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Abstract: A method using remote sensing and large-scale statistical models was developed to assess the influence of riparian land use on river ecological status. It was implemented over the 6000 km long Normandie river network (France). First a detailed fine scale map of Riparian Area Land Cover (RALC) was produced from very high spatial resolution imagery. Then spatial riparian land cover indicators were derived from this RALC map. Finally large-scale statistical models were built that quantify the relationships between ecological status indicators (macroinvertebrate community) and land cover indicators at basin scale and riparian scale. These models revealed the predominant degrading impact of urban zones both at basin and upstream riparian scale, and the beneficial role of tree vegetation within the local riparian buffer (15m wide strip along a 100m reach upstream from the station). Results highlight the need for fine resolution information on RALC for (i) better understanding relationships between land cover and river ecological status; and (ii) prioritising riparian buffer preservation and restoration strategies to reach the targets of the European Water Framework Directive (WFD).

Keywords: Riparian corridor, Riparian vegetation, Remote sensing, High Spatial Resolution, Spatial indicators, Large-scale relationships models, Restoration prioritisation, Water Framework Directive

Introduction

Riparian vegetation influences the ecological status of river ecosystems in many specific ways (Naiman et al. 2005). Maintaining or restoring good riparian conditions could constitute a major action to reach European Water Framework Directive (WFD) targets by 2015. Prior to the definition of such strategies, an improved understanding of the influence of human pressures along river and riparian vegetation on river ecological status is required at regional scale. For this purpose, Riparian Area Land Cover (RALC) maps serve as a basis to calculate land cover spatial indicators (LCSI) related to human pressures and riparian vegetation characteristics and properties, that will help in understanding and predicting river ecological status.

However, traditional photo-interpretation mapping methods, based on aerial photography, are time-consuming and expensive to characterize RALC in an accurate way over large areas. On the other hand, land cover maps derived from moderate spatial resolution optical satellites such as *Landsat* (30 m) or SPOT 4 (20 m) appear to be insufficient for a fine and detailed characterization of RALC (Müller, 1997, Tormos et al., 2010) and inadequate to study the influence on river ecological status of along river human pressures and riparian vegetation (Frimpong et al. 2005). Progresses in optical High Spatial Resolution (HSR 5 to 10 m) and Very High Spatial Resolution (VHSR < 5 m) sensor technologies, make available a variety of remotely sensed images for mapping RALC at different levels of spatial and spectral detail (i.e. spatial resolution, number of spectral bands). Recent developments in Object Based Image Analysis (OBIA) have revolutionized the processing of VHSR data by providing efficient classification techniques whose results come close to those of human photo-interpretation, while being much faster, cheaper and reproducible (Benz et al. 2004, Tormos et al., submitted).

This work was dedicated to the development of new methods for obtaining fine and detailed RALC maps and improving the regional scale understanding of the influence on river ecological status of multiple along river human pressures and riparian vegetation. For this purpose we developed a method to map RALC from HRS and VRSR images using an operational classification procedure based on OBIA, and a method to build large-scale statistical models quantifying the relations between river ecological status indicators and LCSI at basin and riparian scales. These methods were implemented over Normandy rivers (north-west France).

Materials and methods

Study area **-** The present research focused on a part of the Normandy river network (25 000 km² basin; 6000 km long river network) located in the Table Limestone HydroEcoRegion (HER) (see Figure 1-A). This area is dominated by a strong agricultural occupation, primarily focused on field crops and livestock, with special structures in the riparian buffer, such as alternate tree vegetation and grassland near the river. This agricultural landscape is dotted with urban zones, from small to large.

Mapping RALC - A generic classification procedure was used for mapping RALC, based on multi-scale OBIA combining information from Spot5 XS (10m pixels), aerial photography (0.5m pixels) and thematic data, using fuzzy expert knowledge classification rules. A complete description of the classification procedure can been found in Tormos et al. (submitted).

Building statistical large-scale relationships models **-** A large-scale model was built that quantifies relationships between ecological status indicators and LCSI at basin scale and at two riparian corridor scales, upstream riparian corridor (URC) and local riparian corridor (LRC).

Ecological status of rivers in the study zone was assessed using IBGN (Indice Biologique Global Normalisé) indicators measured at river biological stations from the French monitoring network. IBGN indicator results from a combination of two metrics : the total number of macroinvertebrate taxa and their polluosensitivity. The study area is covered by 155 biological stations on which 1034 samples were measured during the 1992–2004 period. For each site, the mean IBGN was transformed to ecological quality ratio values (EQR) by dividing the observed mean values by reference values for corresponding river type, in order to obtain a standardized ecological status indicator (between 0 and 1), particularly sensitive to anthropic variables.

