens and peatland). It is known from other studies that mires are underestimated in maps compiled from aerial imagery (Bryn et al., 2018) and the hypothesis is that this also applies to CLC. The third part is a closer examination of the heath and moorland that constitute a large part of the Nordic landscape, suspecting that the mountain classes are tainted with considerable thematic overlap.

2. Material and methods

2.1. Material

The area covered in this study is the entire mainland of Norway, located in the northern part of the European continent between 58 and 71° N; 6 and 31° E. The size of the study area is approximately 324 000 km^2. The CLC dataset for Norway for the reference year 2018 (CLC2018) was compared to four different national datasets to assess the accuracy and examine the content of the CLC classes. The national datasets used in the study were 1) the detailed land resources dataset AR5; 2) the generalized land resource dataset AR50; 3) the AR18X18 area frame survey of land cover; and 4) the national land use dataset produced by the national statistical agency Statistics Norway. CLC2018 and the four national datasets are described in further detail below. The study also used miscellaneous data obtained from the online statistical databank at Statistics Norway (Statistics Norway, 2018) and statistics published by NIBIO Survey and statistics (NIBIO, 2018).

2.1.1. CLC2018 for Norway

CLC2018 was produced by NIBIO Survey and statistics during 2018. The dataset was commissioned by the EEA as part of the implementation of the pan-European component of the Copernicus Land monitoring program. The dataset is consistent with the technical guidelines provided by Bossard et al. (2000) and Kosztra et al. (2017). The aim of the Norwegian CLC2018 dataset is to explain the Norwegian landscape in the context of the pan-European level. The dataset is coarse and is not meant to be used for generation of environmental analysis and the assessments on the national and local levels.

2.1.2. The land resource dataset AR5

A land resource classification resembles a land cover dataset, but the classes represent a mixture of land cover, land use and land capability. AR5 is the Norwegian high-resolution land resource database. The geometric details are fit for mapping at scale 1: 5 000. AR5 is based on a standardized national classification system with twelve main classes. Three additional characteristics are added to the main classes, resulting in approximately 125 detailed classes. The AR5 dataset describes land resources (emphasizing land cover and productivity) with special attention to the capability for agriculture and forestry. AR5 is a national, seamless database, but detailed information about the land resources is only available for the area below the tree line. Areas above the tree line are mapped as a single class.

The MMU in AR5 is 0.05 ha for agricultural areas, transportation network and water bodies; 0.2 ha for forest, peat bogs and open areas; 0.5 ha for urban areas; and 2.5 ha for perpetual snow and glaciers. The geometric accuracy is 2 m.

2.1.3. The land resource dataset AR50

AR50 is the Norwegian national land resource dataset for use in scale 1: 50 000. AR50 is a generalized version of AR5 below the tree line. The coverage in mountain areas is compiled by combining a satellite-based land cover dataset (Gjertsen et al., 2011) with data from national topographic maps for scale 1: 50 000 (produced by the Norwegian Mapping Authority).

The MMU used in AR50 is 1.5 ha and the geometric accuracy is 20 m. The AR50 nomenclature has eight major LULC classes. Three of these classes are further subdivided, providing 18 classes in total. We used AR50 for areas without AR5 coverage, mainly mountain areas.

2.1.4. The AR18X18 area frame survey

The Norwegian area frame survey of land cover (AR18X18) is a national, homogeneous, unbiased and accurate statistical survey of land cover in Norway (Strand, 2013, Bryn et al., 2018). The survey is a systematic sample with a random starting point, following an 18 X 18 km grid mesh. A Primary Statistical Unit (PSU) is located at each intersection of the grid, giving a total of 1081 PSUs systematically distributed throughout Norway. Each PSU is 1500 X 600 m, i.e. 0.9 km^2.

A complete land cover map for each PSU was compiled through a field survey, using the Norwegian system for vegetation and land cover mapping at intermediate (1: 20 000–1: 50 000) scale (Rekdal and Larsson, 2005). The nomenclature consists of 45 vegetation types and nine other land cover types. The mapping system is using a MMU of 0.1 ha for rare or particularly important vegetation types and 0.5 ha for common types (Strand, 2013).

2.1.5. SSB Land Use

SSB Land Use is a national land use dataset compiled by the national statistical authority Statistics Norway (abbreviated SSB), providing detailed information about built-up and other intensively used areas (Steinnes, 2013). SSB Land Use is based on 18 different geographical data sources. The dataset is prepared and automatically assembled using a hierarchical decision system where the available dataset with the best quality at any particular location is used. SSB Land Use is produced for mapping at scale 1: 5 000 and is updated on a regular basis. The legend is hierarchical, with 13 main classes further divided into 42 second level classes.

2.2. Methods

An overlay (spatial intersect) between the Norwegian CLC2018 and AR5 was carried out for areas with full AR5 coverage (mainly below the tree line). The overlay (spatial intersect) of two polygon datasets is a geometric operation which divides all the polygons in the first dataset into smaller units using the boundaries of the polygons in the second dataset. The new and smaller polygons resulting from this operation will have a 1:1 relationship with one (and only one) polygon unit in each of the two original datasets. In our case, the overlay between CLC and AR5 produced a new dataset where each polygon had a unique CLC code and a unique AR5 code.

