CHARACTERIZATION OF RIPARIAN ZONES IN WALLONIA (BELGIUM) FROM LOCAL TO REGIONAL SCALE USING AERIAL LIDAR DATA AND PHOTOGRAMMETRIC DSM

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ABSTRACT

The present study proposes an innovative approach to automatically extract riparian zone characteristics in order to assess its quality, from pre-determined river management reaches (1-3 km long) to regional scale (ca. 13,000 km for 1,000 management sectors). The aim of this remotely sensed monitoring is to improve river and riparian zone management and planning by providing some key information for river managers.

The methodology was developed based on two watersheds covering approximately 500 km of river network (ca. 200 management sectors). The riparian zone quality is evaluated through various indicators of its ecological integrity (e.g., longitudinal continuity of riparian forest, mean vegetation height and relative standard deviation), hydromorphological quality and physical settings (e.g., flow channel extent, floodplain width, channel sinuosity). The physical characteristics of the riparian zone are mainly extracted from a high quality Digital Terrain Model (derived from ALS data), while the attributes of the riparian forest are derived from a hybrid Canopy Height Model (photogrammetric Digital Surface Model - Lidar derived DTM).

This first research is exclusively based on data which are available at the regional scale (170,000 km^2) to develop automated tools to implement the methodology to the whole Walloon river network (13,000 km) before 2015 with an update frequency of three years (photogrammetric DSM survey frequency). Moreover, our approach is based on a photogrammetric Digital Surface Model which is derived from raw images of an orthophoto coverage. As most European countries are regularly covered by orthophoto surveys, our approach is widely replicable in countries where a quality DTM is available.

INTRODUCTION

Naiman et al. (2005) defined the riparian zone as "*transitional semi-terrestrial areas regularly influenced by fresh water, normally extending from the edges of water bodies to the edges of upland communities*" (1). Riparian zones are central landscape features supporting several functions and services: stream bank stabilization, reduction of sediment and nutrient contamination, aquatic and terrestrial habitat improvement, and recreational and educational opportunities. They are considered as ecotones, located at the intersection of land and water, with an exceptionally rich biodiversity. They form ecological corridors and provide crucial habitats for terrestrial animals and for migrating birds. The width of a riparian zone can range from a few metres to several kilometres, depending on the stream size. Despite their relatively low area coverage, riparian zones consequently represent a major concern for land and water resource managers.

In Europe, several European directives acknowledged the major importance of riparian zones (principally the Habitats Directive and the Water Framework Directive). These directives involve effective multi-scale monitoring (local to network scales) to target restoration activities when needed and to assess the success of previous management actions or existing management policies. Because of the typical shape of the riparian zone, field-based monitoring involves sampling, high manpower costs and time-consuming travels (2,3).

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The increasing availability of very high resolution satellite imagery (IKONOS, QuickBird, GeoEye-1, Pléiades) and aerial Lidar data, combined with more powerful computer capacity and new geomatic procedures to extract information offer opportunities to develop cost-effective, replicable and fully automated riparian zone monitoring at channel corridor to network scales (4,5,6).

High-density point clouds (>10 points/m^2) of Lidar data can provide a 3D view of the features of a floodplain and notably of riparian zone characteristics and ecological attributes, notably through the study of a very high resolution (<1 m GSD) Canopy Height Model (CHM) (6,7). Although they are efficient, high-density LiDAR surveys still involve high relative costs and are restricted to isolated surveys or local areas. However, regional surveys have already been carried out in Europe (case of The Netherlands, Sweden, Finland), but not on a regular basis. For the Walloon context, a low-density LiDAR dataset (0.8 point per m^2) covers the whole territory following a recent survey. This low-density coverage allows a highly accurate Digital Terrain Model (1 m GSD) to be generated, but is not sufficient for the computation of a Canopy Height Model.

