River classification and the derived knowledge about river systems have so far been based on discontinuous sampling along the river course through field works and/or (subjective) interpretation of aerial images. Remote sensing data (RS), in recent years, offer notable opportunities to change this paradigm enriching traditional information with an unprecedented amount of spatially distributed hydromorphological data at basin scale. A river characterization framework based on color infrared orthophotos at 40 cm and a LiDAR derived DTM at 5 m acquired simultaneously in 2009-2010 has allowed us to characterize the main river systems in the Piedmont Region-Italy (10,000 km²) with continuous information of areal and topographic hydromorphological features. The framework delineates the Valley Bottom of each river course and within this the active channel area composed of water channels, unvegetated and vegetated sediment bars, and, if present, islands. Using semi-automated segmentations of river courses and statistical analyses of the derived regional database the distribution of river features across the region can be investigated: e.g. analyzing longitudinal developments of river morphology identifying abrupt changes of natural or anthropic nature or mapping river reach similarities across the whole region. Such novel availability of data offer the possibility to foster a regional vision, supported by quantitative measures, of river style varieties within the region. This knowledge will support in the near future the definition of quantitative restoration targets, their implementation through specific planning priorities based on a regional vision and open novel opportunities for designing cost-effective RS monitoring campaigns.

1 INTRODUCTION

Hydromorphological indices can nowadays be estimated and monitored with semi-automated procedures based on remote sensing (RS) datasets, allowing a continuous and more objective analysis of river systems on wide spatial scales. An essential aspect when characterizing the hydromorphological status of a river system is the identification of the main riverscape units, composing the natural fluvial corridor and the active river channel. The Active Channel (AC) is defined in literature as the active part of a river channel continuously reworked by dominant floods (e.g., one in 2-year floods). It is mainly composed by low–flow water channel plus adjacent exposed sediment bar surfaces between established edges of perennial, terrestrial vegetation generally subjected to erosion or deposition [1]. Vegetation encroachment, which occurs on exposed sediment bars, has a key role in the evolution of alluvial islands, therefore it is very important to distinguish sparsely vegetated patches from densely vegetated ones.

In this work, we exploit the potential of very high resolution (VHR) near infrared aerial imagery (0.4 m) and LiDAR-derived products for mapping the main riverscape units, suitable for the hydromorphological characterization at the regional scale. LiDAR and VHR imagery are combined within a geographic object-based image analysis (GEOBIA) framework, resulting in a method capable of distinguishing the main riverscape units automatically for the whole Piedmont Region (Italy, 10,000 km²). The main challenge consists in automatically distinguishing riverscape units found within the active part of the river channel from the riverscape units found within the floodplain due to spectral similarities. The GEOBIA approach adopted in this study offers new possibilities to enhance the limited spectral resolution offered by the VHR imagery, by integrating the LiDAR topographic information in the classification process at the object level.

2 DATA

During the years 2009/2010, the Regione Piemonte commissioned a flight acquisition campaign to cover the entire region (25,400 km²) with 40 cm near-infrared orthophotos coupled with simultaneous topographic LiDAR from which a Digital Terrain Model (DTM) of 5x5m grid cells it was generated. In this study we focus on the biggest 18 rivers of the Piedmont Region. The ArcGIS “Fluvial corridor” toolbox proposed in [2] was adopted in this study for the delineation of the Valley Bottom (VB). The “Fluvial corridor” toolbox was also employed for the calculation of the Detrended Digital Terrain Model (DDTM), by using the river centerline shapefile and the...
3 RIVERSCAPE UNITS CLASSIFICATION

A hierarchical object-based segmentation strategy was developed: the first level produced by the Slope layer alone, obtained from the LiDAR topographic data (Level 1, Figure 1), and the second level produced by the VHR spectral layers available (Level 2, Figure 1). The hierarchical two-level segmentation procedure was run for the 265 image tiles, within the VB boundaries of the 18 main rivers of the Piedmont Region.