For the remaining areas, we carried out a similar overlay between CLC2018 and AR50 using Python scripting with geoprocessing tools provided in ArcGIS®. The datasets were divided into 19 smaller areas (tiles) due to the large size of the database. Finally, we merged the results of these overlays together, producing a new seamless national dataset combining information about CLC classes and AR5/AR50 classification. Based on this dataset, we compiled statistics showing the distribution (percentages) of AR5 and AR50 classes for each CLC class.

We used AR18X18 for the verification of the CLC class *412 Peat bogs* and the four CLC mountain classes (*322 Moors and heathland; 332 Bare rock; 333 Sparsely vegetated areas; 335 Glaciers and perpetual snow*). An overlay between CLC2018 and AR18X18 was carried out for this purpose.

The precision of CLC class *412 Peat bog* was examined using a confusion matrix were data from the AR18X18 field inventory represented the “actual value” (Congalton, 1991). Overall accuracy was calculated as the percent of the area that was correctly classified. Producer’s accuracy was calculated as the percent of the (actual) area of a class that was correctly classified as this class. The remaining area of the class was considered as the omission error. User’s accuracy was calculated as the percent of the area classified as a certain class that actually belonged to this class. The remaining area, incorrectly assigned to this class, was considered as the commission error (Congalton and Green, 1999).

We compared the composition of peat bogs (mire, fen etc.) in AR18X18 in the areas incorrectly mapped as not mire in CLC2018 to the overall distribution and classification of peat bogs in AR18X18. The purpose of this exercise was to test the hypothesis that particular types of peat bog were more prone to omission errors.

We examined the composition of the four CLC mountain classes using the relative distribution of AR18X18 vegetation classes inside each mountain class. The hypothesis that the composition of each CLC mountain class was different from the others was tested using the Wilcoxon signed-rank test (Wilcoxon, 1946).

SSB Land Use was used to evaluate the built-up areas in CLC. For this purpose, we carried out an overlay between the CLC built-up classes and SSB Land Use and compiled statistics showing the distribution (percentages) of SSB Land Use classes for each built-up class in CLC.

3. Results

3.1. The overall composition of CLC classes

There are 44 classes in the European CLC nomenclature, but only 33 classes are present in Norway. Coverage for 32 classes (excluding 523 *Sea and ocean*) in absolute (km^2) and relative (figures) are found in Table 1. The table also includes summaries for four groups of CLC classes: Built-up land, Agriculture, Forest and Mountains. Some classes (e.g.412 *Peat bogs*) will be found in mountains as well as lowlands and are excluded from the summary. Forest and mountain areas dominate the Norwegian landscape. A small part of the land is built-up, and agriculture is also a marginal LULC category in Norway.

The composition of each CLC class in terms of national land cover classes derived from AR5 and AR50 is illustrated in Fig. 1. This is complemented by Fig. 2, showing the composition of the CLC classes for built-up land in terms of land use derived from the SSB Land Use dataset. Exact figures cannot be read directly from the figures but are provided in the Discussion (below) when relevant.

Table 1
CLC classes in Norway (excluding 523 *Sea and ocean*) with acreage (km^2) and percent coverage for individual classes. Specific figures are given for four groups of classes.

CLC	Name	Km^2	%	Group	%
111	Continuous urban fabric	20	0.01	Built-up areas	0.73
112	Discontinuous urban fabric	1 883	0.57		
121	Industrial or commercial units	238	0.07		
122	Road and rail network	26	0.01		
123	Port areas	12	<0.01		
124	Airports	74	0.02		
131	Mineral extraction sites	89	0.03		
132	Dump sites	5	<0.01		
133	Construction sites	7	<0.01		
141	Green urban areas	64	0.02		
142	Sport and leisure facilities	506	0.15		
211	Non-irrigated arable land	5 782	1.76	Agriculture	5.28
231	Pastures	252	0.08		
242	Complex cultivation	1 601	0.49		
243	Land principally occupied by agriculture	9 667	2.95		
311	Broad-leaved forest	44 153	13.47	Forest (including 324)	35.50
312	Coniferous forest	60 505	18.46		
313	Mixed forest	5 008	1.53		
321	Natural grassland	88	0.03		
322	Moors and heathland	48 025	14.65		
324	Transitional woodland	6 676	2.04		
331	Beaches, dunes and sand plains	17	0.01		
332	Bare rock	22 406	6.84	Mountain (including 322 and 335)	47.32
333	Sparsely vegetated areas	81 826	24.96		
334	Burnt Areas	4	<0.01		
335	Glaciers and perpetual snow	2 840	0.87		
411	Inland marshes	4	<0.01		
412	Peat bogs	21 463	6.55		
423	Intertidal flats	448	0.14		
511	Water courses	453	0.14		
512	Water bodies	13 648	4.16		
522	Estuaries	2	<0.01		
	Total	**327 792**	**100.00**		

3.2. Detailed study of mires

Mires are represented in CLC as class 412 *Peat bog.* This class covers 6.4% of the land area in CLC2018. A cross-tabulation between the land cover classification in AR18X18 and CLC2018 shows that 3% of the sample area in AR18X18 is classified as mire in both datasets (Table 2).