In combination with a LiDAR DTM, photogrammetric Digital Surface Model (DSM) can be a cost-effective and complementary data source for CHM generation. Considering that the ground topography remains stable for the period of analysis, a quality LiDAR DTM can be used to normalize photogrammetric DSM derived from more recent surveys, allowing us to update CHM with half to third costs of a LiDAR survey (8,9,10). In the Walloon context, pre-oriented overlapping aerial images have been regularly acquired for the generation of orthophoto cover since 2006-2007, with a revisiting time of three years. The time series of DSM provides quality 3D information which can be combined with the high quality (but low density) LiDAR-derived DTM to generate CHM.

In this study, we intend to develop an automated approach to extract quality indicators of the riparian zone status. The physical characteristics of the riparian zone are principally extracted from a high-quality Digital Terrain Model (derived from ALS data), while the riparian forest attributes are derived from a hybrid Canopy Height Model (photogrammetric Digital Surface Model – LiDAR- derived DTM).

This first research is exclusively based on data which are available at the regional scale (170,000 km^2). We used the river network (487 km long, 725 km^2) of two tributaries of the Meuse (Belgium), the Houille and the Viroin rivers as a model system in the method development. This methodology will be implemented to the whole Walloon river network (13,000 km) before 2015 with an update frequency of three years (photogrammetric DSM survey frequency).

METHODS

Study site

The Houille and Viroin rivers are two tributaries of the Meuse, located in southern Belgium (Wallonia). The watersheds of the Houille and Viroin rivers are located in the Ardennes and Fagnes eco-regions, respectively. Elevations range between ca. 100 m (confluences with the Meuse) to 502 m (Houille) and 392 m (Viroin).

The watersheds (Figure 1) drain an area of 725 km^2, and a river network of 487 km managed by public administrations (river with a watershed >1 km^2). The land cover of the two watersheds is mostly forested (56% and 63%) and agricultural (36% and 27 %) in the Houille and Viroin catchments.

Remote sensing data

The data used to develop the methodology on the study site are all available at the regional scale (170,000 km^2).

Aerial LiDAR dataset

A LiDAR aerial small footprint dataset was captured on April 2013 with an average point density of 0.8 points/m^2. A Digital Terrain Model was computed by the data provider (1 m GSD). As suggested by previous work of the authors (7), LiDAR data can effectively describe the riparian zone condition. But regarding the relatively low density of the LiDAR dataset, the quality of the LiDAR Canopy Height Model was regarded as not sufficient and had to be completed with other remote sensing data.

Photogrammetric Digital Surface Model and Hybrid Canopy Height Model

Pre-oriented raw aerial images initially captured (May 2012) for a regional orthophoto coverage of Wallonia were used to compute a photogrammetric Digital Surface Model with the open source photogrammetric suite MicMac (11,12). Following the methodology developed by (8), we combined the photogrammetric DSM with the LiDAR-derived DTM to compute a hybrid (LiDAR DTM / photogrammetric DSM) Canopy Height Model at a resolution of 0.5 m (GSD, Figure 2).