Because of the high similarities (both spectrally and topographically) of some of the classes, the riverscape units classification problem was tackled in two phases, at the Level 2 segmentation. In the first step (Step 1 of Figure 1), a Machine Learning (ML) object-based classification was developed for mapping the main classes: Water Channel (WC), Unvegetated Sediment bars (US), Sparsely Vegetated units (SV) and FloodPlain units (FP). The main purpose was to build a supervised classifier able to automatically discern the main land-cover classes found in the active part of the channel (WC, US and SV) from the FP class. A Support Vector Machine (SVM) classifier was trained using the results of a previous classification map realized for a smaller river section of 40 km, based on the use of spectral and DTTM features which produced a K accuracy of 0.91 [3]. New validation samples were collected, randomly distributed along the entire Piedmont Region for the assessment of the classification results at the regional scale. Classification results for the whole Piedmont Region are visually very good for the mountain rivers, while several problems are found in the lowland rivers, resulting in a total K accuracy of 0.42. Big classification errors were manually deleted for the lowland rivers, in the expert-based post-classification phase (Step 2 of Figure 1). Step 2 also included the identification of more detailed vegetation classes. Objects classified in Step 1 as SV were re-classified as Riparian Sparsely Vegetated units (RSV) or as Sparsely Vegetated units of Islands (SVI) if their relative border to the FP class was respectively above or below 0.1. From the FP class, objects being surrounded by WC and/or US and with a mean NDVI higher than 0.35 were classified as Densely Vegetated units of Islands (DVI). Objects classified as FP with a mean NDVI higher than 0.35 and having a border to WC and/or US, were classified as Riparian Densely Vegetated units (RDV). Finally, all remaining objects of the FP class were re-labelled as Other Floodplain Units class (OFU).

Figure 1. Workflow of the multilevel object-based methodology developed for the classification of riverscape units.

4 REGIONAL HYDROMORPHOLOGICAL CHARACTERIZATION BASED ON CLASSIFIED RS DATASETS

The RS-based methodology described above generated a map of seven riverscape units which are available for 18 major river systems in the Piedmont region, for a total of 10,000 km². The data include areal and topographic information extracted from the DDTM continuously along 1200 km of river courses. The VB of each river system has been disaggregated into geographical object of 100 m length along the river course using the “Fluvial corridor” toolbox proposed in [2]. Each 100 m unit is named Disaggregated Geographical Object (DGO) and the
seven classes of riverscape units are disaggregated based on the DGO: 17 hydromorphological (HYMO) variables characterizing extent and topographic features of every riverscape unit are calculated for each DGO (see Table 1). Channel slope is calculated from the LIDAR derived DTM at 5 m resampled at 25 m to avoid over sinuosity, adopting the method proposed by [4]. Channel confinement is calculated as the ratio between the AC area, here composed of WC and US, and the VB area. These HYMO variables characterize the river energy (slope) and its degree of freedom to laterally move in order to adjust the channel size to the incoming water and sediment fluxes. The other HYMO variables are directly derived from the RS classification database: areal extent and topographic variables (namely percentile 16, 50, 84 of DDTM) are calculated for the sediment bars classes (US and SV) and for the Densely Vegetated units of Islands (DVI). Percentiles of DDTM provide the elevation of sediment bars and islands from the WC and the degree of (dis)-connectivity of WC from the FP class.

Table 1. HYMO variables derived by the RS classification analyzed at regional level for each DGO.