The overall accuracy of this class is 90%, because large areas are correctly classified as "not mire". User's accuracy is only 43%, implying that 57% of the area classified as 412 *Peat bog* is the result of commission errors. Producer's accuracy is even lower, at 33%, demonstrating considerable omission errors as well. The accuracy is not stationary. In general, lower accuracy is found in southern and central Norway (where between 25% and 50% of the land classified as 412 *Peat bog* is some kind of mire) than in the rest of the country, where between 50% and 75% of the area included in this class is mire.

The omission error for mire is examined in Fig. 3. The figure compares the mire omitted in CLC to the overall distribution of mire types in the AR18X18 survey. There is no apparent trend in this figure. The omission of mire from CLC2018 is randomly distributed between the different types of mire. No type appears to be more prone to omission than other types.

3.3. Mountain areas

Large parts of Norway are covered by mountains. CLC class 333 *Sparsely vegetated areas* is consequently the most common CLC class in Norway, covering 25.0% of the land. The other major classes in the mountains are 322 *Moors and heath land* (14.7%), 332 *Bare rock* (6.8%) and 335 *Glaciers and perpetual snow* (0.9%). We used the land cover survey AR18X18 (with data collected in-situ) to examine and compare the composition of these classes. An overview of the results is found in Fig. 4 (detailed numbers will be provided as part of the Discussion).

We tested the differences between the four mountain classes 322 *Moors and heath land*, 332 *Bare rocks*, 333 *Sparsely vegetated areas*, and 335 *Glaciers and perpetual snow* using the Wilcoxon signed ranks test. The null-hypothesis (no difference) could not be rejected ($p < 0.05$) when we compared 322 *Moors and heath land* and 333 *Sparsely vegetated areas*, indicating that these two CLC classes in some respect are similar. Both 332 *Bare rocks* and 335 *Glaciers and perpetual snow* were different from all other mountain classes.

A confusion matrix of the mountain classes could not be produced because the "correct" classification is unknown. The analysis demonstrate that 322 *Moors and heath land* and 333 *Sparsely vegetated areas* are fairy similar in terms of LULC content but does not allow us to determine the areas that should be assigned to 322 and 333 respectively.

4. Discussion

4.1. Built-up land

The combined coverage of the CLC built-up classes (111–133) in Norway constitutes 0.7% of the total land surface. Statistics Norway has estimated that built-up land (excluding recreational facilities, agricultural buildings, and the transport network) covers 0.71% of the land (SSB 2018, Table 09594). This agreement is due to omission errors in CLC in rural areas being balanced by commission errors in urban areas. The result is a fairly correct overall estimate.

We found that 97.7% of CLC class 111 *Continuous urban fabric* and 67.8% of CLC class 112 *Discontinuous urban fabric* was mapped as built-up land in the national datasets. According to the definition, CLC class 111 *Continuous urban fabric* should contain more than 80% impermeable features and the land use should concentrate on residential areas (Kosztra et al., 2017). SSB Land Use showed that the class had 95.4% impermeable surfaces and the residential areas made up 42.4% of the class.

CLC class 112 *Discontinuous urban fabric* is defined as having between 30 and 80% impermeable features. SSB Land Use showed 68.8% impermeable features inside the class, with 45.0% of the class being residential areas. The CLC class 121 *Industrial or commercial units* contained 45.9% industrial, commercial or service areas, mixed with 12.7% roads and 10.6% residential areas. Industrial and commercial areas constitute 0.07% of the total area in CLC but 0.14% according to Statistics Norway.

According to Statistics Norway, the road and railway system is the dominant category of built-up land in Norway, covering 0.69% of the total land area. Conversely, <0.01% of the area is mapped as CLC class 122 *Road and railway network*. Much of the Norwegian road and railway network is crossing through forests and mountain areas. The width is too narrow to be mapped in CLC (minimum feature width 100 m). The omission of roads and railways in rural areas is therefore in agreement with the mapping instructions. The areas mapped as CLC class 122 *Road and rail network and associated land* contained 22.3% roads, rail network and associated land. In this case, a fair amount of surrounding land has

