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ABSTRACT

The high-resolution layers (HRLs) are land cover maps produced for the entire Italian territory (approximately 30 million hectares) in 2012 by the European Environment Agency, aimed at monitoring soil imperviousness and natural cover, such as forest, grassland, wetland, and water surface, with a high spatial resolution of 20 m. This study presents the methodologies developed for the production, verification, and enhancement of the HRLs in Italy. The innovative approach is mainly based on (a) the use of available reference data for the enhancement process, (b) the reduction of the manual work of operators by using a semi-automatic approach, and (c) the overall increase in the cost-efficiency in relation to the production and updating of land cover maps. The results show the reliability of these methodologies in assessing and enhancing the quality of the HRLs. Finally, an integration of the individual layers, represented by the HRLs, was performed in order to produce a National High-Resolution Land Cover map.

1. Introduction

Over the last several decades, the European Union has developed several initiatives and strategies for protecting soils, such as the 'establishment of a Community strategy for the protection of the soil' (COM n.179/ 2002), the 'Roadmap to a Resource Efficient Europe' (COM n.571/2011), and the recent Seventh Environment Action Programme (2014–2020). The monitoring of land cover is also recognized as a fundamental activity, especially in the European Union, to provide spatial data for the comprehensive assessment and mapping of ecosystem services, thus offering a helpful tool to support decision-making activities (Maes et al., 2012).

In this context, the European Environment Agency (EEA) has developed the Copernicus Initiative in collaboration with other European and national institutions. It includes both satellite data and *in situ* data and services, providing valuable information for environmental monitoring. The acquisition of data from multiple satellites and the integration of the data with field surveys aim at ensuring the homogeneity of land cover classification at the European level. Most databases at the national level are created for specific purposes (e.g. agricultural controls, statistical reports, land planning, and environmental assessment), resulting in very different classification systems that are often not directly comparable. This leads to a high variability in estimates, especially for the monitoring of soil consumption and land use (ISPRA, 2013a).

As part of the Copernicus framework, several high-resolution layers (HRLs) were produced, with 2012 as the reference year. The main objective of the HRLs is to monitor the land cover of European countries at a high spatial resolution to assist major environmental issues, such as soil sealing and natural cover (forest, grassland, wetland, and Permanent Water Bodies). Several service providers produced the HRLs in 2012 by means of semi-automatic techniques.

The 2012 HRLs were produced for 39 European countries, including Italy, within the framework of the Pan-European component of Copernicus. The main objective of the HRLs is land-cover monitoring using remote sensing with a homogeneous classification system among European countries. The Copernicus HRLs represent the evolution of the CORINE Land Cover (CLC) for environmental monitoring (Di Gregorio & Jansen, 2005), counting on frequent updates (expected every three years) and a high spatial resolution of 20 m.

The 2012 HRLs are composed of six raster layers corresponding to five thematic classes of land cover. Two layers represent continuous phenomena ranging between 0% and 100% (Degree of Imperviousness and Tree Cover Density) and four layers represent thematic classes with discrete class boundaries (Forest Type (broadleaved, coniferous), grassland, wetland, and Permanent Water Bodies) (Main Map).

These intermediate HRLs require a mandatory process of validation and optionally, a subsequent phase of

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enhancement, aimed at improving their thematic accuracy. Although the EEA developed two guidelines for the verification and enhancement of the HRLs, each Member State is free to modify and improve these methodologies, according to their needs, environmental distinctiveness, availability of national reference data, and expertise.

In Italy, verification and enhancement are undertaken by the Italian Institute for Environmental Protection and Research (ISPRA), acting under the vigilance and policy guidance of the Italian Ministry of Environment, Land and Sea. The aim of this paper is to illustrate the methodology and results of the verification and enhancement processes of the intermediate HRLs in Italy.

The verification of the HRLs has been designed by the EEA and described in the guidelines, which require the use of a qualitative approach to assess the quality of the HRLs. The guidelines also suggest the use of a quantitative approach for the evaluation of omission and commission errors (EEA, 2012a). The data from the national networks and land use inventories, developed by several institutions, were used to perform the quantitative verification. This verification process resulted in low accuracy or major errors in particular areas; the enhancement process aims at correcting these errors through manual editing or automatic classification processes on the intermediate HRLs.

We developed a methodology for HRL enhancement that uses available national data (land use and land cover maps) to reduce the manual work of operators. The results of the verification and enhancement process are presented and show that the thematic accuracy of the intermediate HRLs was not always adequate, thus justifying the need and the effectiveness of the enhancement process to improve their final quality. Several recommendations helpful for future verification and enhancement processes are also reported in the final considerations.

