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From CORINE Land Cover to CLCplus: assessment and applicability of a new system for land use and land cover mapping in Slovakia

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Abstract

Land cover and land use mapping initiatives provide important support for detecting the state and landscape changes. One of the longest land cover mapping projects is the CORINE Land Cover (CLC), which has found a wide range of uses over the last decades. Its potential successor, CLCplus, introduces a new approach that can process various landscape data to create new specific land cover products. In this paper, we used the CLCplus methodology to create a CLCplus Legacy map, which complements the existing CLC product but has much better spatial and thematic accuracy. We evaluated the resulting map by using the conformity at the first and third hierarchical levels of the CLC nomenclature for the whole territory of Slovakia and specifically at the landscape level in two selected areas with landscape metrics. The resulting map showed a high level of conformity — 90% at the first hierarchical level compared to 64% at the third hierarchical level with original CLC product, mainly due to the more detailed mapping method and the complexity of the classes at the third hierarchical level, which caused a change in the composition and configuration of the landscape as evidenced by the changes in landscape metrics. Landscape metrics highlighted disparity of CLC and CLCplus Legacy due to higher spatial detail of CLCplus, especially with the increased number of patches (from 122 to 1453 and from 24 to 423) and their richness (from 15 to 18 and from 8 to 15) on the landscape level.

Key words:
land use, land cover, mapping, CLCplus, EAGLE, Slovakia, landscape metrics

1 INTRODUCTION

The need for detailed characterisation of landscapes and their usage has emerged in recent decades, not only because of the more frequent changes in landscape structures but also because of technological advances in remote sensing and geographical information systems. These needs established high expectations on land use and land cover products to meet current requirements for researchers and policymakers for mapping the land cover structures at the national scales, likely coupled with the „modern era“ of land cover and land use mapping, which started in 1970s when civilian remote sensing provided operational, positionally accurate, and temporally up-to-date identification of objects on Earth‘s surface (Loveland, 2012; Oťaheľ & Feranec, 1997). The activities in the 1970s established a foundation for land use and land cover mapping with the growth of mapping initiatives over the following decades around the world, e.g. USGS National Land Cover Database, Coordination of Information on the Environment (CORINE), The United Nations Food and Agriculture (FAO) Africover, etc. (Loveland, 2012).

Co-Ordination of Information on the Environment (CORINE) program approved by the European Commission (EC) on June 27th 1985, with the objective of creating an information system about the state of the environment in the European Union (Heymann et al., 1994). At the meeting of environmental ministers of the European countries in 1991 in Dobříš, Czech Republic, it was decided that the implementation of the Biotopes, Corinair, and Land Cover (LC) projects under CORINE program would also be extended to 13 states of Central and Eastern Europe (Feranec, 2016). Given this situation, the CORINE Land Cover (CLC) program started, incorporating remote sensing-based mapping into a single land use and land cover dataset with continuity and maintaining specifications, making it a pan-European land monitoring system standard. CLC product with a Minimum Mapping Unit (MMU) of 25 ha, Minimum Mapping Width (MMW) of linear elements of 100 m, and hierarchical nomenclature with three levels and 44 classes at the third hierarchical level, was first inventoried for the reference year 1990 with first update for the reference year 2000, followed with more updates with 6-year cycle. Implementing CLC production is based on a bottom-up approach, where national teams produce a database for their country, with management, guidance, and quality control from the European Environmental Agency (EEA). Product CORINE Land Cover Change (CLC-Change) has been created since the first update (CLC2000), with an MMU of 5 ha. CLC became widely used and contributed to numerous European studies and applications (Büttner, 2014; Büttner et al., 2021).

Thanks to the coverage, temporal range, open-data policy, and many referenced applications of data, CLC brought interest in the academic community, making CLC and CLC-Change an essential part of research, even with needed awareness of its limitations of mapping and change detection methodology (Feranec et al., 2016; Bielecka & Jenerowicz, 2019). Technical parameters of these products reflect the needs of the European Commission (EC), while the requirements of other users may differ. However, throughout its lifetime, CLC has maintained its technical specifications (Büttner et al., 2021). With an MMU of 25 ha, the accuracy provided by CLC is not high enough to capture all locations affected by the change (Popovici et al., 2013), this is due to poor resolution and geometric accuracy of satellite images at the beginning of CLC and a labour-intensive and costly process of production with photointerpretation (Büttner, 2014). Expanding the nomenclature provides more thematic detail and contributes to capturing the current landscape and its changes (Falťan et al., 2020; Oťaheľ et al., 2017; Kopecká et. al., 2025). The CLC has proven to be a valuable source of land cover and land use information for assessments related to environmental problems (Erhard et al., 2016). Use cases for ecological sustainability (Lumia et al., 2023) or urbanisation (Cieślak et al., 2020) show good premise for the usage of CLC data, while other cases showed that limitations such as temporal resolution for assessing vegetation carbon stock (Gemitzi et al., 2021) or thematic detail for environmental evaluations (Pelorosso et al., 2021) highlight the need for higher spatial and thematic resolution. These limitations are suggested in future enhancements of CLC, with an approach that uses already existing data to derive information more efficiently, particularly in further improvements to Copernicus Land Monitoring Service (CLMS) products, including the second generation of CLC – CLCplus, with improved spatial and thematic performance (Büttner et al., 2021; Kleeschulte et al., 2016).