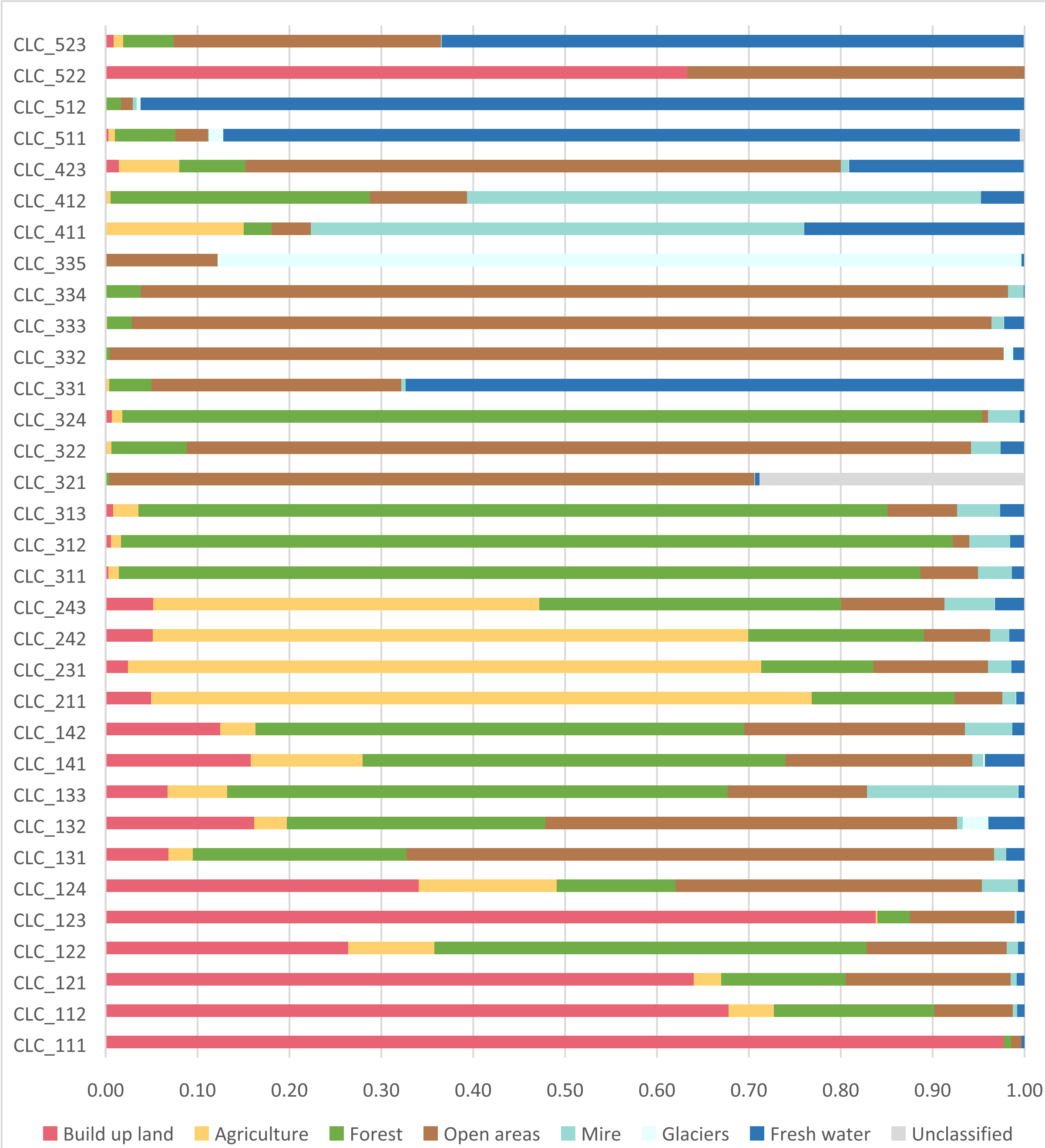

Fig. 1. The content of the CLC classes in Norway described by the main classes of the land resource datasets AR5 and AR50.

been included into the class in CLC2018, while a large part of the actual transportation network is omitted.

The CLC class 123 *Port areas* contained only 2.6% quay and port areas. As much as 50% of the land assigned to the class was industrial, commercial and service areas. The border between the ports and the surrounding built-up land is understandably hard to determine from satellite imagery. The CLC class 124 *Airports* was more precisely delineated and consisted of 68.1% land that belonged to airports. Both ports and airports are small classes in terms of acreage. The considerable commission errors have marginal influence on the national statistics but do also show that the CLC data is of little relevance for these classes.

The CLC class 141 *Green urban areas* is a minuscule class in CLC2018 for Norway (0.02% of the total). Furthermore, only a small portion (3.6%) of the land assigned to this class turned out to be real urban green areas, according to SSB Land Use. Another 5.7% were sport facilities, but the main part (73.9%) was forest and open land not assigned to any particular land use. The land mapped as CLC class 142 *Sport and leisure facilities* proved to be more meaningful and includes 16.4% recreational facilities and 9.3% sport facilities. However, also this class contained considerable areas (62.3%) of forest and open land not assigned to any particular land use.

The results show that built-up land in general is correctly classified when the generalization rules implied in the CLC specifications are considered. CLC shows built-up land when the category is continuous over sufficiently large areas. Small patches or narrow features are (by definition) omitted. The error caused by omission of small or narrow built-up features in rural areas is balanced by inclusion of forest and open spaces near the larger built-up areas. The more detailed classification of built-up land is, however, inconsistent and of little statistical or cartographic value in a Norwegian context.