2. Methods

2.1. Production of the HRLs by the EEA

As described by the EEA (2012a), the HRLs were produced using a semi-automatic classification of the IMAGE2012 dataset, which is composed of remote sensing images, such as RapidEye and AWiFS. The classification methodologies developed for the production of the HRLs are based on the multispectral classification and object-oriented classification of remote sensing images; multi-temporal classification (use of time series data); vegetation indices (e.g. normalized difference vegetation index (NDVI)) and biophysical parameters for improving the identification of vegetated and non-vegetated areas; and the use of

ancillary data (e.g. existent land use and land cover maps).

In particular, for the Degree of Imperviousness, the classification procedure was based on the NDVI calculation and a comparison of the preliminary results with the Degree of Imperviousness in 2009 (the only HRL available since 2012). This comparison allowed automatic detection of change candidates using a rule-based approach; these derived built-up change candidates are visually corrected and merged with the built-up areas existing in 2009, thus obtaining the Degree of Imperviousness in 2012 (EEA, 2012a). For the Tree Cover Density and Forest-Type HRLs, a per-pixel classification of the Tree Cover Density and the dominant forest type (broadleaved or coniferous) was performed applying an automated analysis of the images. This procedure was also supported by interactive editing at the end of the production chain, when needed (EEA, 2012a).

The HRL Permanent Grassland was produced by using three reference years (2006, 2009, and 2012) to detect the permanent presence of grassland. In this case, the main aim was to discriminate the Permanent Grassland from the arable land and bare soil. The classification process was based on an object-oriented classification approach to analyse multi-sensor/multi-scale data together with the C5.0 classifier (EEA, 2012a).

Specific indices (e.g. Wetland Presence Index and Water Presence Index) were developed to facilitate the identification of the land cover classes. As described by EEA (2012a), the water and wetland indices are derived by means of an integrated methodology. The seasonal fluctuation of the water level is mapped by computing an index based on the frequency of water occurrence across the whole time series of satellite images. This allows for the identification of the 'permanent water' layer characterized by the highest ratio of water/image values. The other areas with low to medium water/image ratio values are classified as 'temporary water' and are included as a part of the Wetlands layer.

If needed, interactive editing was performed on the classification results (EEA, 2012a).

2.2. Verification and enhancement of the HRLs

Verification is the process of assessing accuracy, which can be performed in several ways (Richards & Jia, 2006). This section describes the HRL verification using the EEA methodology (EEA, 2012a) and the enhancement process that we developed based on European guidelines (EEA, 2012b).

According to the EEA, in order to reach a target accuracy of 85% for the final HRLs (by reducing omission and commission errors), several steps for the verification (General Overview, Look and Feel, and

Statistical Verification) and the enhancement of the intermediate HRLs were implemented (EEA, 2012a, 2012b).

2.2.1. General Overview Verification

The General Overview is a mandatory part of the verification process that aims for a general evaluation of data quality. It consists of a wide comparison of the intermediate HRLs and high-resolution images, using a geographical information system (GIS), to identify major classification errors; at this stage, the use of *in situ* data is recommended. The following are the main *in situ* data that we have used for this purpose: Italian topographic maps (scale 1:25,000), Corine Land Cover 2006, the National monitoring network of soil consumption (ISPRA, 2013a, 2013b), the Italian