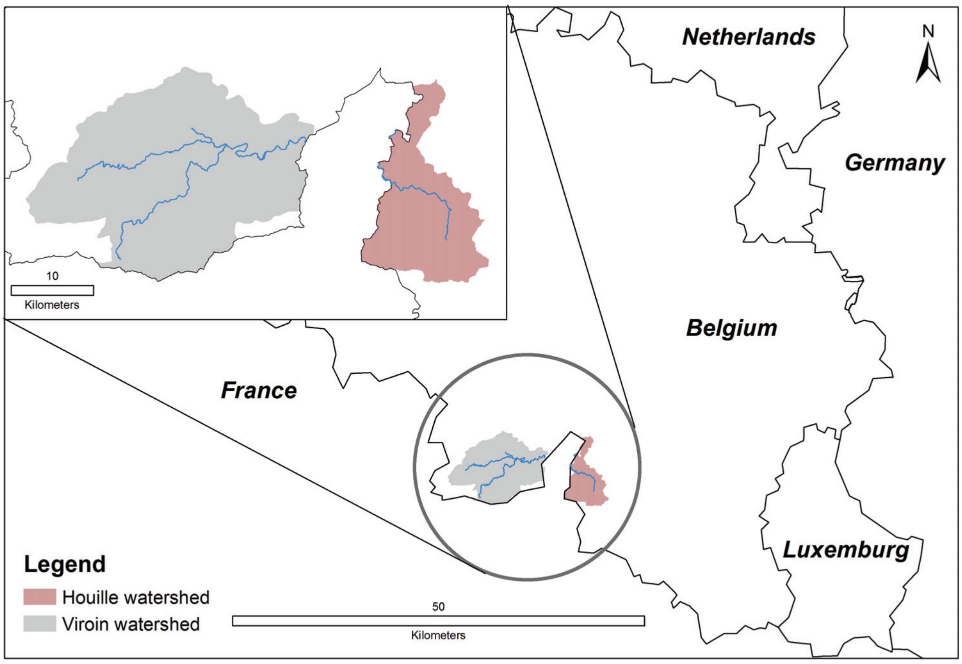

Figure 1: The watershed of the Houille and Viroin rivers (725 km², 487 km of river network).

Figure 2: Hybrid Canopy Height Model. Adapted from (13).

Hybrid Canopy Height Model allows to derive cost-effective 3D information which can densify or update LiDAR-derived Canopy Height Models. They can generally be derived from raw images of regional orthophoto coverages, allowing 3D information to be extracted from already ordered (and budgeted) remote sensing surveys.

River network segmentation

The finest scale of analysis is the river reach, for which all the information will be extracted. We used the segmentation of the river network used by river managers in Wallonia (14). This procedure is based on homogenous river reaches defined by expert operator advice, with a mean length of 2.3 km, within the whole river network of Wallonia.

Disaggregation and re-aggregation process

Based on the work of Alber and Pégay (15), a disaggregation procedure was used to characterize the variation of attributes from upstream to downstream. The analysis was performed within flood-plain samples distributed regularly (at 50 m intervals) along a director axis derived by smoothing the centreline of the floodplain area. The floodplain area is derived from the regional mapping of potentially flooded areas (16).

When appropriate, an upstream-downstream analysis was performed at different lateral scales: left-right bank, wetted channel plus 6 and 12 m riparian buffers, and entire floodplain (Figure 3).