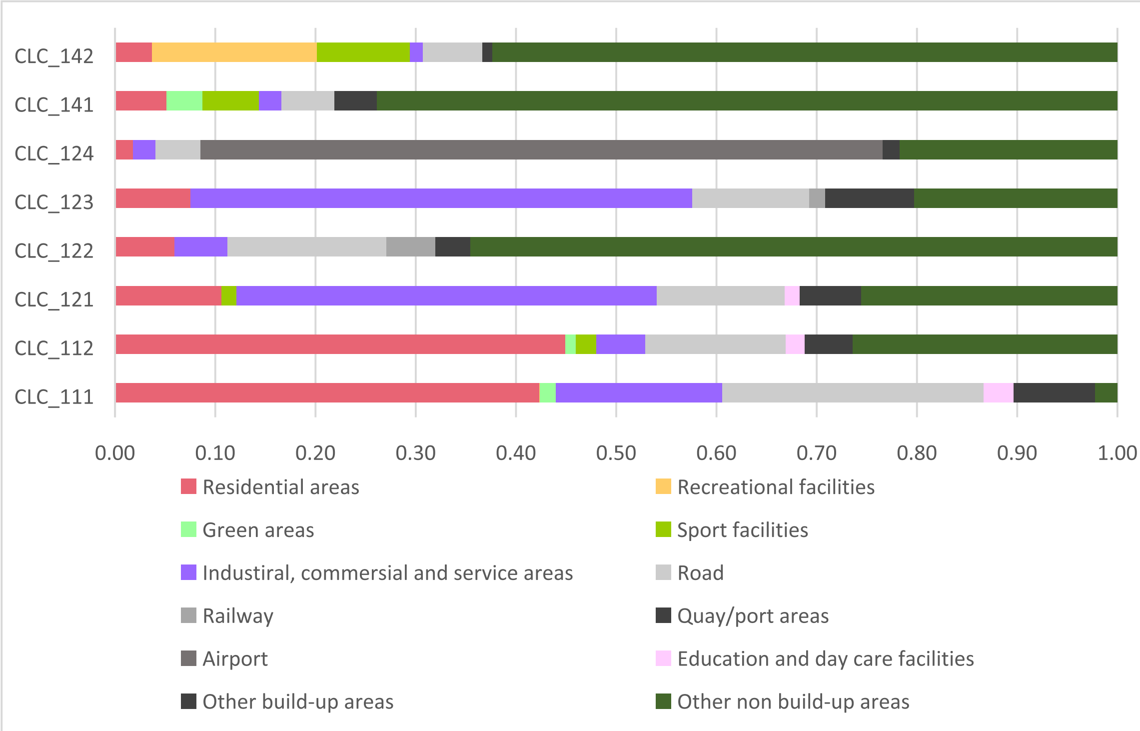

Fig. 2. The content of the built-up classes of CLC in Norway described by the SSB Land Use classes. The class «other built-up areas» contains buildings for religious and cultural activities, agriculture, fisheries, cargo and transport, emergency services, health services, technical infrastructure, telecommunications and unclassified buildings.

Table 2
Cross-tabulation of area (%) included in the area frame survey AR18X18 and CLC2018, both reclassified as mire and not-mire.

	CLC2018			
		Mire	Not mire	Total
AR18X18	Mire	3	6	9
	Not mire	4	87	91
	Total	7	93	100

4.2. Agricultural land

The CLC class 211 *Non-irrigated arable land* constitutes 1.8% of the land area in CLC2018. Another 0.08% of the land is mapped as 231 *Pastures*. CLC also includes two classes of mixed agricultural areas; 242 *Complex cultivation* and 243 *Land principally occupied by agriculture with significant areas of natural vegetation*. These classes cover 0.5% and 3.0% respectively. Together, the CLC agricultural classes found in Norway cover 5.3% of the land, but the classes will (by definition and generalization) include built-up land on the farms (0.16% according to Statistics Norway) as well as a considerable amount of semi-natural and natural vegetation. The actual figure for arable land is 2.8% (NIBIO, 2018) and another 0.7% is managed pastures.

The results imply that approximately 1.8% of the land classified as agriculture in CLC is semi-natural and natural vegetation included in the CLC agricultural classes by generalization (provided that all the agricultural land is included in these CLC classes). We found that agriculture is the dominant land cover in the three classes where this is expected:

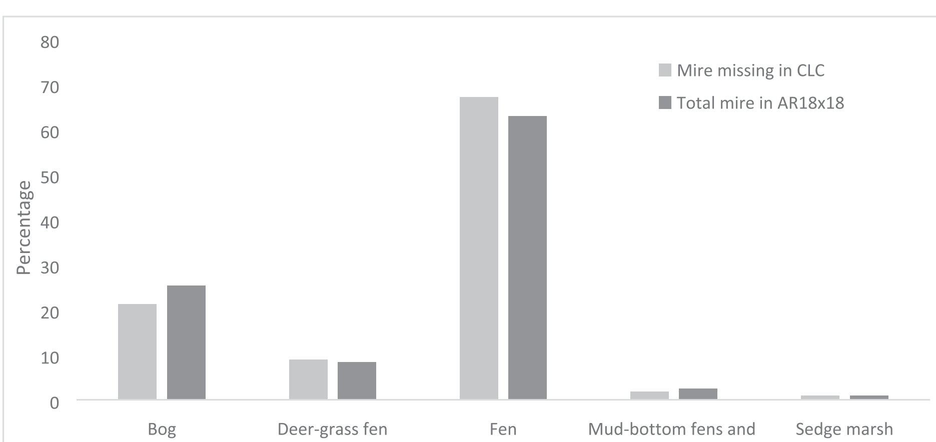

Fig. 3. Composition of peatland by mire land cover types (%). Light grey: Peatland omitted in CLC2018. Dark grey: All peatland in the AR18X18 field survey. The probability for omission errors is equally distributed across the mire land cover types.