Land Use Inventory (IUTI, Marchetti, Bertani, Corona, & Valentini, 2012), Italian hydrological and inland water data (http://www.pcn.minambiente.it), the Italian Ramsar zones map (http://www.pcn.minambiente.it), and a large set of digital colour aerial orthophotos covering the entire national territory provided by the Italian Ministry of Environment, Land and Sea. The results of the General Overview allow the detection of critical areas where further verification should be performed (see Figure 1). For instance, the general overview of the Forest Type highlighted generally good quality data with some minor errors of omission and commission. For the Degree of Imperviousness, the omission errors were mainly found in the periphery of the cities and along minor
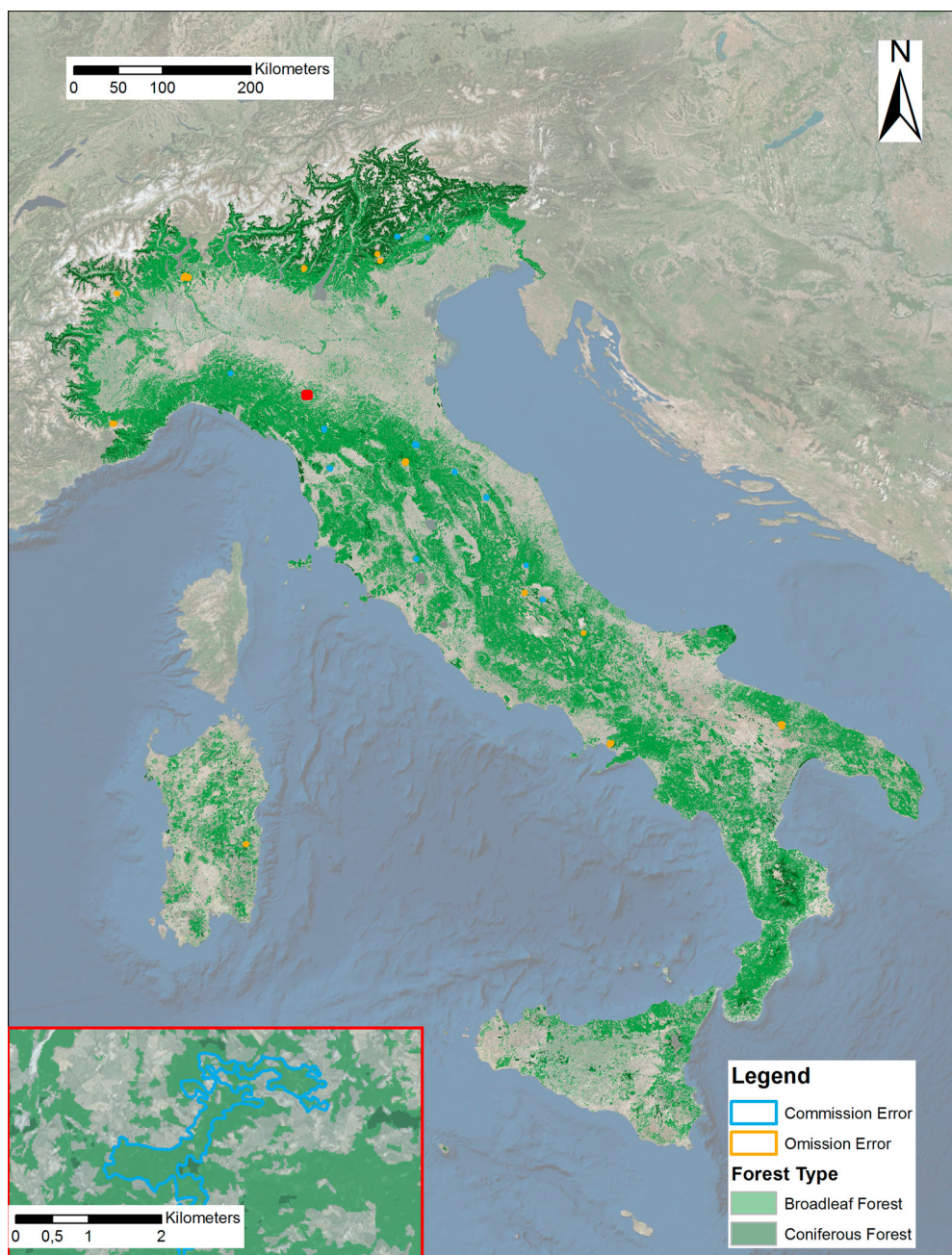

Figure 1. Example of omission and commission areas identified for the forest-type broadleaf.

Table 1. Look and Feel evaluation (EEA, 2012a).

Evaluation	Description
Excellent	The accuracy of the HRL is expected to reach almost 100%; practically no errors can be found in the verified areas
Good	The expected accuracy of the HRL is at least 85%; only sporadic errors are encountered in the verified areas
Acceptable	The accuracy of the HRL is estimated to reach 85% in most of the verified areas; minor errors can be detected in the verified areas
Insufficient	The accuracy of the HRL is not expected to reach the minimum 85%; several errors are encountered in different regions
Very poor	The expected accuracy of the HRL is bad and much below 85%; majority of verified areas are wrongly mapped

roads; only a few commission errors were found in the bare soil areas.

2.2.2. Look and Feel Verification

The Look and Feel Verification is a mandatory step for assessing the accuracy of the HRLs. The EEA suggests a set of critical layers for each HRL that ease the evaluation process by concentrating the search for omission and commission errors to a limited area (EEA, 2012a).