Then, for each site, several LCSI quantifying the surface percentage of a given land cover category in a given area (or pressure footprint), were built using specific GIS techniques. At basin scale, surface percentages on the upstream basin were assessed using land cover derived from the CORINE Land Cover map (CLC built from moderate spatial resolution satellite, 30m pixels) according to the most detailed typology (44 categories). At riparian corridors scale (URC and LRC) surface percentages were derived from the Very High Resolution RALC map according to the most detailed typology. These riparian LCSI were computed over different riparian buffers : at URC scale they were built over 15 upstream riparian buffers that differ by their lateral distance to the river (10 buffers from 5m to 50m in steps of 5 m and 5 buffers from 100m to 300m in steps of 50m) ; at LRC scale they were built over 150 local riparian buffers that differ both by their lateral distance to the river (same lateral distances used at URC scale) and their longitudinal river network distance upstream to the ecological station (for each lateral distance, 5 buffers from 100m to 500m in steps of 100 m and 5 buffers from 1000m to 3000m in steps of 500m).

Finally, correlations between mean EQR-IBGN (Y-variable) and land cover proportions over different spatial footprints for the various scales (X-variables) were quantified following a 2 step statistical procedure. The first step is dedicated to the selection, for each land cover category and each riparian scale (upstream and local), of the spatial footprint over which the LCSI has the strongest correlation with river ecological status indicator, using bi-variable correlations techniques. The second step is devoted to establishing the correlation between mean EQR-IBGN and LCSI (surface proportion) at basin scale and on selected riparian spatial footprints (step 1) using Partial least Square (PLS) regression technique with a 95 % confidence degree as used in French large-scale relationships models (Wasson et al., 2010).

Results and discussion

The generic classification procedure produced a detailed (62 categories) RALC map. An illustration of the resulting map, according to an 8-class synthesized typology in order to obtain a more visual representation, can be found in Figure 1-B. As observed in Figure 1-C on a river reach of the study area, the resulting map is incomparably more finely resolved and informative than CLC map. This observation confirmed the need of HSR and/or VHSR images for a better quantification of LCSI at riparian corridor scale as demonstrated by Tormos et al. (2010).

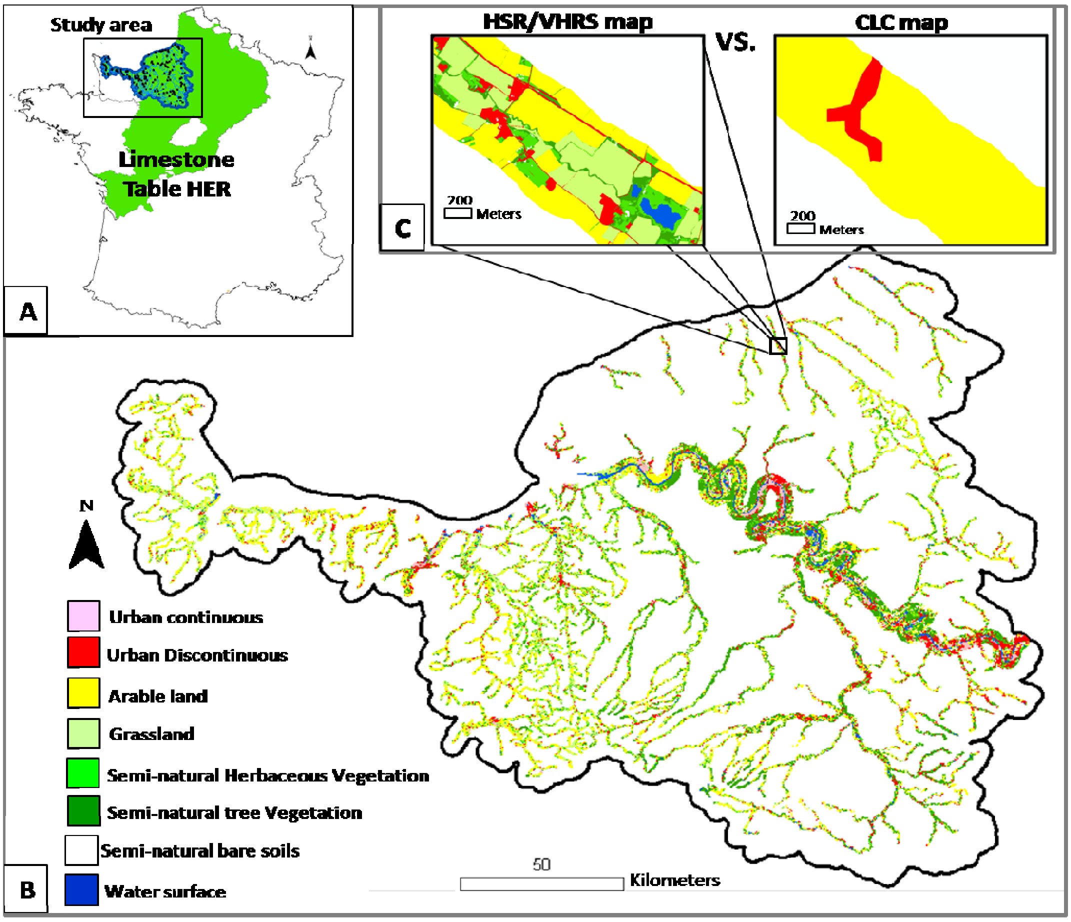

Figure 1. (A) Location of the study area (A); (B) RALC map resulting from the OBIA classification based on HSR and VHRS images (Spot 5 10m pixels; aerial photography 0.5m pixels) and thematic data; (C) the comparison on river reach of the resulting map and the CLC map.