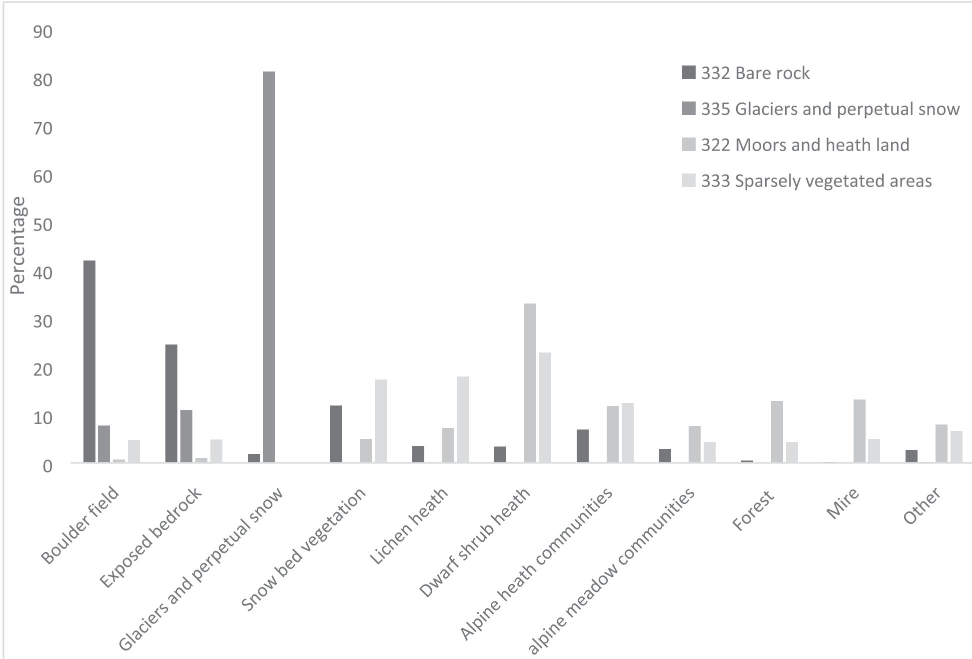

Fig. 4. The composition of the four mountain classes in CLC (%) in terms of vegetation classes from AR18X18.

211 *Non-irrigated arable land* (72%), 231 *Pastures* (69%) and 242 *Complex cultivation* (65%). Most of the agricultural land is correctly classified in CLC, but we also found tracts of agricultural land in a few other CLC classes (see Fig. 1).

Some of the 72% agricultural land included in CLC class 211 *Non-irrigated arable land* is actually pasture (3.6%). Only 68.3% of the area is fully cultivated land. By definition (Kosztra et al., 2017) this class should contain >75% fully cultivated land, and this aspect of the definition is not satisfied. The fact that the proportion of agricultural land inside the class is lower than expected is a result of topographic differences between the small-scale agriculture in Norway and the open agricultural landscapes found in other parts of Europe. CLC polygons with <75% agricultural land should probably be reclassified as 243 *Land principally occupied by agriculture with significant areas of natural vegetation*.

The Norwegian CLC dataset includes two classes of mixed agricultural areas: CLC class 242 *Complex cultivation* and CLC class 243 *Land principally occupied by agriculture with significant areas of natural vegetation*. These classes cover 0.5% and 2.9% respectively. CLC class 242 *Complex cultivation* is a mixture of different cultivation types. Built-up areas can occupy up to 30% of the surface (Kosztra et al., 2017). Natural or semi-natural components should not exceed 25% of the area. The examination of the class in Norway showed that 63.2% of the area inside polygons classified as CLC class 242 *Complex cultivation* was some form of agricultural area. This complies with the specifications. Build up areas including infrastructure cover 5.1% of the area, well below the defined threshold. Natural or semi-natural components make up 30.0% of the area, slightly exceeding the threshold allowed by the definition of this class.

An examination of the spatial distribution of the content of the CLC 242 *Complex cultivation* also revealed that failure to conform with the definition is more common in the southernmost part of Norway than in the rest of the country. In the south, <50% of the polygons assigned to this class have the correct composition of basic land cover types. The frequency of this CLC class is also higher in the southernmost region than in rest of the country. The natural and semi-natural component of the class in this region constitute between 50% and 75% and it is more appropriate to assign these areas to class 243 *Land principally occupied by agriculture with significant areas of natural vegetation*.

The CLC class 243 *Land principally occupied by agriculture with significant areas of natural vegetation* includes agricultural land mixed with a significant amount (25%−75%) of natural and semi-natural vegetation (Kosztra et al., 2017). The amount of agricultural areas should not exceed 75%. 42.0% of the land assigned to this class is some form of agricultural areas. This is within the allowed range. Natural and semi-natural areas cover 52.7% of the class, while built-up areas (including infrastructure) cover 5.2%.

4.3. *Forest*

National high-resolution datasets show that 37.7% of Norway is covered by forest (NIBIO, 2018). The forest classes in CLC2018 constitute 35.8%, which is close to the actual figure. Most of the forest is classified as CLC class 312 *Coniferous forest*. This is the second largest CLC class in Norway, covering 18.5% of the land in CLC2018. The official figure is 19.8% (NIBIO, 2018). Polygons assigned to class 312 *Coniferous forest* in CLC usually include >75% conifer forest according to the more detailed datasets. For large areas in the central forested region in southeast Norway, more than 90% of the areas mapped as 312 *Coniferous forest* complied with the definition when examined using more detailed data.