The verification is performed in a GIS environment by visually comparing HRLs and very high-resolution images, with the help of *in situ* data (e.g. maps, inventories) available at the national level. In particular, the following data have been used: RapidEye images acquired in 2012 (provided by the EEA), Google Earth and Bing Map services, and national aerial images with 30 cm spatial resolution (i.e. AGEA, provided by the Italian Ministry of Environment, Land and Sea).

The results of this process are expressed in qualitative terms by the operators, using the criteria reported in Table 1 (EEA, 2012a). The results of the Look and Feel Verification are an important indicator of where and which layers are prone to classification errors, thus guiding the enhancement process.

2.2.3. Statistical Verification

The Statistical Verification is not obligatory, but is recommended by the EEA to improve the accuracy and reliability of the HRLs. This verification is based on the random selection of statistically representative parts of the territory, allowing the comparison of the HRLs and the best available *in situ* data (in terms of thematic compatibility, spatial resolution, and reference date).

The EEA guidelines (EEA, 2012a) recommend the selection of at least 280 samples for the estimation of omission and commission errors, with a maximum uncertainty of ±3.16%. Note that the estimation of omission errors requires a stratification of samples in order to achieve the desired maximum uncertainty with a limited number of samples; furthermore, these guidelines suggest specific CLC classes for the sample stratification of each HRL. According to the EEA

(2012a), the density errors of the density layers (such as the Degree of Imperviousness) are not assessed. Instead, the omission and commission errors should be evaluated using a binary layer produced using density thresholds (EEA, 2012a; Maucha, Büttner, & Kosztra, 2010).

For the Italian case, we developed a statistical verification methodology slightly different from that suggested by the EEA, particularly for the number of samples that were used. The samples are usually represented by points classified using specific classification systems and belong to land use and land cover inventories (Munafò, Assennato, & Congedo, 2015), among which, for instance, are thousands of points belonging to the National monitoring network of soil consumption. A large number of samples were used for the assessment of the HRL accuracy, allowing for the estimation of errors with very low uncertainty. The statistical verification was performed using the following data as reference: the National monitoring network of soil consumption (Munafò et al., 2015), the Italian Land Use Inventory (IUTI, Marchetti et al., 2012), and POPOLUS (Pulighe et al., 2013). The data used for the verification process (i.e. samples already classified with their own original classification system) were not produced in this study, but already existed and were available from other national sources.

The land cover classes of the reference data compatible with the HRLs classification scheme were selected according to the classification system (see Table 2) for evaluating errors of omission (i.e. samples selected outside the HRL) and commission (i.e. samples selected inside the HRL), as shown in Figures 2 and 3. The comparison between each HRL and the corresponding reference data was based on a spatial overlay. A sample was considered 'correct' if the assigned land cover classification was coherent with the HRL class of the pixel beneath the sample; it was considered 'incorrect' if there was a mismatch between them.

In addition to the direct overlay and comparison between HRLs and national data, in some cases we applied different approaches, such as:

- Shrink, consisting of the exclusion of border pixels in order to improve the geometric registration of the HRLs and sample data.
- Stratification, consisting of the selection of samples (in particular, layers) using CLC in order to highlight errors in critical areas, as suggested by the guidelines.

In the end, it was possible to calculate the number of samples classified correctly, as well as the omission and commission errors. The standard deviations for error values were calculated using the statistical model of the binomial distribution. The uncertainty of the commission errors was calculated as the ratio between the

Table 2. Reference data used for the HRLs validation.

HRL	Reference data	Reference classes selected for validation	Number of selected samples
Degree of Imperviousness	National monitoring network of soil consumption	Class 1 (soil consumption, excluding unpaved roads, roads, quarries and mines, dump sites, and railway lines) Class 0 (not soil consumption)	479 samples for omission 473 samples for commission
Forest Type	IUTI (Italian Land Use Inventory)	Classes 1.1 (Woodland) , 1.2 (Wooded land temporarily unstocked areas), 3.2 (Other wooded land)	464,414 samples for omission 430,893 samples for commission
Tree Cover Density	IUTI (Italian Land Use Inventory)	Classes 1.1 (Woodland), 1.2 (Wooded land temporarily unstocked areas), 2.2.1 (Fruit orchards and plant nurseries), 2.2.2 (Wood product plantations), and 3.2 (Other wooded land)	596,211 samples for omission 479,275 samples for commission
Permanent Grassland	IUTI (Italian Land Use Inventory)	Class 3.1 (Grasslands and pastures)	138,549 samples for omission 50,093 samples for commission
Permanent Water Bodies	POPOLUS	Class 6.2 (Inland water)	3094 samples for omission 12,925 samples for commission
Wetland	POPOLUS	Class 6.1 (Wetland)	2436 samples for omission 1584 samples for commission

Figure 2. Example of omission error of the Degree of Imperviousness HRL along a main road.