Model results are presented in Figure 2. The mean EQR-IBGN was explained at 45.3% (R^2) by 5 LCSI. Although this regression coefficient is relatively low, due to the gap between LCSI and ecological status indicators in terms of ecological processes (for instance some processes such as influence of invasive species or effects of dams, are not taken into account in LCSI), it appears as a good result compared to other works studying large-scale relationships (see for example Wasson et al., 2010). Therefore, using fine resolution information at riparian scale improves the understanding of the land cover influence on river ecological status. On the one hand the model shows that the major factors degrading ecological status are first discontinuous urban zones at basin scale and at URC scale (over a 300m large buffer), and to a lesser extent arable land at LCR over a 30m large buffer close to the station (100m upstream). As observed by several authors and especially in France by Wasson et al. 2010, urban zones, causing organic and toxic pollution in addition to hydromorphological alterations, are predominant factors of the degradation of macroinvertebrate indicator values on aquatic ecosystems. On the other hand, the models reveals that the major factors protecting the river ecological status are tree vegetation on a 100m-buffer at URC and on 15m-buffer close to the station (200m upstream). Therefore thanks to fine resolution information at riparian scale, the beneficial role of the riparian tree vegetation on river ecological status, observed by several studies at local scale (Naiman et al., 2005), could be statistically highlighted at regional scale in a large-scale relationship model.

Such results are of high interest for decision-makers that can estimate the interest of investing in riparian restoration strategies by anticipating their expected effect in terms of WFD standards :

for example according to these results converting arable land to tree vegetation on 30 m riparian band could increase the ERQ-IBGN indicator by more than 0,2.

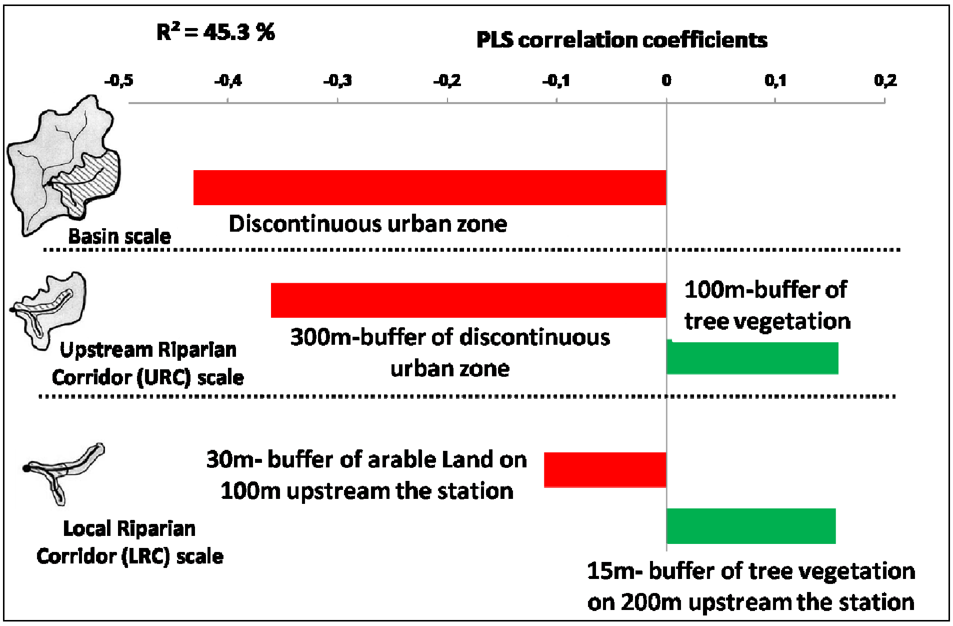

Figure 2. PLS analysis and resulting correlation coefficients. In red, spatial indicators that are negatively correlated with EQR-IBGN and in green spatial indicators that are positively correlated.

Conclusions

This research has demonstrated that fine resolution information at riparian scale, derived from HSR and VHSR remotely-sensed images, is indispensable (i) for improving the understanding of landscape influences on river ecological status in large scale relationships models and (ii) for supporting managers in the prioritising of riparian preservation and restoration strategies to reach the targets of WFD. In order to reinforce these results and support managers in their decision-making process, such studies have to be reproduced in various HydroEcoRegions, using other families of ecological status indicators (fish, diatomae) and specific spatial indicators related to riparian vegetation conditions, as developed by Tormos et al., 2010.

Acknowledgments

This study has been made possible by a PhD grant from the French Ministry of Research. Acquisition of remote sensing data benefited from the support of the ISIS programme of the French national space agency CNES (Spot5 images, distribution Spot Image), while IGN airborne orthophotos were made available by the French Ministry of Agriculture.

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