In this paper, we introduce CLCplus, apply the methodology of its framework, and demonstrate its application in the Slovak Republic. We present the CLCplus Product Suite and explain the workflow in CLCplus Core, which is the main component in deriving final products. The aim is to assess the potential of CLCplus to derive products with better spatial and thematic detail, compared to the traditional CLC product. Using heterogeneous spatial data, we derive the CLC-compatible product CLCplus Legacy for the reference year 2018. To evaluate the derived product's quality, we first compared CLC and CLCplus Legacy, providing conformity of these two datasets. With the promise of higher spatial and thematic accuracy, we also calculate selected landscape metrics on two chosen case study areas, representing two different types of landscapes: an urban area surrounded by agricultural and hilly landscape, and a lowland agricultural landscape. Selected metrics characterise the distribution and composition of land cover classes and systematically showcased the improved resolution of CLCplus.

2 CONCEPTUAL FRAMEWORK OF CLCPLUS

CLCplus cannot be considered a final dataset (such as CLC), but rather a set of interlinked components describing different landscape properties. The interlinked components, known as CLCplus Product Suite, can be delivered in discrete production phases, and each can have different technical specifications and production methodology (Büttner et al., 2021). The CLCplus Product suite consists of three main components: CLCplus Backbone, CLCplus Core and CLCplus Instances.

The CLCplus Backbone component is described as a large-scale, spatially detailed inventory of European land cover, building upon the legacy of CLC. The CLCplus Backbone comprises two main status layers: I. Raster product with an 11-class land cover classification at 10m spatial resolution, II. Vector Product with a minimal mapping unit of 0.5ha and an 18-class classification delineating small-scale landscape objects (EEA, 2022a). As of 2025, CLMS provides CLCplus Backbone raster products for the reference year 2018, update for the reference year 2021m and CLCplus Backbone layer for the reference year 2018. This study only uses the CLCplus Backbone raster product for the reference year 2018. Nevertheless, for the reference year 2021, a similar mapping approach was applied. Both CLCplus Backbone raster products are based on Sentinel-2 time series for

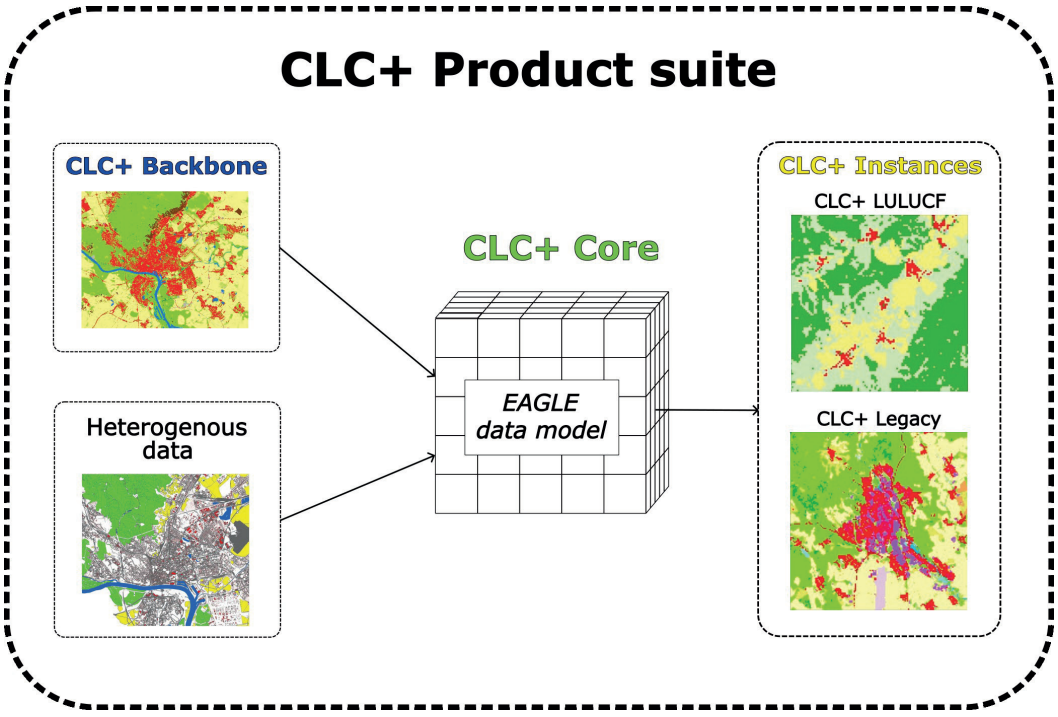


Fig. 1. Illustration of the structure of the CLCplus Product suite

the respective period. Each pixel depicts dominant land cover assigned either by a 50% area threshold or relative majority (EEA, 2022a). The classification scheme of CLCplus Backbone is shown in Table 1.

In contrast, CLCplus Core is functioning as a web application and database that is best described through the annexes to EU tenders (e.g., EEA.DIS.R0.22.001 Annex 4 to TS: Detailed description of the services - Production of CLCplus Instances). EEA (2022b) presents CLCplus Core as an "effective engine", "data container" and "data modeller" containing land information from heterogeneous sources in a grid-based information system. Data in the database can be exploited within grid-based analyses or spatial queries driven by objects from vector datasets. Differing from raster or vector, the grid is geometrically similar to a raster. However, each cell besides containing only one value is characterised by the size of spatial information, losing its geometric information. However, overall loss of information is less compared to a raster. EEA (2022b) titled grid data model "geometrically uniform polygons. Information obtained in CLCplus core aligns with the EAGLE data model, which standardised the land cover classification and land use information across Europe. The CLCplus Core initiative was launched in December 2020 and is operated by a consortium of companies awarded by the EEA.

Integrating pan-European and national data requires a harmonisation scheme that will ensure the integrity of national data sources and pan-European information layers. Such a scheme provides the EAGLE data model (Arnold et al., 2013) that acts as a tool for analytical decomposition of class definition for semantic translation between nomenclatures. Elements of the EAGLE model represent elementary landscape descriptors: I. Land Cover Components, II. Land Use Attributes, III. Land Characteristics. Usage of the elements in flexible combinations with each other will ensure comparison of attached elements to a specific class in one classification system (Arnold et al., 2023a).