Figure 3. Example of commission error of the Permanent Grassland in a forest area.

standard deviation and the number of samples, while the uncertainty for the omission errors was calculated according to EEA guidelines using a function based on the commission uncertainty and the extension of the HRL classes (EEA, 2012a).

2.2.4. HRL enhancement

The EEA guidelines for enhancement do not impose any particular procedure for correcting omission and commission errors, but generally suggest the use of the best available *in situ* data (EEA, 2012b). Note that for the density layers (i.e. Degree of Imperviousness and Tree Cover Density), as requested by EEA, the correction of the omission errors was performed by assigning a new code (i.e. 201) without any information about

density. These density values will be directly assigned by the EEA before the final delivery of the products.

ISPRA developed several methodologies for enhancing the HRLs based on the use of GIS and national, regional, and local cartographic data, to limit the manual editing required for error correction. In particular, the available land use and land cover maps were selected based on the following rules (in order of importance):

- The extent of thematic correspondence with the target HRL
- The spatial resolution of the data
- If multiple dates were available, the data for the date closest to the reference time of the HRLs (2012) were selected.

Table 3. Regional and local data used for the HRL enhancement.

| HRL	Data used for the enhancement
Degree of Imperviousness	Topographic geodatabase of Regions Veneto, Lombardia, Campania, and Liguria; land use maps of Regions Piemonte, Emilia Romagna, Toscana, Puglia, and Sardegna; Urban Atlas 2006 by EEA, OpenStreetMap
Forest Type	Forest Maps of Regions Lazio, Molise, Abruzzo, Marche; land use maps of Regions Piemonte, Emilia Romagna, Toscana, Puglia, and Sardegna
Tree Cover Density	Forest Maps of Regions Lazio, Molise, Abruzzo, Marche; land use maps of Regions Piemonte, Emilia Romagna, Toscana, Puglia, and Sardegna
Permanent Grassland	Grassland Maps of Regions Lazio, Molise, Abruzzo, Marche; land use maps of Regions Piemonte, Emilia Romagna, Toscana, Puglia, and Sardegna
Permanent Water Bodies	National hydrographical network by the Italian Ministry of Environment, Land and Sea; Special Areas about Permanent Water Bodies by ISTAT (Italian National Institute of Statistics)
Wetland	AGEA wetlands areas by the Italian Ministry of Environment, Land and Sea; Special Areas about wetlands by ISTAT (Italian National Institute of Statistics); Corine Land Cover Class 2006 by EEA
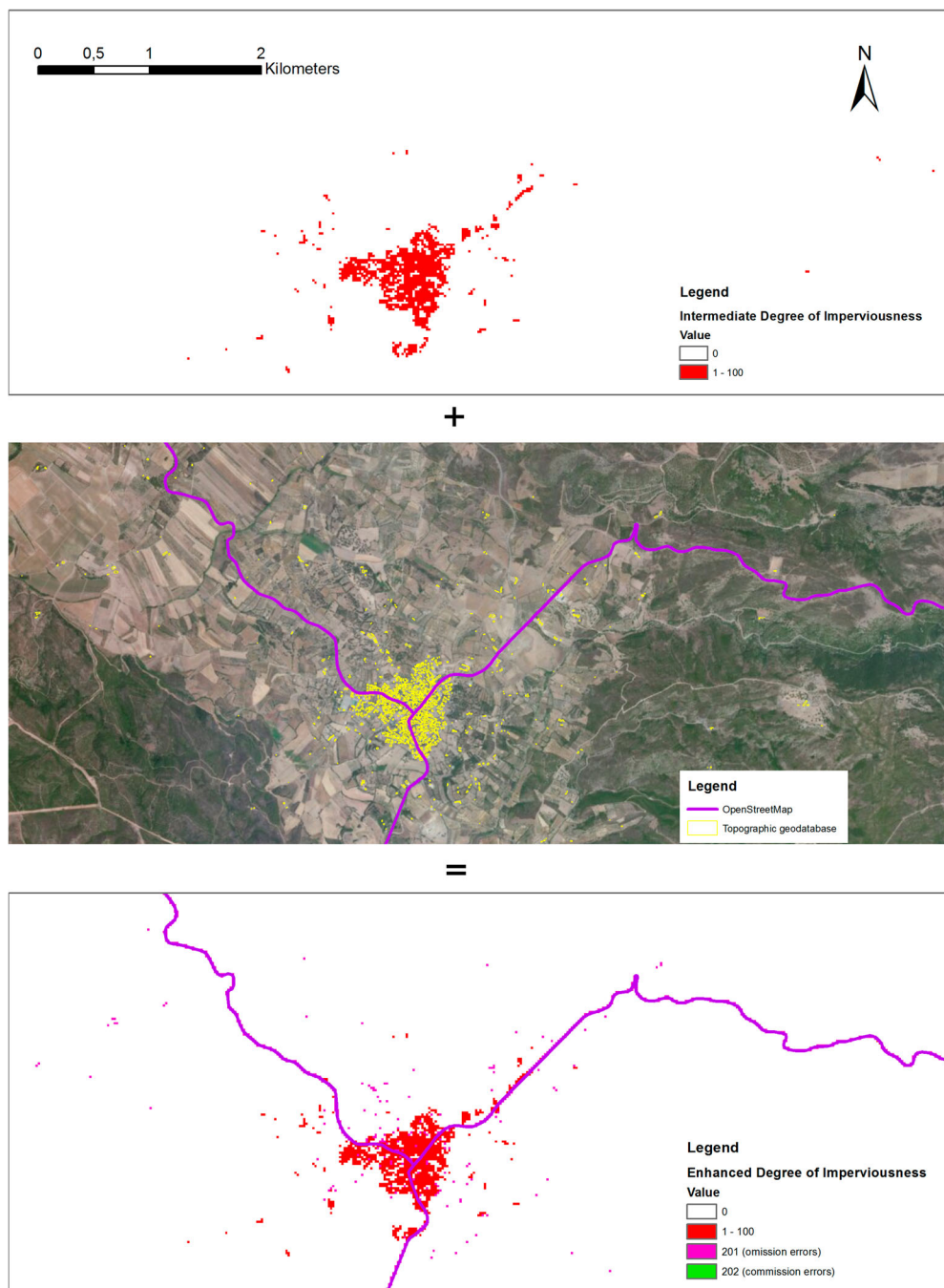
Figure 4. Example of enhancement process of the HRL Degree of Imperviousness (upper image), using OpenStreetMap and the Topographic geodatabase (central image), producing the enhanced HRL (lower image).