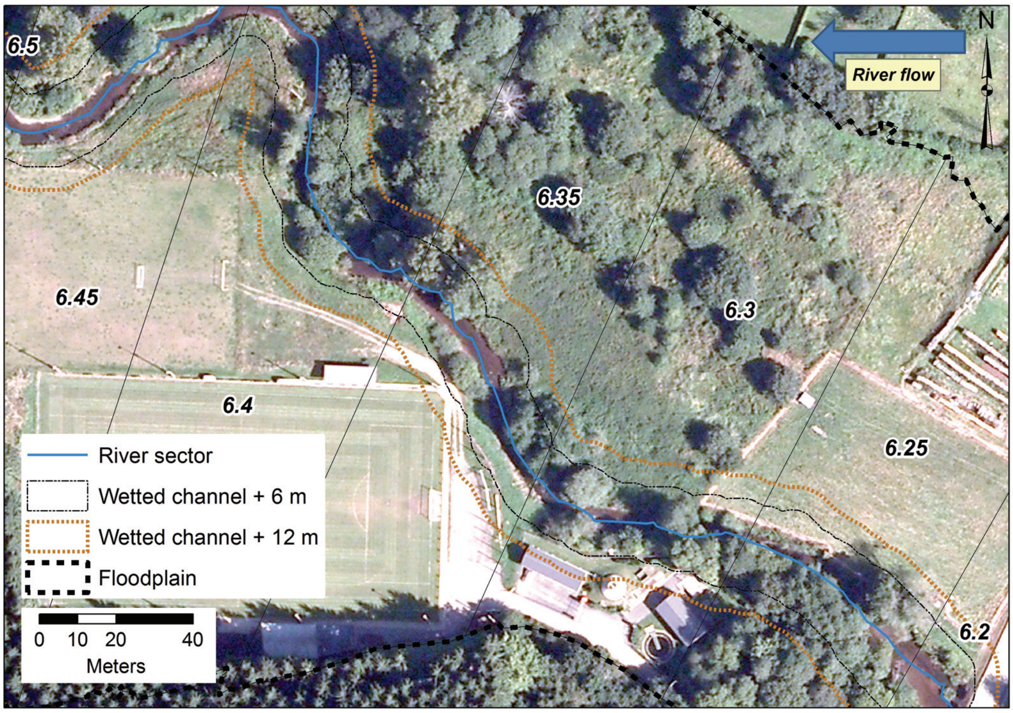

Figure 3: Longitudinal sampling of 50 m long segments and of lateral sampling buffers.

After this disaggregation process, a re-aggregation process could be performed, analysis at the sample scale (50 m long channel axis reach) being computed at a higher scale, e.g., at a 1 km channel axis reach (Figure 4).

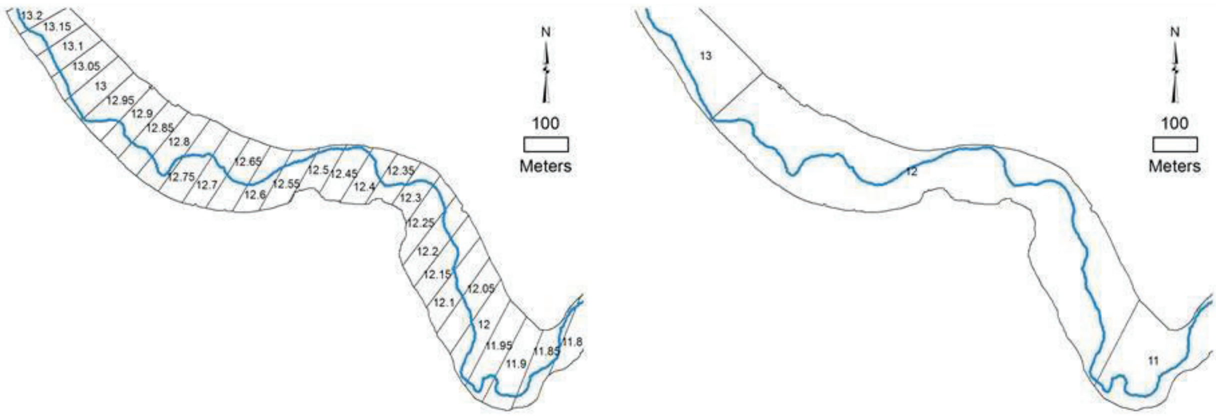

Figure 4: Re-aggregation process: 50 m long disaggregated to 1 km long re-aggregated reaches

Extraction of physical settings of riparian zone

Table 1 synthetizes the riparian zone attributes which were extracted from the low density LiDAR dataset. These attributes are derived from thematic data (floodplain extent) or from several metrics of the LiDAR dataset, based on previous work of the authors (see (7) for details).

Table 1: Physical settings of riparian zone

Riparian zone attribute	**Source data**	**Interest as indicator**
Relative water level	Relative DTM (derived from LiDAR DTM)	Anthropization / Terrestrialization of the riparian zone (presence of artificial levees, reinforced river bank, …)
Channel extent	LiDAR point cloud	Structural feature of riparian zone
Channel width	LiDAR derived channel extent	
Channel sinuosity	LiDAR derived channel extent	
Floodplain width	Thematic data (regional mapping of potentially flooded area)	

As an example, Figure 5 illustrates the relative water level, which can be an indicator of the nearness to water. This information can be related to a riparian zone sample or to its riparian forests.