Finally, the CLCplus Instances are raster land use and land cover products, with multipurpose application domains, derived from CLCplus Core with improved spatial and thematic performance compared to the current CLC product (Büttner et al., 2021). Foreseen CLCplus Instances include: LULUCF instance (CLCplus LULUCF), CLC legacy instance (CLCplus Legacy), Biodiversity strategy, CAP monitoring, etc. CLCplus LULUCF is an instance with the highest priority, contributing to the EU's 2030 emission reduction target, including the land use sector. CLCplus Legacy aims to provide a consistent European CLC-compatible product that could match increasing requirements in terms of update frequency, spatial resolution, and level of automation of EO-based products (Büttner et al., 2021; EEA, 2022b).

3 MATERIAL AND METHODS

The methodology and partial results of this paper are based on the master's thesis of Hudcovič (2024) and published as the dataset CLCplus Legacy 2018, Slovak Republic (Hudcovič, 2025; https://doi.org/10.5281/zenodo.15175096). This thesis aimed to test CLCplus for creating instances using open data from the Slovak Republic. The collection of these data was based on a search for appropriate thematic datasets to construct the first hierarchical level classes of the CLC nomenclature, from which the lower hierarchical level classes would be derived. Datasets that were found suitable:

- Artificial surfaces: INSPIRE – Buildings, INSPIRE – Transport network
- Agricultural areas: Land parcel identification system (LPIS)
- Forest and seminatural areas: Suitable data not found
- Wetlands: INSPIRE – Hydrography
- Water bodies: INSPIRE – Hydrography

Full temporal compatibility could only be achieved for the LPIS dataset, which is cyclically updated annually. In the case of INSPIRE datasets, the temporal compatibility is plausible by filtering the datasets by the date when the object was created. However, this was incorrect in the vast majority of cases. Since the INSPIRE datasets were mainly used for the thematic enrichment, we decided to use all the objects in the datasets when the data were accessed (November 2023).

Web application CLCplus Core is not publicly accessible and is only available to EIONET (European Environment Information and Observation Network). For the research purpose of the thesis Hudcovič (2024), access was provided by the EIONET Help Desk. The main part of the CLCplus Core web application is

Tab. 1. CLCplus Backbone raster product land cover classes

Class name	Description
SEALED	Impervious and sealed surfaces that are covered mainly by features with a specific height above ground or features without a specific height above ground.
WOODY – NEEDLE LEAVED TREES	Needle leaved trees with typical needle-shaped leaves (botanical group Gymnospermae).
WOODY – BROADLEAVED DECIDEOUS TREES	Broadleaved trees which are leafless for a certain period during the year (botanical group Angiospermae).
WOODY – BROADLEAVED EVERGREEN TREES	Trees that are never entirely without green foliage (botanical group Angiospermae).
LOW-GROWING WOODY PLANTS	Perennial woody plants with shrub growth form.
PERMANENT HERBACEOUS	Grasslands or arable areas with a continuous vegetation cover throughout a year.
PERIODICALLY HERBACEOUS	Areas with at least one land cover change between bare soil and herbaceous vegetation within one year.
LICHENS AND MOSSES	Any type of lichens and plants in the land plant division Bryophyta.
NON- AND SPARSELY-VEGETATED	Consolidated and unconsolidated materials as well as permanent bare soils.
WATER	Water in liquid state of aggregate regardless of location, shape, salinity and origin.
SNOW AND ICE	Areas covered permanently with snow throughout the year, persistent ice cover formed by accumulation of snow and combinations of both.

Sources: EEA 2022a

the Data Catalogue, which is divided into Ingestions and Extractions. Ingestions are input data processed for further use to derive extractions. Extractions are the opposite; they are the output from which specific instances are created.

Ingestions uploaded to CLCplus Core can be both vector and raster datasets. In our case, all uploaded datasets were vectors, so the most important part of uploading is choosing an attribute that will be used as a class code input parameter. Each class is assigned its EAGLE elements, defined by bar-coding. Bar-coding is the procedure to standardise and concisely represent a semantically decomposed class definition according to its importance and mutual relationships between elements within the class definition. This approach simplifies the process of representing complex information about different classes, making it easier to process and compare them with other classification systems (Arnold et al., 2023b). Extraction begins by selecting input classes from multiple Ingestions, using only those needed to create output classes. Output classes are defined by Class Conditions, which consist of Rules and Rulesets that compare the coverage value of selected EAGLE elements with a specified bar-code value (BCV) and threshold within a grid cell. At the same time, Rank determines the hierarchical order of classes when multiple classes apply (CLC+ Core 2024). The complete set of class conditions is excessive; therefore, it is published along with the results in the Zenodo dataset (Hudcovič, 2025; https://doi.org/10.5281/zenodo.15175096).

Based on this approach and the chosen data, we have tried to create as many CLC classes as possible on the third hierarchical level for the reference year 2018. Despite differences in the technical specifications of each product, we compared the created CLCplus Legacy with the CLC2018 raster product in two different ways. First, the areas on the first and third hierarchical levels were compared, and their conformity was evaluated in the Slovak Republic. This was done by change detection in ArcGIS Pro. In another way, we used the landscapemetrics R package (Hesselbarth et al., 2019) for calculating landscape metrics for two representative 10x10 km case study areas:

a. Vicinity of the city Banská Bystrica in central Slovakia that represents an inhomogeneous irregular urban area surrounded by agricultural land and semi-natural and natural hilly landscape.
b. Vicinity of village Tvrdošovce in Podunajská nížina lowland that represents homogeneous agricultural land with small, regular urban areas.

