POTENTIAL OF COPERNICUS RIPARIAN LAYERS TO ASSESS RIPARIAN ZONES INTEGRITY WITH LANDSCAPE METRICS

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TRAVAIL DE FIN D'ETUDES PRESENTE EN VUE DE L'OBTENTION DU DIPLOME DE MASTER BIOINGENIEUR EN GESTION DES FORETS ET DES ESPACES NATURELS

ANNEE ACADEMIQUE 2018-2019

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Préambule

Ce travail de fin d'études est en lien avec le Converges COST Action et a bénéficié d'une bourse afin d'effectuer une partie de ce mémoire à la faculté des sciences agronomiques de Lisbonne (ULisboa) et d'assister au meeting annuel concernant la thématique des zones riveraines à Pruhonice.

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Résumé

Les zones riveraines sont des milieux exceptionnellement riches en biodiversité mais font également partie des écosystèmes les plus menacés. Avec l'augmentation de la pression démographique, l'Homme exerce à l'heure actuelle des perturbations majeures sur ces milieux, qui s'amplifieront davantage avec les changements climatiques. Dès lors, les outils basés sur l'imagerie sont devenus indispensables pour caractériser ces zones sensibles à de larges échelles, dans le but de favoriser des politiques de conservation de la biodiversité. Les données Copernicus, disponibles à l'échelle européenne, ont pour objectif de répondre à ces enjeux. Dans cette étude, le potentiel des données Copernicus a été comparé avec deux autres jeux de données à très haute résolution afin de déterminer si elles permettent d'évaluer l'intégrité écologique des zones riveraines, par une approche basée sur les métriques paysagères. Les résultats ont montré que les données Copernicus réagissent positivement à l'influence d'un gradient de perturbation anthropique. Cependant, les données Copernicus ne sont pas montrées aussi précises que les jeux de données à très haute résolution, ce qui peut avoir des conséquences sur la gestion de ces milieux. L'influence de l'échelle spatiale sur la structure de la végétation riveraine a été étudiée et a montré que la végétation située à proximité du cours d'eau est la plus impactée. Le présent travail a également montré la pertinence de l'utilisation de l'approche paysagère mais a pointé une limite dans le sens où cette approche n'a pas pris en compte les variables tri-dimensionnelles, pourtant indispensables pour caractériser les zones riverains.

Mots clés : Zone riveraine, intégrité écologique, Métriques paysagères, Occupation du sol, Perturbation anthropique

Abstract

Riparian zones are environments exceptionally rich in biodiversity but are also among the most threatened ecosystems. With the increase in population pressure, humans are currently causing major disruptions to these environments, which will increase further with climate change. As a result, image-based tools have become essential to characterize these sensitive areas on a large scale, with the aim of promoting biodiversity conservation policies. Copernicus data, available at European level, aim to meet these challenges. In this study, the potential of the Copernicus data was compared with two other very high resolution data sets to determine whether they can assess the ecological integrity of riparian zones using a landscape metric approach. The results showed that the Copernicus data react positively to the influence of an anthropogenic disturbance gradient. However, Copernicus data are not shown as accurate as very high resolution datasets, which can have consequences on the management of these environments. The influence of spatial scale on the structure of riparian vegetation was studied and showed that vegetation near the watercourse is the most affected. This work has also shown the relevance of using the landscape approach but has pointed out a limitation in that this approach has not taken into account the three-dimensional variables, which are essential to characterize riparian environments.

Keywords : Riparian zone, Ecological integrity, landscape metrics, Land use, Human disturbance

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List of abbreviations

ARZ	Actual Riparian Zone
IIC	Integral Index of Connectivity
LPI	Largest Patch Index
LULC	Land use Land cover
MNN	Mean Nearest-Neighbor
MPFD	Mean Patch Fractal Dimension
MPI	Mean Proximity Index
MPS	Mean Patch Size
MSI	Mean Shape Index
NP	Number of Patches
ORZ	Observable Riparian Zone
PD	Patch density
PRZ	Potential Riparian Zone
PSCV	Patch Size Coeffcient of variation

1. Introduction

1.1 Context

With the increase in population pressure, urbanization and industrialization, the impact of Man on ecosystems and climate has increased from the middle of the 20th century to a point where in many parts of the world, ecosystems are more driven by anthropogenic pressures than by natural processes (Meybeck, 2003) (Stella et Bendix, 2019), leading scientists to call this period Anthropocene (Meybeck, 2003 ; Downs et Piégay, 2019).