All the data were reprojected to WGS84 UTM32N. The data used for the enhancement processes are described in Table 3.

The methodological steps for the enhancement were the following (see e.g. Figure 4):

- Selection of classes (from land cover maps) compatible with the target HRL
- Conversion of vector data (selected land cover classes) to raster format with the same spatial resolution and pixel alignment as the HRLs
- Correction of the HRLs using the raster land cover maps (reference) as input for the conditional statement function within the ArcGIS Raster Calculator tool. This function assigns a correction code to the HRL's pixels based on correspondence with the reference land cover map. For example, in the case of pixels with omission errors, this process allowed the value of each of those pixels to be replaced by a new value that was assigned based on the value of the pixel beneath, which belonged to the reference land cover map.
- A manual editing (i.e. manual correction of pixels) was then performed for correcting additional errors that were still present after the raster calculation.

The main difficulties of the enhancement process were (a) the different classification systems, especially different class definitions (e.g. classification of urban areas is not equivalent to impervious surfaces), which complicate the harmonization process, (b) the method of resampling and the co-registration procedure, which can cause a shift between the data and the HRLs, and (c) the time reference of the cartographic data used for correcting the HRLs. Accordingly, an accurate selection of sources and classes was performed before the enhancement process. After the correction of the individual HRLs, a merging operation was performed to correct residual commission errors due to their possible overlapping. In the case of overlapping pixels belonging to different HRLs, a new conditional statement function within the ArcGIS Raster Calculator tool was applied for checking these overlying pixels. These pixels were corrected by assigning them the HRL code of the most reliable HRL in terms of accuracy but, at the same time, respecting the following hierarchy between them in case of equivalence: Degree of Imperviousness, forest, Permanent Water Bodies, wetland, and Permanent Grassland.

3. Results of the verification and enhancement processes

The General Overview Verification highlighted several omission and commission errors in all the HRLs. In

Table 4. Correction of omission and commission surfaces for HRLs, after the enhancement process.