Calculated landscape metrics were chosen to represent the composition and configuration of the landscape in both product case study areas (Table 2). These metrics can be calculated on three different levels: landscape, class, or patch, depending on the intended focus. In our case, it was on the landscape and class levels. Composition quantifies properties associated with patch diversity and abundance without considering their spatial character, placement, or position (NP, PR, PLAND, LPI – abbreviations are explained in Table 2). Configuration can be quantified by spatial character, arrangement, position, or orientation of patches within the landscape or classes (PAREA_MN, LSI, CONTAG, PAFRAC, COHESION, SHAPE_MN – explained in Table 2) (McGarigal et al., 2023).

4 RESULTS

Using CLCplus Core, we were able to create an instance of CLCplus Legacy on the third hierarchical level of CLC nomenclature for the reference year 2018 that covered 99,7% of the total area of the Slovak Republic and classified 22 out of 32 classes located in the Slovak Republic (Table 3). The decrease in classified classes was due to a lack of land usage information on input datasets. Higher conformity at the first hierarchical level (Table 4) than at the third hierarchical level (Fig. 3, for all classes: 64,43%) represented a problem in modelling classes at the third hierarchical level, often due to their complexity or missing input data, although their essence was captured, hence higher conformity at the first hierarchical level.

Landscape metrics at the landscape level (Table 5) showed that the composition of the landscape substantially changed for both case study areas, not only in the number of patches (NP) in both cases, but also in richness of classes (PR), particularly in the b)

Tab. 2. Description of landscape metrics used in case study

Level	Name	Abbreviation	Desricption
Landscape	Number of patche	NP	Describes fragmentation of landscape, value increases as number of patches increases.
Landscape	Patch richness	PR	Number of different patch types present within landscape.
Landscape	Mean patch area	PAREA_MN	Describes landscape composition and patch structure as the mean of all patch areas.
Landscape	Landscape shape index	LSI	Ratio between actual landscape edge length and hypothetical minimum edge length. As value increases patches become less compact.
Landscape	Connectance	CONTAG	Describes the probability of two random cells belonging to the same class. Value equals 0 if all cells are unevenly distributed and 100 indicates that all cells are equally adjacent to all other classes.
Landscape	Perimeter-area fractal dimension	PAFRAC	Describes the patch complexity of the landscape. Value approaches 1 if patches have simple shapes and approaches 2 if patches have irregular shapes.
Class	Percentage of land	PLAND	Percentage of the landscape belonging to class.
Class	Largest patch index	LPI	Percentage of the landscape covered by the corresponding largest patch of each class.
Class	Patch cohesion index	COHESION	Connectedness of patches belonging to class, gives information if patches of the same class are located aggregated or rather isolated. Value approaches 0 if patches of class are more isolated and increases if patches are more aggregated.