Riparian areas are no exception to this rule. Currently, on the Old Continent, the percentage of riparian areas in good condition is low, ranging from 20 to 30%, but varying between regions (Stella and Bendix, 2019). In Europe, the number of inhabitants living in urban areas is close to 75%. This trend will be marked in the future by an increase in habitat fragmentation, the proliferation of invasive species, pollutant emissions and physical alterations, and will be particularly pronounced in southern and eastern European countries (Tockner et Stanford, 2002; Stella et Bendix, 2019).

In addition, climate change will alter hydrological cycles and temperature in some regions (Fernandes et al., 2016), leading to an increase in the demand for drinking water when the distribution of these resources is already under threat (Meybeck, 2003). It was only after the Dublin Water Conference in 1992 that water issues started to occupy an important place in the international programmes for sustainable development and in scientific programmes (Meybeck, 2003).

Thus, at the European level, the Water Framework Directive (2000/60/EC) was implemented in 2000 with the objective of ensuring sustainable water management and is based on a river basin approach across political boundaries (Schmutz, 2018). The objective of this directive is to improve water quality, which is assessed on the basis of biological, chemical and hydromorphological parameters. The assessment of the ecological status of European rivers is alarming because only 38% of them have a good ecological status (Stella et Bendix., 2019) It is therefore necessary to rehabilitate the riparian areas that are the most affected aquatic environments (Stella and Bendix, 2019) and to understand their functioning.

1.1.1 Riparian zone, an ecosystem to be conserved

The term “Riparian zone” is a complex subject of study in terms of definition and delineation. Over the past several decades, many definitions of riparian zones have been developed. Most definitions use a functional approach by highlighting the mutual influences between terrestrial and aquatic systems in terms of biological, chemical, hydrological and morphological processes. (Dufour et al., 2018). In a sense, these areas can be defined as « transitional areas between terrestrial and aquatic ecosystems and distinguished by gradients in biophysical conditions, ecological processess, and biota » (Dufour et al., 2018).

Riparian vegetation forms the terrestrial compartment of the hydrosystem (Piegay & al., 2003). Today, despite the increase in the number of studies on riparian vegetation, the definition/terminology of riparian vegetation is still a matter of debate. In addition to being numerous, the terms differ according to the languages used (Dufour et al., 2018). In English, more than 30 different terms exist to characterize vegetation adjacent to aquatic systems (Fischer et al., 2001). This diversity of terms used is linked to the different background of the actors who study riparian zone (Pautou & al., 2003 ; Dufour et al., 2018). Also, the different geographical context can finally lead to a misunderstanding between actors (Dufour et al., 2018). For example, a riparian forest may be a “narrow strip of trees” in a grassland or a large “floodplain forest”. They can also have a variety of floristic compositions, depending on the stage of plant succession in which they are located (Piégay & al., 2003). First, species with an r-strategy will colonize the sediments deposited by the floods. These are species such as willows (Salix spp.), birches (Betula spp.), poplars (Populus spp.). After successional phases that can last for centuries, species with a k-strategy dominate the riparian forest (Piégay & al., 2003). These species, which are part of the final stage of plant succession, are part of the genera Quercus, Fraxinus, Ulmus. Communities differ according to bioclimatic regions, from white alder for the northernmost region (the least productive) to white poplar for the southernmost regions (the most productive).

Rich in biodiversity, natural riparian zones are considered among the most diverse and complex habitats on earth and provide many ecosystem services (Naiman et Décamps, 1997 ; Nilsson et Svedmark, 2002). Riparian vegetation, with their elongated conformation are likely to support a large diversity of bird populations that vary with the stage of plant succession and provide important insect food resources (Frochot & al., 2003 ; Mayer et al., 2007). Riparian vegetation serves as a filter for pollutants, such as nitrogen and phosphorus, that come from agricultural activities. The nitrate filtration can range from 5 to 30% per metre of width (Sabater et al., 2003) and riparian forests have a greater purifying potential than grasslands (Piegay et al., 2003 ; Mayer et al., 2007 ; Corenblit et al., 2018). These pollutants can severely affect water quality and can lead to eutrophication of rivers (Mayer et al., 2007 ; Brogna et al., 2017). Through their canopy, riparian vegetation regulates incident light flow by providing shade and limits the increase in water temperature essential for fish survival (Piegay et al., 2003). Riparian areas are sources of deadwood production that modify channel flow rates and thus control bed geometry and grain size (Hawes, n.d.). By accumulating other woody debris, they provide habitat for

salmonids and macroinvertebrates (Naiman and et Décamps, 1997). They help stabilize the banks by anchoring their roots (Piegay & al., 2003) and finally have an important social role as they are the location of sports and recreational activities (Le Lay, 2007)