HRL	Corrected omission area (ha)	Corrected commission area (ha)
Degree of Imperviousness	196,379	2666
Forest Type	600,888 (Broadleaved) 245,729 (Coniferous)	156,206
Tree Cover Density	372,668	190,452
Grassland	368,073	417,140
Wetland	82,900	89,200
Permanent Water Bodies	94,700	222,500

particular, the Degree of Imperviousness showed numerous omission errors in low-density and discontinuous urban areas. The Look and Feel Verification confirmed the results obtained in the previous one, showing, for instance, several commission errors for the Degree of Imperviousness near mines and bare soils. According to the classification in Table 1, the Look and Feel Verification results were:

- Degree of Imperviousness: Acceptable
- Forest Type: Acceptable
- Tree Cover Density: Acceptable
- Grassland: Acceptable
- Wetland: Very poor
- Permanent Water Bodies: Acceptable

Through the Statistical Verification process, we assessed the omission and commission errors in quantitative terms. With particular regard to the Degree of Imperviousness, the Grassland, and the Wetland HRLs, the high range of errors obtained by using different approaches is due to the geometric registration of the HRLs and the sample data, especially the location uncertainty of small objects, which can be reduced with the shrink operation (i.e. considering patches of more than one pixel reduces this uncertainty). The enhancement process was performed according to the outputs of the verification process, and the results are summarized in Table 4.

4. National High-Resolution Land Cover (NHRLC) map

The enhanced HRLs were integrated in a map representing the NHRLC map. Considering the HRL characteristics, reclassification of the Degree of Imperviousness was required in order to obtain a binary map, where imperviousness values greater than 29% were considered built-up, according to Maucha et al. (2010). Using the Forest-Type HRL as a source for the forest domain, the final NHRLC map allows the discrimination of broadleaf and coniferous forests. The entire legend of the NHRLC map (Figure 5) is described in Table 5.
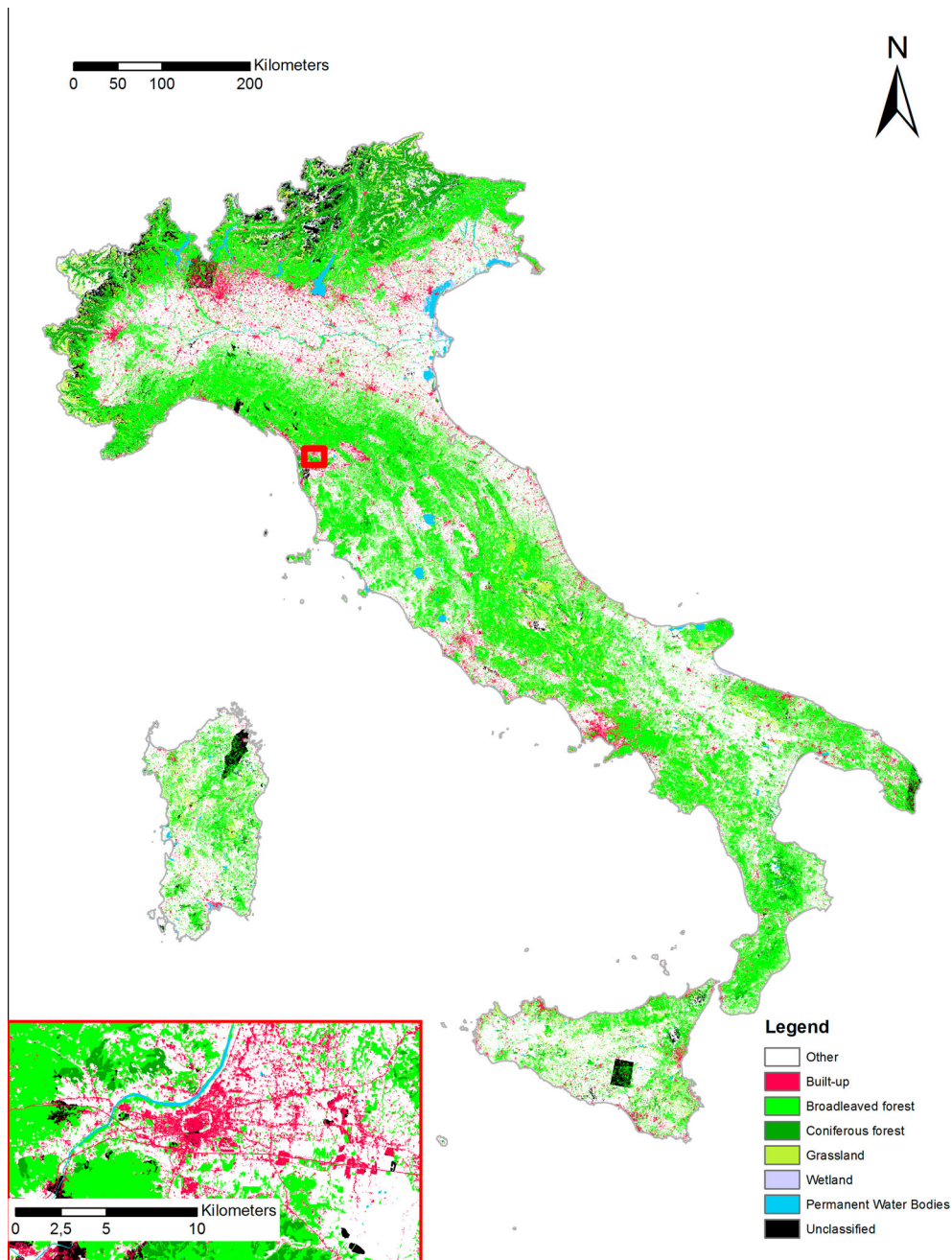
Figure 5. The NHRLC map.