Sources:McGarigal et al., 2023

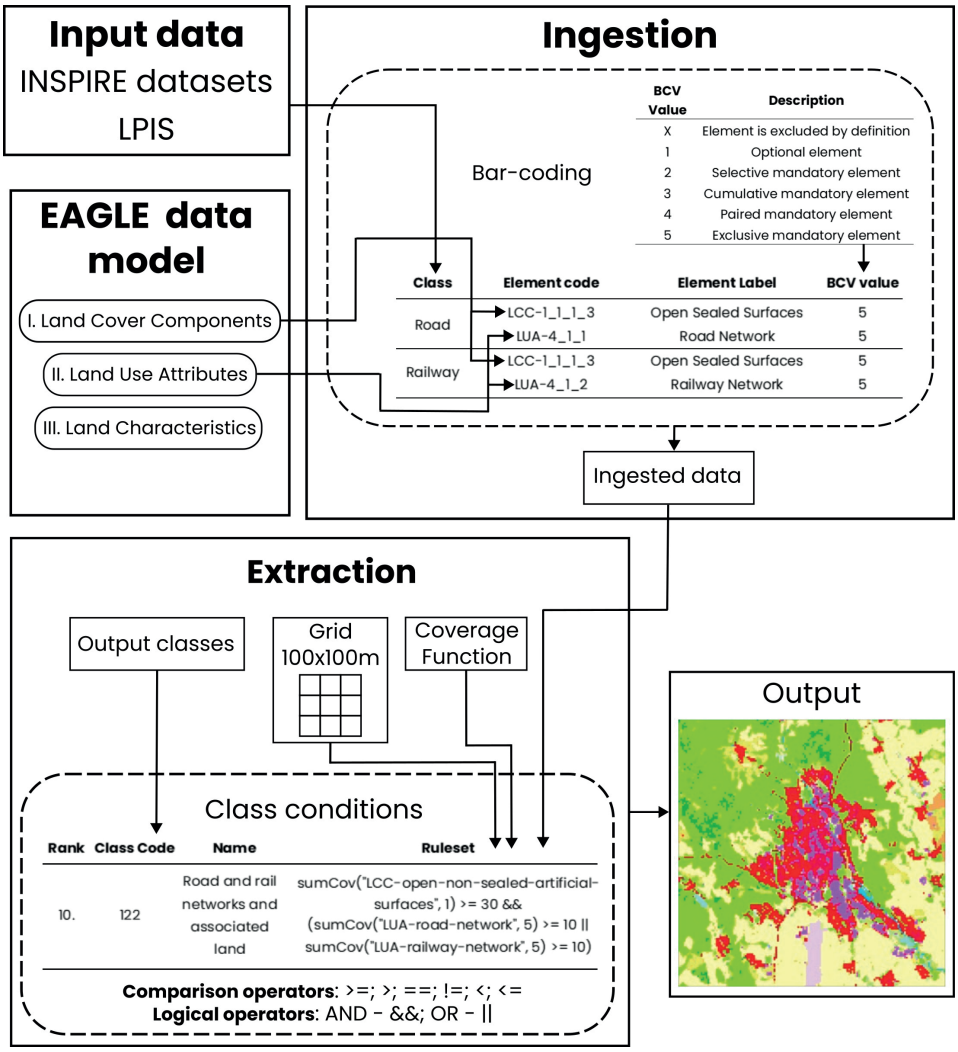


Fig. 2. Illustration of the CLCplus methodology framework

case study area. That could be attributed to the ability of CLCplus to model each 100x100m cell separately, unlike CLC, which has a 25 ha MMU. Considering PAREA_MN, we found that they are far too small if we have many more patches. Using other configuration parameters, in the case of CLCplus Legacy patches, the landscapes were less compact (lower LSI), and their shapes were more complex (higher PAFRAC).

Comparison of landscape metrics on class level required caution, because some classes that were contained in CLC may have not been modelled in CLCplus Legacy, or there may be new classes modelled in CLCplus Legacy.

Area a) (Table 6):

- For classes 112, 211, 243, and 313, both PLAND and LPI had decreased, which means that these classes became less dominant in the landscape because their area and their largest patches got smaller. In the case of classes 112 and 211, their COHESION did not change much, meaning their patches stayed aggregated to each other. For classes 243 and 313, their COHESION got significantly lower, so they became more scattered throughout the landscape.
- The opposite was the case with class 311, which became more dominant in the landscape because its area (PLAND) and largest patch got bigger (LPI). There has also been a minor increase in COHESION, which means that patches of this class became more aggregated.
- In the case of classes 111, 121, and 312, where the area (PLAND) that classes cover got bigger, but their largest patch (LPI) is smaller, which indicates that they became more fragmented within the landscape. All classes had a decrease in COHESION, which means they have become more scattered throughout the landscape.

Area b) (Table 7):

- For classes 112 and 222, PLAND and LPI had decreased, so they became less dominant in the landscape because their area and largest patches got smaller. In the case of classes 112 and 211, their COHESION did not change much, meaning their patches stayed aggregated to each other. For classes 243 and 313, their COHESION got significantly lower, so they became more scattered throughout the landscape.
- The opposite was the case with class 311, which became more dominant in the landscape because its area and largest patch grew. There has also been a minor increase in COHESION, which means that patches of this class became more aggregated.
- There were some specific cases like classes 111, 121, and 312 where the area that classes covered got bigger, but their largest patch was smaller, which indicates that they became more fragmented within the landscape. All classes had a decrease in COHESION, which means they have become more scattered throughout the landscape.

Tab. 3. CORINE Land Cover classes located in the territory of Slovak Republic and their size in the produced CLCplus Legacy 2018

First hierarchical level		Third hierarchical level		
Class code	Class name	Class code	Class name	CLCplus Legacy 2018 *area (ha)*
1	Artificial surfaces	111	Continuous urban fabric	11938
		112	Discontinuous urban fabric	139468
		121	Industrial or commercial units	39994
		122	Road and rail networks and associated land	5149
		123	Port areas	0
		124	Airports	1933
		131	Mineral extraction sites	0
		132	Dump sites	0
		133	Construction sites	0
		141	Green urban areas	0
		142	Sport and leisure facilities	0
2	Agricultural areas	211	Non-irrigated arable land	1400937
		221	Vineyards	15546
		222	Fruit trees and berry plantations	8708
		231	Pastures	528377
		241	Annual crops associated with permanent crops	0
		242	Complex cultivation patterns	22695
		243	Land principally occupied by agriculture, with significant areas of natural vegetation	235884
3	Forest and semi natural areas	311	Broad-leaved forest	1468419
		312	Coniferous forest	635374
		313	Mixed forest	121498
		321	Natural grasslands	146763
		322	Moors and heathland	25479
		324	Transitional woodland-shrub	15319
		332	Bare rocks	5934
		333	Sparsely vegetated areas	9344
		334	Burnt areas	0
4	Wetlands	411	Inland marshes	3835
		412	Peat bogs	0
5	Water bodies	511	Water courses	21976
		512	Water bodies	22942