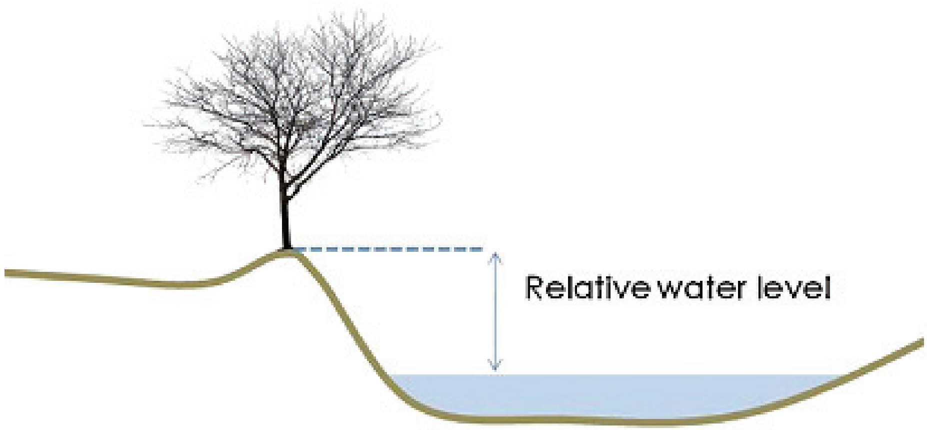

Figure 5: Illustration of relative water level as an indicator of the nearness to water, from (7).

Riparian forest characterization

We propose to adapt the strict LiDAR approach developed in (7) with a mixed approach, based on hybrid Canopy Height Model (photogrammetric DSM and LiDAR DTM). The riparian forest attributes (see Table 2) will be extracted at the river reach scale, allowing us to identify fundamental information about the riparian forest quality, as a major proxy of the riparian zone quality on itself. All these riparian forest attributes can be used as indicators of the ecological integrity of the riparian zone. They can be updated once raw images from a new orthophoto survey are available (currently on a three-year basis).

Table 2: Riparian forest attributes derived from the LiDAR dataset

Riparian forest attribute	**Source data**	**Interest as indicator**
Relative water level	Relative DTM (derived from LiDAR DTM), Hybrid CHM	Flooding frequency of riparian forest, terrestrialization of the riparian zone
Longitudinal continuity	Hybrid CHM	Corridors for plant dispersal, habitats and migration corridors for birds and mammals
Tree/forest height (mean, relative SD)		Mature stand localization (mean height); spatial heterogeneity and habitat quality(relative SD)
Mean Core Area Index (CAI)		Habitat fragmentation
Mean Fractal Dimension Index (FDI)		Spatial heterogeneity and habitat quality

RESULTS

Altogether, 192 river reaches were characterized within this study. To illustrate the potential of such an approach to characterize riparian zone at a network scale in order to help field managers, we propose to aggregate the results at the scale of the water bodies (as defined by the Water Framework Directive). The graphical representation of aggregated results (Figure 6 - case of riparian forest longitudinal continuity) can help public administration to identify priority areas for action plans. The case of longitudinal continuity of the riparian forest in the Viroin river watershed allows us to identify the water body “MM04R” as endangered regarding its riparian forest. This water body is located in an area of intense agriculture, which results in a very reduced and fragmented riparian forest.