However, the sustainability of these services is disrupted by anthropogenic pressures that have an unprecedented impact on these environments. Man has always exerted stressors on these ecosystems, hindering the development of native species by reducing the availability of light, water, nutrients and space and hampering the dispersion, germination and establishment of vegetation (Stella and Bendix, 2019). Worldwide, 95% of riparian areas have already been exploited by agriculture or logging (Tockner et Stanford, 2002 ; Stella et Bendix, 2019). Deforestation of riparian areas began during the Neolithic period, when sedentary populations settled there (Piégeay et al., 2003) This anthropogenic pressure, some of which dates back to the Neolithic period (Dufour and Piégay, 2006), was especially marked in the 19th and 20th centuries by the exploitation of sub-footland coppice, with short rotation, as well as by the expansion of grazing areas, thus forming open landscapes (Piégay, 1997), increasing habitat fragmentation and modifying structural and plant characteristics. In the 20th century, following the economic situation, the rural exodus caused people to migrate to the cities (Flamant, 2010). Technological developments in agriculture have concentrated populations near the most fertile areas, leaving livestock to riparian areas. This rural exodus was the origin of a spontaneous reforestation of riparian forests during the 20th century.

Man also affects the contribution of water flows and sediments through the creation of dams. These reduce the magnitude and frequency of floods, which hinders the supply of nutrients, which are essential for the formation of floodplains. Dams also limit the supply of groundwater needed for plant growth (Nilsson et Berggren, 2000) and block the plant dispersion, leading to a modification of the plant compositions of the minor and major beds, by favouring the establishment of xeric species (Piegay et al., 2003 ; Stella and Bendix, 2019). In Europe, more than 7000 dams (> 1ha) were built between 1950 and 2010 (Ferreira et al., 2019). Also, the chennalization of watercourses has made it possible to promote soil drainage, but as a result, modifies plant communities (Pedersen, 2009).

Natural disturbances such as floods are the phenomena that most controls the formation of riparian plant communities (Bendix et Hupp, 2000). Vegetation can be destroyed by the force of the water, which will cause severe erosion and destroy the substrate on which it is rooted. Long-term saturation of the substrate in which the roots are found can lead to their death and promote the dynamics of dead wood in the watercourse (Bendix et Hupp, 2000). Floods play a major role in the dispersion of diasporas to new settlement sites, through hydrochory and have a role in seedling recruitment of pioneer species and the establishment of adult communities (Corenblit et al., 2007). On the other hand, vegetation, through its roughness and structure, also conditions sediment transport and controls erosion processes (Stallins, 2006). Thanks to its roots, vegetation promotes bank stabilization, by modifying substrate cohesion (Corenblit et al., 2007) and can decrease the speed of the watercourse (Gazelle & al., 2003 ; Stallins, 2006). The mutual

interaction between hydrogeomorphic processes, plant communities and alluvial plains can be called biomorphology (Stallins, 2006 ; Corenblit et al., 2007).

Changes in water flows and land use changes are also favourable conditions for the development of invasive species (Richardson et al., 2012). These species have a high rate of fecundity, a high dispersal capacity (Perry et al., 2015) and a phenotypic plasticity allowing them to adapt to their environment. Indeed, (Saccone et al., 2010) have shown that *Acer negundo* has a high survival rate in shade and strong growth in bright light. With climate change, flood intensity and distribution are likely to change (Fernandes et al., 2016), causing droughts and promoting the development of xeric species in warmer latitudes (Stella et Bendix, 2019).

All these pressures must be taken into account in order to manage these environments sustainably. In view of global changes, it is necessary to use new management tools, capable of providing information and anticipating large-scale changes.