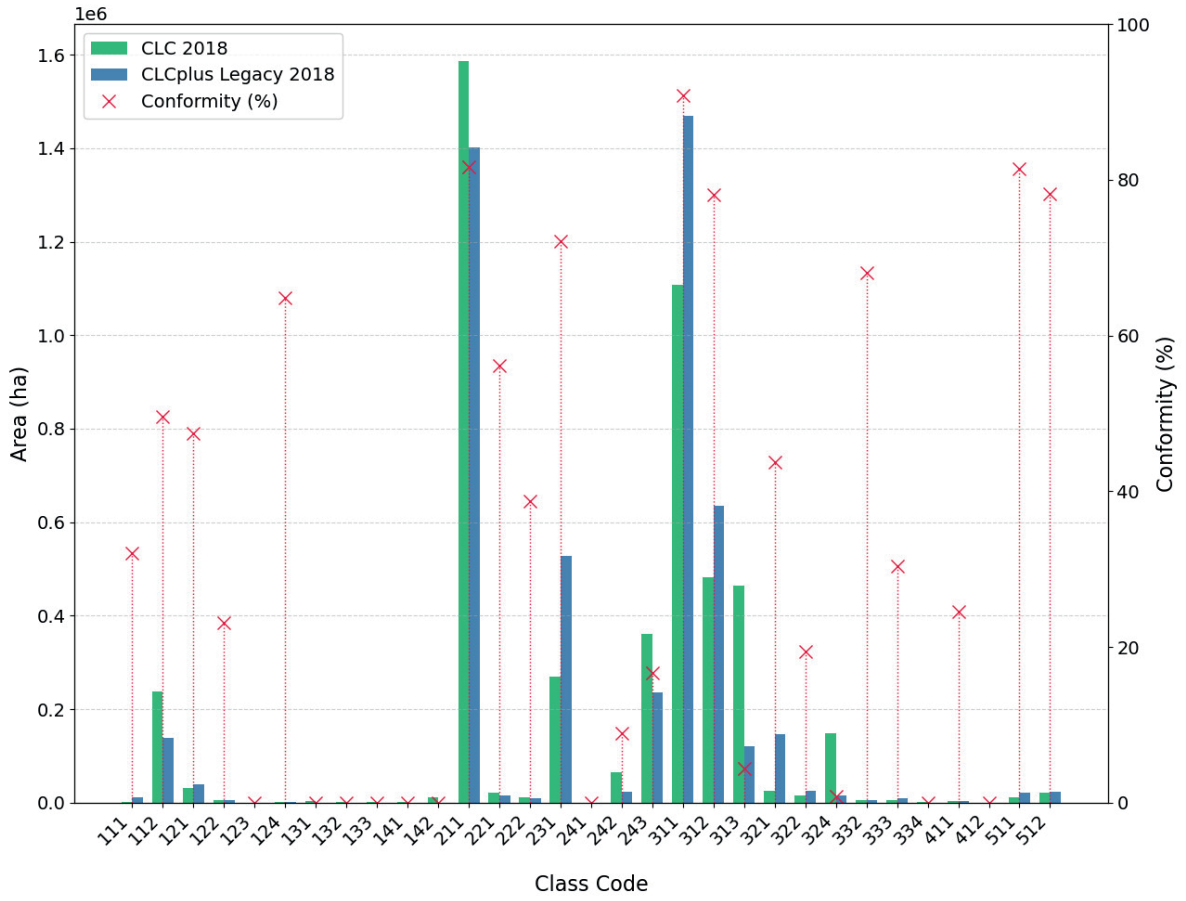


Fig. 3.Comparison of area size and conformity on third hierarchical level

Tab. 4. Comparison of area size and conformity on first hierarchical level

Class code	Class name	CLC 2018 *area (ha)*	CLCplus Legacy 2018 *area (ha)*	Conformity (%)
1	Artificial surfaces	297228	196917	59.62
2	Agricultural areas	2312917	2312250	91.46
3	Forest and semi natural areas	2255729	2330622	93.04
4	Wetlands	4044	2915	20.27
5	Water bodies	32739	44920	92.27
	All classes	*4902657*	*4887624*	*89.96*