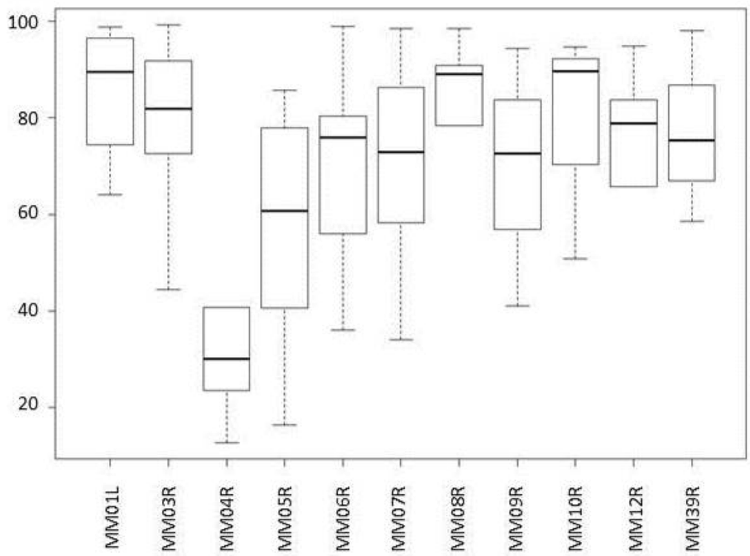

Figure 6: Longitudinal continuity (%) of riparian forest (wetted channel +6 m, watershed of the Viroin river) - the water body "MM04R" presents a very low value of riparian forest continuity and should be subject to special attention by the river managers.

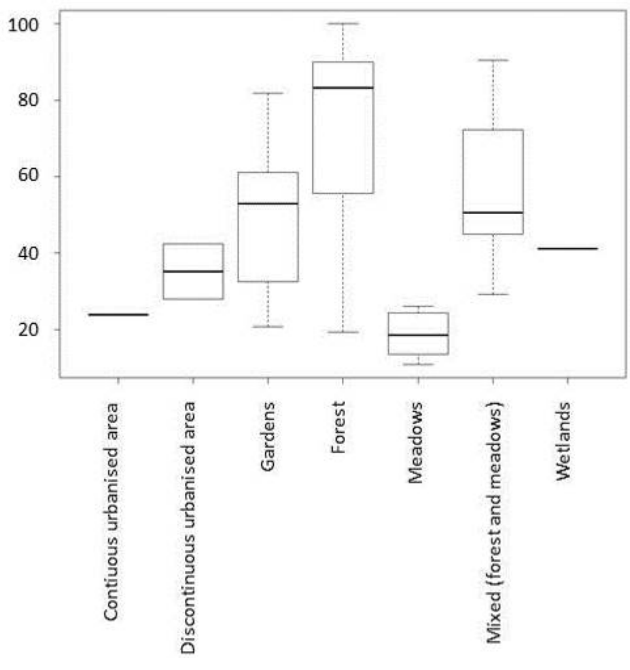

Figure 7: Longitudinal continuity (%) of riparian forest (wetted channel +6 m, watershed of the Houille river) VS land use in the buffer. Urbanized areas must be a major concern for land manager in terms of riparian forest continuity.

Another aggregation process can be performed through the proxy of the land use in the riparian zone. Figure 7 highlights lower riparian forest longitudinal continuity values in urbanized areas. Even if the watersheds are mostly rural, without the presence of a major city, the riparian forests in urbanized areas are relatively more fragmented. This kind of information is of significant interest and can objectively provide guidance for land managers.

CONCLUSIONS

This research was conducted on a test site (487 km length) and will be implemented at the Walloon hydrographic network scale (13,000 km) in the medium term (2014-2015). Those indicators will be used to assess the riparian zone quality in terms of ecological integrity and hydromorphology. Further analysis of those preliminary outcomes will extract management indicators which will be used as decision-making tools for planning and evaluating riparian zone management:

- Evaluate management strategy (e.g. priorization of river reaches in relation to ecological network or the presence of endangered habitats)
- Localize areas with high potential for river restoration
- Rationalize riparian forest strips management: e.g. maintenance logging planning in relation to tree height data.

Our preliminary promising results show the potential of the approach to implement a regional monitoring of the Walloon riparian zone on a regular basis (minimum 3 years), focusing on their riparian forests. By an objective and cost-effective monitoring of the riparian zone in the entire river network, our approach will provide tools for public administrations to focus on endangered riparian areas. More generally, these tools will improve the planning and the evaluation of the action of management (notably on the riparian forest).

As most European countries have been covered by orthophoto surveys regularly since the late 90's and are being more and more covered by quality LiDAR DTM, our approach is highly replicable. Depending on the parameters of the flight surveys, time series of photogrammetric Digital Surface Model also represent an interesting potential for historical analysis of riparian zones.