CLC class 311 *Broad-leaved forest* covers 13.5% of the land area according to CLC2018. The actual figure is 9.0% (NIBIO, 2018). User's accuracy for this class is 49%, with a commission error of 51%. User's accuracy was highest in the northernmost and southwestern part of Norway, where more than 75% of the area assigned to this class turned out to be actual broad-leaved forest. User's accuracy in central and southeastern Norway was generally low. Areas classified as 311 *Broad-leaved forest* in these regions mostly turned out to have <25% broad-leaved forest.

CLC 313 *Mixed forest* covers 1.5% in the Norwegian CLC2018. The official statistics is 2.3%. The commission error (53.3%) was mostly (34.8%) other types of forest. Both broad-leaved and coniferous forests were occasionally classified as mixed forest. The accuracy was high in the central part of south Norway, but lower along the coastline.

4.4. *Water*

The two inland water classes, 511 *Water courses* and 512 *Water* *bodies*, both had a high user's accuracy. Streams and rivers constitute 86.7% of the area classified as 511 *Water courses* and lakes constitute 96.2% of the area classified as 512 *Water bodies*.

4.5. Mire, fens and peatland

Mire, fens and peatland is particularly difficult to map using any kind of image interpretation. A recent study of Norwegian mires showed that while mires cover 5.8% of the land according to topographic maps, the actual coverage estimated from a statistically unbiased field survey is 8.9% (Bryn et al., 2018). Mires in CLC cover 6.4% and was verified using data from the same field survey. The study revealed that <50% of the land mapped as mire and peatland in CLC belonged to this class. Furthermore, only 38% of the actual mire and peatland was correctly classified as such in CLC.

Exact match between CLC and a detailed area frame survey is not to be expected. Small patches of mire should not appear in the CLC data. Patches of forest and heathland in larger mires will also introduce noise. Still, the results show that CLC is faced with the same challenge as other mapping systems that rely on remote sensing (including those based on interpretation of aerial imagery) when attempting to detect mires and peatland. Mire and peatland omitted from CLC had the same composition of mire types as the overall distribution of mire in Norway (Fig. 3). This shows that no mire type is more prone to omission than other types.

4.6. Mountains

Class 322 *Moors and heathland* cover 14.7% of the CLC area. The class consists of vegetation with low and closed cover, dominated by bushes, shrubs, dwarf shrubs and herbaceous plants (Kosztra et al., 2017). Class 322 *Moors and heathland* should be used for arctic moor areas with moss, lichen, gramineous coverage and small dwarf or prostrated shrub formations and alpine heath with dwarf shrubs, mosses and lichens. The tree-like species cover should not exceed 30% of the surface. In CLC2018 for Norway, we found that 51.9% of the class was covered by alpine heath communities, of which 33.0% was dwarf shrub heath. 5.0% was snow bed vegetation and 7.6% was alpine meadow communities. 12.8% of the area in the class was forest and 13.1% was mire.

Class 332 *Bare rock* constitutes 6.8% of CLC2018. The land classified as 332 *Bare rock* should by definition contain >90% rocks and should only be sparsely vegetated (Kosztra et al., 2017). The land assigned to this class in Norway contained 66.4% rocks, 1.8% glaciers and perpetual snow and 31.7% areas with vegetation. Approximately half of the vegetated area was sparsely vegetated. The class does not comply with the definition since the proportion covered by bare rock is too low. This conclusion also stands if the sparsely vegetated area is assumed to contain exposed rocks.

Class 333 *Sparsely vegetated areas* is the largest CLC class in Norway, covering 25.0% of the mainland. The class should be used for areas with sparse vegetation, covering 10% to 50% of the surface (Kosztra et al., 2017). Lichen heath and scattered high-altitude vegetation is the expected content in Norway. The scattered vegetation can be composed of herbaceous and/or ligneous and semi-ligneous species. The analysis revealed that 9.5% of the area assigned to this class was bare rock while 90.4% was covered by some form of vegetation. 35.1% of the area was snow bed vegetation and lichen heath; the remaining 55.3% of the area was covered with more vigorous vegetation, including larger herbs and small bushes.

Class 335 *Glaciers and perpetual snow* covers 0.9% in CLC2018. The area assigned to this class was composed of 81.1% glaciers and perpetual snow and 18.9% rocks. Up to 50% rocks is allowed according to the nomenclature guidelines (Kosztra et al., 2017) and the content in the Norwegian dataset was well within this limit.

The Wilcoxon signed ranks test was used to test the differences between the four mountain classes. There was no statistical difference between 322 *Moors and heath land* and 333 *Sparsely vegetated areas*, indicating considerable overlap between the two classes in terms of vegetation content. This is probably due to the combination of the large size of the CLC polygons and the complex mosaic of vegetation with sparse vegetation on exposed ridges and heath vegetation in the intermediate recesses.