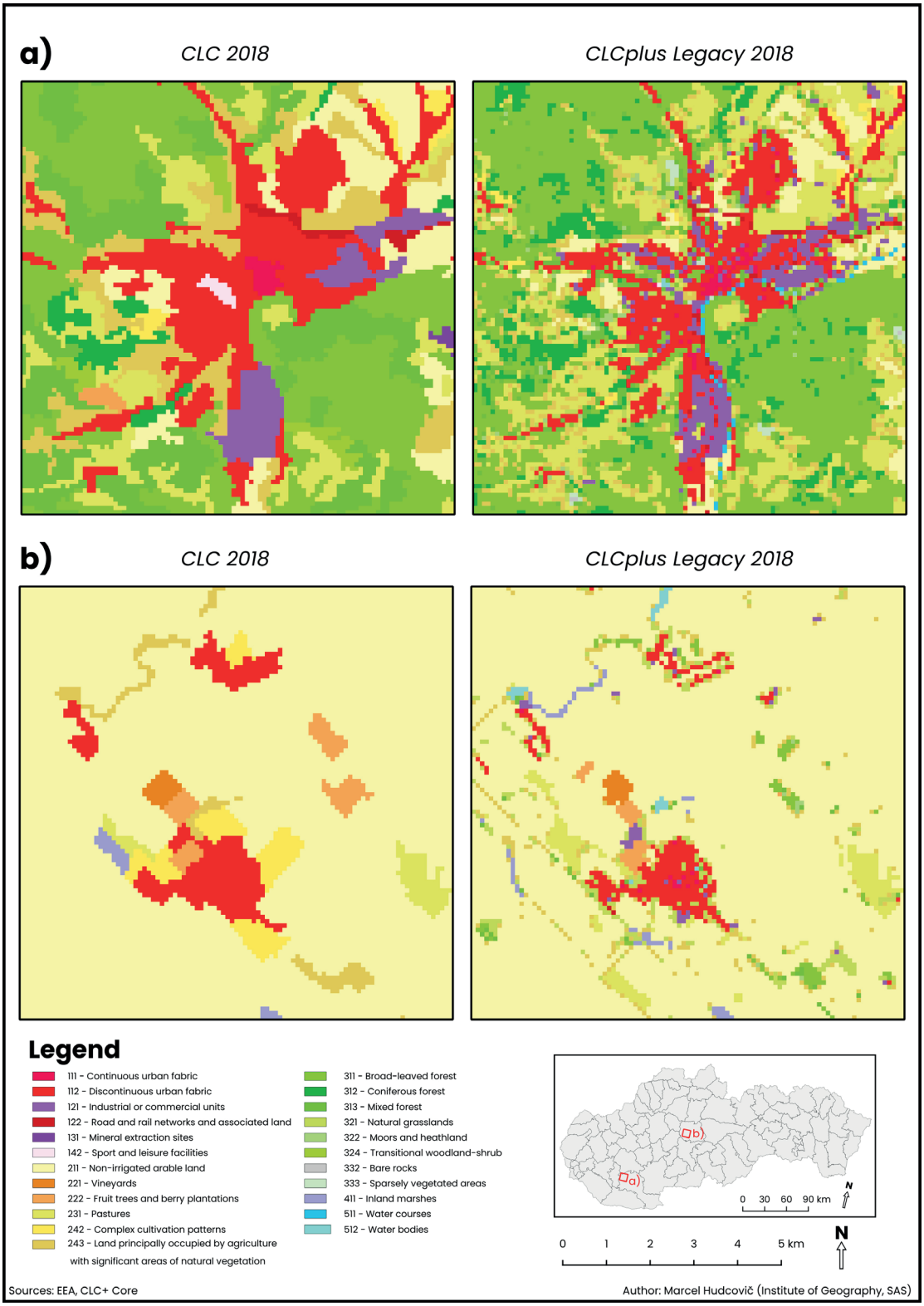


Fig. 4. Comparison of CLC2018 and resulted CLC2018 in two case study areas for landscape composition and configuration evaluation. a) Vicinity of the city Banská Bystrica in central Slovakia. b) Vicinity of village Tvrdošovce in Podunajská nížina lowland

Tab. 5. Landscape metrics for both case study areas at landscape level.
NP -Number of patches, PR - Patch richness, PAREA_MN - Mean patch area, LSI - Landscape shape index, CONTAG – Connectance, PAFRAC - Perimeter-area fractal dimension

Metric	a)		b)	
	CLC 2018	CLCplus Legacy 2018	CLC 2018	CLCplus Legacy 2018
NP	122	1453	24	423
PR	15	18	8	15
PAREA_MN	80,3	6,7	408,4	23,2
LSI	10,1	21,2	3,5	7,8
PAFRAC	1,4	1,5	1,3	1,5

Tab. 6. Landscape metrics at class level for area a).
PLAND - Percentage of land, LPI - Largest patch index, COHESION - Patch cohesion index

Class code	PLAND		LPI		COHESION	
	CLC 2018	CLCplus Legacy 2018	CLC 2018	CLCplus Legacy 2018	CLC 2018	CLCplus Legacy 2018
111	0,5	0,8	0,5	0,4	86,9	66,5
112	17,9	12,1	11,9	4,5	96,6	93,3
121	4,2	4,8	2,3	1,5	92,4	81,3
122	0,7	0,7	0,4	0,1	82,6	40,1
131	0,2	x	0,2	x	74,3	x
142	0,3	0,3	x	x	82,3	x
211	9,1	5,4	1,3	1,0	89,2	80,7
222	0,4	x	0,4	x	85,4	x
231	9,3	16,4	1,4	1,4	88,7	83,9
242	1,1	1,1	0,4	0,1	81,9	59,1
243	10,9	6,9	2,0	0,2	89,8	40,6
311	24,9	35,9	7,7	13,9	94,6	96,0
312	2,5	7,0	1,0	0,8	87,3	72,1
313	16,4	4,4	3,3	0,2	93,1	38,6
321	x	3,0	x	0,1	x	35,9
322	x	0,6	x	0,1	x	18,8
324	1,5	0,0	0,6	0,0	87,1	0,0
332	x	0,0	x	0,0	x	20,1
333	x	0,4	x	0,1	x	55,6
511	x	0,4	x	0,0	x	29,8
512	x	0,1	x	0,0	x	27,1

Tab. 7. Landscape metrics at class level for area b).
PLAND - Percentage of land, LPI - Largest patch index, COHESION - Patch cohesion index

Class code	PLAND		LPI		COHESION	
	CLC 2018	CLCplus Legacy 2018	CLC 2018	CLCplus Legacy 2018	CLC 2018	CLCplus Legacy 2018
111	x	0,1	x	0,0	x	20,2
112	5,3	3,2	3,5	2,4	94,1	91,3
121	x	0,5	x	0,2	x	49,4
122	x	0,0	x	0,0	x	29,6
211	85,2	84,3	85,2	84,1	99,9	99,9
221	0,5	0,4	0,5	0,4	86,4	84,8
222	1,8	0,7	0,6	0,3	86,1	78,9
231	1,5	2,6	1,1	1,0	89,3	82,4
242	3,2	x	0,9	x	88,4	x
243	2,0	3,0	0,8	0,1	87,6	33,9
311	x	1,1	x	0,2	x	56,9
313	x	0,4	x	0,1	x	21,1
321	x	2,7	x	0,3	x	52,4
322	x	0,1	x	0,0	x	28,1
411	0,5	0,7	0,4	0,3	81,6	73,0
512	x	0,3	x	0,1	x	66,1

5 DISCUSSION

CLCplus is intended to bring a new approach to land cover and land use mapping with improved thematic and geometric accuracy. Based on our case study, in this section, we provide a comprehensive overview and evaluation of our methodological approach and derived results, using the CLCplus Core application.

CLCplus workflow

The CLCplus Core, based on the EAGLE data model, offers enormous possibilities for storing and delivering landscape information. CLCplus Core allows the model to include land cover and land use maps and every other characteristic of the landscape as an element within the EAGLE data model. When defining classes with EAGLE elements, the classes can be described in great detail by characterising rather than classifying landscape features (Cole et al., 2022). However, it depends on whether the elements are defined based on a clear semantic definition of the class or whether the elements that could be in the class are also defined. The recommendation is to work with all possible elements in the class definition (Arnold et al., 2023b), which makes it hard to define when the class description is not semantically comprehensive enough, and there are many possible elements in the class. The proper definition of EAGLE elements should then be addressed by their producers, making additional burdens during production, as these data may not be intended for such use. With the technical specifications of the CLCplus system, we should achieve that internally, inhomogeneous classes should be easier and more precise to define and classify. As EEA (2022b) mentioned, the first instance of CLCplus Legacy was supposed to be done for the 2018 reference year to compare with the existing CLC. However, using our case studies as examples, we found several drawbacks in compiling the CLCplus Legacy with CLCplus that arise here, which are described below.