1.1.2 Remote sensing, a tool for the management of natural environments.

Initially, remotes sensing's techniques applied to riparian zones were based on aerial images. The mapping of riparian zones rapidly shows his limits to characterize these zones at large scale because of the time it takes to carry out the photointerpretation (Goetz, 2006).

Subsequently, automatic methods based on satellite imagery with moderate spatial resolution (5-30 m) began to develop. Landsat and Ikonos satellites provided land use maps within the riparian buffers (Goetz, 2006). They have also been used to characterize the structural aspect, such as the foliar percentage of the canopy, as well as to map the species composition of the riparian zone (Johansen and Phinn, 2006). Nevertheless, the use of satellites has always been unsatisfactory in terms of vegetation classification: Compared to the photo-interpretation of aerial images, (Congalton et al., 2002) have shown that satellite data classifications correspond between 25-30% with those of photo-interpretation based on the aerial image. However, satellite data have the advantage of being able to be used at larger scales, while classifications based on photo-interpretation of aerial images are much more expensive if they have to be used over larger areas (Congalton et al., 2002).

Since 2010, new technologies such as LiDAR (Light Detection and Ranging) data, UAV images and multispectral satellite images have been developed and used to characterize riparian environments (Dufour et al., 2013 ; Dufour et al., 2018). Lidar data, as Light Detection and Ranging, are obtained from the pulse of a light beam from a laser. This will be reflected by an obstacle and finally sent back to the sensor. Knowing the speed of the light beam and the time between the pulse and the return of light to the sensor, the distance can thus be determined (Goetz, 2006).

These data make it possible to characterize riparian areas with high accuracy (0.5-1m spatial resolution). They provide a three-dimensional characterization of vegetation structure by determining parameters such as tree height, vegetation density, crown diameter with high accuracy and thus reduce the time to acquire data over large areas compared to field surveys (Akay et al., 2012 ; Hutton and Brazier, 2012). They can thus be used to analyze the successional stages of riparian vegetation (Lallias-Tacon et al., 2017) and have also been used at regional scales to determine the volume of wood available (Huylenbroeck, 2017). At this scale, these very high resolution data can also provide numerical terrain models (Hutton et Brazier, 2012 ; Dufour et al., 2013). The development of these new technologies also makes it possible to accurately assess the composition of riparian vegetation (Michez et al., 2016 ; Richter et al., 2016) and to estimate their integrity by detecting invasive species. Thus, Michez et al., (2016) have developed a method to map invasive species by UAV with an accuracy of up to 97% for H. *mantegazzianum*. However, LiDAR data have several disadvantages. These have a high acquisition cost and are more complicated to process. In addition, LiDAR has difficulty penetrating dense vegetation (Dufour et al., 2013). These limitations mean that these data are not available everywhere, which does not currently allow for a very high resolution European-wide assessment of riparian areas.

Knowledge of the species composition of riparian areas is of major interest for their conservation. Data acquisition at large scales and temporal resolutions allows diachronic analyses to be established that can be used in a context of restoration (Bauer et al., 2018) and anthropogenic disturbance analysis (Richter et al., 2016).

The major contribution of satellite imagery to riparian environments has been the characterization of the riparian buffer by using several datasets. The delineation of riparian zone is important for understanding and protecting the ecosystem services they provide (de Sosa et al., 2018). However, due to the transitional nature of riparian areas, there is no single method for delimiting them. The first models, the simplest ones, require a fixed buffer width on either side of the channel (Hawes et Smith 2005). This method has the advantages of being widely applied and used in several guidelines for many countries (USA, Brasil, Slovenia) (Richardson et al., 2012). However, there are insufficient to prevent stream alterations, riparian functions and river organism's conservation (Richardson et al., 2012). An other drawback of this method is that it doesn't take into account specific site characteristics such as fluvial landform configuration or processes which are crucial for understanding riparian functioning and thus for adequately managing them

Alternatively, other more complex methods, based on land cover, soil properties, topographic position (Verry et al., 2004) vegetation types(de Sosa et al., 2018) exist and can provide variable delineation of riparian zones (de Sosa et al., 2018). The accuracy in riparian delineation has also improved over the last decade with the use of Geographic Information System (GIS) and the availability of high-resolution data and imagery (de Sosa et al., 2018). It is therefore possible to implement more variables in the models, making them more complex but flexible over time (Weissteiner et al., 2016).