<table>
<thead>
<tr>
<th>HYMO variable</th>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Slope</td>
<td>SL</td>
<td>Channel slope calculated every 25 m, after [4].</td>
</tr>
<tr>
<td>Confinement: AC/VB</td>
<td>CONF</td>
<td>Ratio of AC and VB.</td>
</tr>
<tr>
<td>Unvegetated Sediment bars ratio: US/AC</td>
<td>US*</td>
<td>Area of HYMO features normalized by the AC.</td>
</tr>
<tr>
<td>Sparsely Vegetated units ratio: SV/AC</td>
<td>SV*</td>
<td></td>
</tr>
<tr>
<td>Densely Vegetated units of Islands ratio: DVI/AC</td>
<td>DVI*</td>
<td>Altitude of HYMO features from the WC as derived from DDTM. For each feature 16, 50, 84 percentiles are calculated.</td>
</tr>
<tr>
<td>Unvegetated Sediment bars: US</td>
<td>USp16/50/84</td>
<td>Altitude of HYMO features from the WC as derived from DDTM. For each feature 16, 50, 84 percentiles are calculated.</td>
</tr>
<tr>
<td>Sparsely Vegetated units: SV</td>
<td>Svp16/50/84</td>
<td></td>
</tr>
<tr>
<td>Densely Vegetated Islands: DVI</td>
<td>DVlp16/50/84</td>
<td></td>
</tr>
<tr>
<td>FloodPlain: FP</td>
<td>FPp16/50/84</td>
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</table>

The first step of the analysis segments the river course based on homogenous reaches in terms of the AC area (WC plus US). It is well established in literature that the AC is a sensitive parameters which significantly varies for different river functional types or various degrees of anthropic pressures acting on the river course [5]. We adopted the Hubert test as proposed by [5] to detect segments characterized by the highest differences in terms of population samples, i.e. a subdivision of reaches for which the values of AC area every DGO generate distribution probabilities with the highest differences in between reaches: an example is plotted on the top-left of Figure 2 for a 40 km river stretch. Similarities and dissimilarities between homogenous reaches can then be investigated with a regional perspective. As illustrative example, two different types of maps are plotted in Figure 2. The graph in Figure 2(ii) plots five classes of longitudinal changes between upstream-downstream reaches, as derived by the Hubert segmentation Fig.2(i). Changes are calculated as the sum of normalized difference between upstream and downstream hydromorphological variables of Table 1. Green spots indicate smooth longitudinal transition, whereas red ones abrupt changes. The map is a first characterization of hydromorphological connectivity, which can be altered either by geological constraints as well as by anthropic disturbances. Similar dissimilarity indicators can be generated at the level of the single hydromorphological variable described in Table 1, and related with available knowledge on the system in terms of acting anthropic pressures, so to address more detailed assessments on the state of river hydromorphological connectivity at the regional level. The map in Figure 2(iv) shows dissimilarities between a reference reach selected by the user, in this case a wandering river reach (see Figure 2(iii)), and the segmented regional river systems. Here green spots indicate similar river reaches whereas red ones different ones, with respect to the reference condition. This assessment allows us to identify reaches with a similar hydromorphological character at the regional level. Hydrological, geological, geomorphological and historical drivers acting on those reaches can be analyzed and their role as drivers in determining the hydromorphological status of the river reach can be better clarified.

5 CONCLUSIONS
This paper presents a procedure to classify riverscape units at the regional scale. The classification generated continuous information on extent and topographic features of river hydromorphology. The database generates valuable information to characterize river type diversity not only in terms of frequency, typology and extent of fluvial forms, as traditionally done analyzing orthophotos of river stretches [6], but also in terms of topographic dimension, a novelty allowed by the available RS dataset. Furthermore, the framework provides a semi-automated procedure allowing its large-scale implementation, a task rarely undertaken so far in the past. Recent availability of RS data are opening new perspectives in the way we analyze and manage our river systems [7]. A regional vision based on objective, repeatable and quantitative data provides an unprecedented potential to
deepening our understanding of river systems, to set up restoration targets and to prioritize in a cost-effective way the implementation of measures based on a regional perspective. The variety of river functional types existing in a region can be quantified through statistical analysis (e.g. Figure 2(iv) for wandering river type) and their cause-effect relation with anthropic and natural drivers established on more quantitative basis than ever done in the past at this scale of analysis. This knowledge will support the identification of reference restoration targets based on quantitative objectives. Moreover, the assessment of hydromorphological connectivity (e.g. Figure 2(ii)) will enhance the identification of reaches potentially more reactive to recovery measures. Future acquisition of RS datasets will finally monitor the progress on the implemented measures based on standardized and objective indicators.

Figure 2. Regional analysis of hydromorphological RS datasets.

REFERENCES