Data availability

The completeness and accuracy of the resulting instances are strongly sensitive to the ingested data used for modelling. With a lack of some necessary data, we were not able to create some specific classes. However, these were small-sized classes that either reflect a specific type of artificial surface use (e.g., 142 - Sport and leisure facilities) or are a particular type of natural area (e.g., 412 - Peat bogs). There was also a lack of information in thematic datasets, e.g., dataset INSPIRE – Transport network, which contains all the necessary information to model classes 122 and 124, lacked information to model class 123. This is reflected by the decrease in the number of classes we could model for the whole Slovak Republic, from 32 to 22. However, patch richness in both case study areas has increased, meaning that CLCplus can capture class presence even with less data. CLCplus Backbone, as a core component of the CLCplus, provides raster maps of basic land cover classes and supplements them in so-called instance creation. Although CLCplus Backbone includes a limited number of land cover classes, integrating additional datasets to enrich its information can significantly enhance the value and thematic detail of the final product (Pundsack et al., 2025). CLCplus Backbone products are supposed to shape Copernicus land monitoring during this decade (Probeck et al., 2021) and have already demonstrated higher quality compared to similar datasets such as Esri Land Cover, Dynamic World or ESA WorldCover (Ursu et al., 2025; Fonte et al., 2024). A drawback was the unavailability of the CLCplus Backbone vector layer when our work was conducted, which could have improved the quality of the created instance.

Landscape composition and configuration changes

With our two case studies, we were able to demonstrate how a different mapping approach in CLCplus affects landscape composition and configuration. MMU directly affects the composition and diversity of the landscape, causing an abundance of certain classes that are distributed in small patches within the landscape with increasing MMU (Saura, 2002). Large MMU in CLC limits the level of detail possible to capture in landscape, leading to neglecting some small features and patches and their boundaries and composition (Olah et al., 2025), which CLCplus can model with its ability to model each 1 ha cell separately. This is reflected by increased patches and patch richness in both study areas, creating less compact patches with more complex shapes. From that, we can assume that patches of classes with complex definitions consisting of multiple land cover types will be in CLCplus divided into smaller multi-class patches, raising a problem with their delineation (Waśniewski et al., 2022). In the case of class 313, its area has decreased in size. With a smaller MMU of CLCplus and thematic and spatial resolution of CLCplus Backbone, it was easier to distinguish forest vegetation types from each other clearly. Thus, the size of this class in CLCplus Legacy has decreased, while the size of the classes 311 and 312 that identify forest vegetation type has increased. This trend can also be seen within study area a), where the percentage of area of class 313 lowered and its patches became smaller and more scattered within the landscape, while the opposite effect occurred for class 311.

Classes that are defined based on a pattern or landscape texture appeared to be more challenging for modelling. CLCplus Core does not consider the arrangement and localisation of features in the landscape but works purely on their coverage. Therefore, we believe that a reassessment of the appropriateness of classifying such complex classes should be considered essential, and more emphasis should be placed on classifying definable classes, enriching the information provided by these classes from their boundaries and their created mosaics (Martín et al., 2006). The fact that classes at the third hierarchical level of the CLC nomenclature are challenging to model and distinguish between in CLCplus is supported by the higher conformity at the first hierarchical level, where classes are uncomplicated and definable. This problem particularly concerns classes 242 and 243, whose size has decreased in CLCplus Legacy mainly due to their complex definitions and the need to respect the internal structure of the patch.

Rule-based class modelling

Rules by which CLCplus Legacy classes were modelled were created specifically for our case study in the area of the Slovak Republic. Since CLC is produced on a national level to meet standards of the EEA, discrepancies in production have emerged when some countries have adopted new methodological and technical procedures (Martínez-Fernández et al., 2019; García-Álvarez et al., 2023). In the territory of the Slovak Republic, there are 32 out of the total 44 classes of the third hierarchical level of the CLC, and

we were able to define 22 with our rules. In the case of being able to define more classes, in addition to defining rules for new classes, the rules of other classes could also change. Furthermore, our rules are defined based on the input data, so the rules could have been significantly different if we had worked with different input data. This means that the definition of the rules for the classes can be strongly influenced by the area of interest and the input data used. For example, in our work, we did not consider using other input data or possible modelling on a different territory. It would make sense to test these rules on a different territory of interest, possibly with different input data, and see how much these results would differ. The EAGLE data model is intended to ensure uniformity of use across the EU and consistency when using heterogeneous data. Therefore, even when using heterogeneous data in any territory, these results should differ minimally, ideally, they should be identical.

6 CONCLUSIONS

This paper aims to describe the methodological process of creating the CLCplus Legacy 2018 product for the Slovak Republic and assess the comparison to CLC 2018. The results showed that this methodological approach is highly dependent on the completeness and quality of input data, which restricts the full potential of instance creation. Furthermore, results showed how much landscape composition and configuration changed with a smaller MMU of CLCplus. The discussion outlined several limitations that we have encountered in CLCplus legacy production, primarily related to input data dependency, varying spatial detail, and the complexity of modelling certain classes using a rule-based approach. To fulfil CLCplus Legacy‘s potential to bring greater thematic and geometric accuracy in landscape monitoring in the EU, necessary changes in the production methodology and the definition of the final product might be needed. With the CLCplus core application still updated, and new CLCplus Backbone vector and raster data released, CLCplus Legacy will need additional research on optimal support data and validation.

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