Table 5. Legend of the NHRLC map.

Code	Land cover class	Description
0	Other	Land cover class that does not belong to any of the HRLs
1	Built-up	Class where the Degree of Imperviousness > 29%
2	Broadleaved forest	Class where HRL Type of Forest is Broadleaved
3	Coniferous forest	Class where HRL Type of Forest is Coniferous
4	Grassland	Class where HRL Grassland is classified accordingly
5	Wetland	Class where HRL Wetland is classified accordingly
6	Permanent Water Bodies	Class where HRL Permanent Water Bodies is classified accordingly
254	Unclassified	No satellite image available or clouds, shadows

5. Conclusions

Although the verification processes highlighted the generally low accuracy of the intermediate HRLs, the enhancement process allowed the correction of the majority of commission and omission errors and improved the quality of the final results. The main issue of the enhancement processes resides in finding the reference data to be used for error correction. These data are often out dated or characterized by different land cover or land use classification systems with respect to the pure land cover classification of the HRLs. For example, considering the Degree of

Imperviousness, which represents a classical example of pure land cover classification, the availability of several regional maps allowed for a significant enhancement of the intermediate HRL. The Grassland HRL had the most accuracy issues, due to the lack of available data for the enhancement process. As a consequence, in order to achieve better results with future updating, it would be desirable to improve the classification process, especially for the detection of sparse grassland. The remote sensing constraints (in terms of spatial and spectral resolution) and the seasonal and regional variability of grassland make the classification of grassland very difficult, especially in those places with low grass density.

The HRLs will be updated every 3 years, with the next update expected for 2015. In light of this work, some considerations emerge on improving the definitions and product delivery for the HRLs. For example, the HRL Degree of Imperviousness does not include railway lines, but considering them as sealed soils (at least partially), they should be included in this domain. Regarding the Forest HRL, a general heterogeneity of Tree Cover Density per pixel was observed, especially in sparse vegetation areas (i.e. similar areas were not always classified as forest), therefore a minimum Tree Cover Density should be defined in order to avoid incoherence in the classification system.

According to the EEA (2012b), the final products will be provided to the end user with a spatial resolution of 100 m, but it would be preferable to provide the original products with a raster resolution of 20 m. The spatial resolution plays a fundamental role in the surface estimation, as confirmed by the national built-up map with 5 m spatial resolution developed by ISPRA (Munafò et al., 2015).

Integration of the HRLs into a NHRLC map is one of the numerous uses that Copernicus data can offer. The availability of up-to-date maps, with high resolution and thematic accuracy, and a homogeneous European classification system represents a substantial advance towards environmental monitoring efficiency. In addition to their simple use for the monitoring of land cover changes, these maps play a primary role as input data for several environmental modelling tools, such as those used in the mapping and assessment of ecosystem services (Sallustio, Quatrini, Geneletti, Corona, & Marchetti, 2015).

One of the ambitious objectives of the Copernicus programme is the launch of satellites for Earth observation, aiming to improve environmental monitoring and offer better support for management, planning and policies, depending on the scale. In particular, the Sentinel missions (Sentinel-1 launched in 2014 and Sentinel-2 launched in 2015) will foster the update of land cover data such as HRLs.

Software

The enhancement operations were performed using ArcGIS 10.1 and Idrisi Selva. The coordinate system transformation and the Merge operations of the local maps used for enhancement were performed using ArcGIS10.1. QGIS was used for the verification process and the manual editing of vector data for the enhancement processes.

Disclosure statement

No potential conflict of interest was reported by the authors.

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