In this case study, further work will focus on the characterization of riparian zones based on historical orthophoto surveys (years 2006 and 2009). Going further than forest 3D information, spectral information derived from satellite imagery will also be used to improve the forest characterization. The imminent launch of the Sentinel-2 will enable free-of-charge intra-annual time series of spectral data to be generated, which can be used to identify species or groups of species, notably those whose ecological traits differ.

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REFERENCES

1 Naiman R J, N Décamps & M E McClain. 2005. Riparia: Ecology, Conservation, and Management of Streamside Communities (Elsevier/Academic Press) 448 pp.

2 Debruxelles N, H Claessens, P Lejeune & J Rondeux, 2009. Design of a watercourse and riparian strip monitoring system for environmental management. Environmental Monitoring and Assessment, 156(1): 435-450

3 Myers L, 1989. Riparian area management. Inventory and monitoring of riparian areas. US Department of the Interior, Bureau of Land Management, TR-1737-7 (Denver, CO, U:S.A.) 79 pp.

4 Arroyo L A, K Johansen, J Armston & S Phinn, 2010. Integration of LiDAR and QuickBird imagery for mapping riparian biophysical parameters and land cover types in Australian tropical savannas. Forest Ecology and Management, 259(3): 598‑606

5 Goetz S J, R K Wright, A J Smith, E Zinecker & E Schaub, 2003. IKONOS imagery for resource management: Tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. Remote Sensing of Environment, 88(1-2): 195‑208

6 Johansen K, L A Arroyo, J Armston, S Phinn & C Witte, 2010. Mapping riparian condition indicators in a sub-tropical savanna environment from discrete return LiDAR data using object-based image analysis. Ecological Indicators, 10(4): 796‑807

7 Michez A, H Piégay, F Toromanoff, D Brogna, S Bonnet, P Lejeune & H Claessens, 2013. LiDAR derived ecological integrity indicators for riparian zones: Application to the Houille river in Southern Belgium/Northern France, Ecological Indicators, 34: 627‑640

8 Lisein J, M Pierrot-Deseilligny, S Bonnet & P Lejeune, 2013. A photogrammetric workflow for the creation of a forest canopy height model from small unmanned aerial system imagery. Forests, 4(4): 922‑944

9 Véga C & B St-Onge, 2008. Height growth reconstruction of a boreal forest canopy over a period of 58 years using a combination of photogrammetric and lidar models. Remote Sensing of Environment, 112(4): 1784‑1794

10 White J C, M A Wulder, M Vastaranta, N C Coops, D Pitt & M Woods, 2013. The utility of image-based point clouds for forest inventory: A comparison with airborne laser scanning. Forests, 4(3): 518‑536

11 Deseilligny M P & I Clery, 2011. Apero, an open source bundle adjustment software for automatic calibration and orientation of set of images. 4th ISPRS International Workshop 3D-ARCH-11, 269-276

12 Deseilligny M P, 2007. B.1 MicMac, un logiciel pour la mise en correspondance automatique d'images dans le contexte géographique. Institut National de l'Information Géographique et Forestière, 7 pp. (last date accessed: 21 Nov 2014)

13 Bonnet S, 2009. Un modèle numérique de canopée pour l'estimation de la hauteur dominante des peuplements résineux en Région wallonne. Forêt Wallonne, 98, 53‑59

14 Burton C, F Henrotay, A Borensztein & H Claessens, 2010. La sectorisation des cours d'eau wallons. Poster, University of Liège (last date accessed: 01 Dec 2014)

15 Alber A & H Piégay, 2011. Spatial disaggregation and aggregation procedures for characterizing fluvial features at the network-scale: Application to the Rhône basin (France). Geomorphology, 125(3): 343‑360

16 Service Public de Wallonie, 2013. Aléa d'Inondation, Zones Inondables Risques d'Inondation. Méthodologie de la Cartographie. Notice Technique. Version 19 Décembre 2013 (Géoportail de la Wallonie, Namur, Belgium) 52 pp. (last date accessed: 21 Nov 2014)