4.7. Other land

The CLC2018 data also includes a few marginal, in terms of acreage, classes of natural land. Classes like 423 *Intertidal flats*; 331 *Beaches, dunes and sand plains*; 411 *Inland marshes*; and 522 *Estuaries* cover only 0.1% of the land, even when they are counted together. Taking class 331 *Beaches, dunes and sand plains* as an example, this class occupy 17 km^2 (0.005% of the land) according to CLC2018. The area frame survey AR18X18 (although using slightly different class definitions than CLC) estimated that sand dunes and gravel beaches cover approximately 20 km^2 (0.006% of the land). Apparently, the figure provided by CLC is quite correct, but a closer examination of the area mapped as CLC 331 *Beaches, dunes and sand plains* revealed that it contains 67.3% water and only 25.3% open areas (possibly beaches dunes and sand plains, but details are not available in AR5). The estimate for this class is therefore a result of balancing omission and commission errors. Small beaches, dunes and sand plains are omitted from the class and a considerable area with ocean committed to the class by generalization. The errors cancel each other out. The actual information about rare classes with negligible presence in CLC is that they are present, but that the exact acreage is uncertain.

We also compared the content of individual polygons with the formal definition found in the CLC guidelines for some of the CLC class. For 243 *Land principally occupied by agriculture with significant areas of natural vegetation* 82.3% of the polygons (representing 89.2% of the area) assigned to this class complied with the class definition. A similar result was obtained for 312 *Coniferous forest* where 80.6% of the polygons (representing 94.3% of the area) were compliant. The results for other classes were less impressing. Only 15.8% of the polygons (representing only 9.0% of the area) assigned to class 211 *Non-irrigated arable land* conformed to the corresponding class definition.

Improvement in the CLC classification is therefore possible, simply by using detailed LULC data to characterize and classify the polygons. Taking CLC class 211 *Non-irrigated arable land* as an example, 19% of the polygons assigned to this class should be reclassified as 242 *Complex cultivation* and 53% as CLC class 243 *Land principally occupied by agriculture with significant areas of natural vegetation*. These changes would reduce the commission error for 211 *Non-irrigated arable land* and the omission error for the other two classes.

Overall, increased use of ancillary data can lead to major improvement of the CLC dataset for countries where such information is available. The initial CLC classification may not even be required. As suggested by the Harmonization of European Land Monitoring (HELM) project (Ben-Asher et al., 2013), a partition of the land surface based on spectral similarity in satellite imagery may be a more appropriate starting point. The content of each polygon in the partition can subsequently be characterized using auxiliary data and the appropriate class assigned to the element according to the resulting statistical profile. The result can be a better, thematically more accurate CLC dataset for use in European land monitoring.

5. Conclusion

The main purpose of this study was to describe the LULC composition of the CLC classes and evaluate the results against the definition provided in the CLC technical guidelines. The results show that the overall quality of CLC2018 in Norway is high and the content mostly compliant with the class definitions.

CLC does not provide high accuracy when evaluated against detailed high-resolution data but this is not important. CLC is by definition a generalized product. The main purpose is to provide a common standard for use across Europe. Similar studies are therefore needed from other European countries as a basis for comparison and a documentation of the variability inside the individual classes. Completion of CLC data with national LULC data can also provide conditions for the environmental analysis and assessment conducted at more detailed levels than the pan-European one.

The study showed that the thematic accuracy was best for the broad classes. Lower accuracy was encountered for the more detailed classes. Based on the current assessment, we would suggest removing these classes from the nomenclature. It is, however, likely that classes appearing as small in Norway cover larger areas in other European countries. The solution is therefore not to change the nomenclature, but users should be aware of the high uncertainty linked to these marginal classes in the Norwegian dataset.

Adding auxiliary information is to populate the polygons with characteristics obtained from national registers. Examples are demographic information, number or acreage of buildings and the presence/absence of selected land use features. The result would be an enriched CLC dataset with informative characteristics added to the individual polygons, in addition to their assigned CLC land cover class.

A closer examination of mires (fens and peatland) revealed large errors and a general underrepresentation of this land cover type. The result was expected and in agreement with other studies documenting a similar bias in maps compiled by interpretation of aerial photographs. Mire is a difficult and challenging feature to map from satellite and aerial imagery.

A closer examination of the heath and moorland that constitute a large part of the Nordic landscape, revealed a considerable thematic overlap between the two CLC classes used in these areas. A possible explanation is that the variation in the mountain vegetation is a spatial mixture where individual classes are undetectable at the mapping resolution used in CLC. On the other hand, it may also be an error caused by the image interpretation. A closer examination of the problem is required before conclusions can be drawn.

Finally, the study showed that parts of the Norwegian CLC should be reclassified at the polygon level to improve compliance with the class definitions. This can easily be done using the data created during this study. The method used in this study can thus also be included in the CLC mapping methodology.

An unintended but interesting result from this study is that it demonstrates a possible improvement of the CLC production method. The visual interpretation of remote sensing imagery can be replaced by automated segmentation, producing a partition of the surface into polygons appearing spectrally homogeneous in the remote sensing images. The polygons must comply with CLC geometrical standards (minimum mapping unit of 25 ha and minimum feature width of 100 m) but no classification is needed. The polygons in the partition can subsequently be populated with LULC data from national sources and CLC class assigned using a rule-based interpretation of the LULC composition of each polygon. The result would be a CLC dataset compliant with CLC definitions, standardized to a common nomenclature throughout Europe and based on a more detailed and reliable approach than the manual interpretation of satellite images.

CRediT authorship contribution statement

Linda Aune-Lundberg: Conceptualization, Methodology, Formal analysis, Writing - original draft, Project administration, Writing - review & editing. **Geir-Harald Strand:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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