With the development of GIS tools and the contribution of satellite imagery, new approaches based on landscape analysis have been developed in response to the decline in biodiversity.

1.1.3 The landscape approach, a solution for assessing ecological integrity ?

Landscape ecology is the study of the interaction of spatial patterns and ecological processes (Wiens, 2002). Introduced in Central and Eastern Europe in 1939 (Turner & Gardner, 2015) and developed as a result of the potential provided by aerial image, landscape ecology is an interdisciplinary science that is based on the spatial approach of geography and the functional ecology (Turner and Gardner, 2015).

Landscape structure is a combination of the landscape composition and landscape configuration. Composition refers to the presence and proportion of certain types of land cover. Configuration refers to the shape and the size of the patches forming the landscape and the spatial arrangement between them (Turner and Gardner, 2015). Generally, to represent the landscape pattern, the two-dimensional Patch Model Matrix (PMM) is used (Lausch et al., 2015). Patches are the basic units that make up the landscape, characterized by their size and shape as homogenous area. The matrix refers to the dominant land use in the landscape and patches can be bounded across the matrix by corridors.

Landscape ecology provides information on the assessment of ecological processes, such as flows of energy and nutrients, biomass biological diversity, from the spatial structure of the landscape. This approach has already shown that it can characterize the ecological integrity of riparian areas (Aguiar and Ferreira, 2005a) Fernandes et al., 2011). Ecological integrity can be defined « as the capacity to support and maintain a balanced, integrated and adaptive biological system having the full range of elements and processes expected in a region's natural habitat » (Michez et al., 2013). In riparian zones, the width, longitudinal continuity and floristic composition of riparian vegetation are often used to assess ecological integrity (Apan & Ferreira., 2005).

In order to understand the link between the landscape pattern and ecological processes and consequently, to assess ecological integrity, landscape metrics are numeric descriptors that quantify patch configuration and the spatial relationships among patches (Turner and Gardner, 2015). Thus, a wide variety of composition and configuration metrics have been developed (Uuemaa et al., 2009). In addition to these landscape metrics, several indices assessing landscape connectivity have been created (Pascual-Hortal et Saura, 2007). Landscape connectivity refers to "the degree to which the landscape facilitates or impedes movement among resource patches" (Pascual-Hortal et Saura, 2007) and its assessment is of crucial importance for safeguarding and maintaining ecosystem integrity (Collinge, 1996; Saura & al., 2007) to the extent that it should be taken into account in decision-making and management plans.

However, the landscape metrics landscape approach has some limitations. First, many landscape metrics are sensitive to grain size and extent (Wu, 2004 ; Uuemaa et al., 2009). This modifies the assessment of the landscape pattern and, consequently, the assessment of ecological processes and ecological integrity (Arponen et al., 2012; Turner and Gardner, 2015).

In addition, the Patch Matrix Model, the most commonly used, is criticized for not taking into account the three-dimensional aspect of the landscape, which is a major component in understanding ecosystem dynamics (Hoechstetter et al., 2006). With 2D landscape metrics, parameters such as slope and height are not taken into account, which constitutes a loss of information (Blaschke & al., 1995; Hoechstetter et al., 2006). Indeed, height provides an interesting added value because a forest with several strata is composed of several niches constituting different habitats (Freeman et al., 2003).

This approach also has several advantages. This allows the evolution of landscape structure to be studied through diachronic analyses (Freeman et al., 2003). Also, landscape metrics relating to the shape of the patches may have been linked to the diversity of the floristic composition as well as the presence of invasive species (Fernandes et al., 2011). Landscape analysis also makes it possible to determine if the catchment or segment scale that has the greatest influence on the riparian structure (Aguiar et Ferreira, 2005 ; Fernandes et al., 2011 ; Dufour et al., 2015). Finally, landscape metrics can be used in management planning (Botequilha Leitão et Ahern, 2002; La Rosa et al., 2013).

The need to better understand the implications of environmental change on riparian zones has led to the requirement to develop large-scale datasets and tools capable of assessing their ecological status and providing better analysis and understanding of long-term changes.

1.1.4 Copernicus data, a major challenge

A first European-scale mapping of riparian areas has already been established and used to assess the retention of pollutants by riparian vegetation (Clerici et al., 2013 ; Weissteiner et al., 2014) However, with technological development and the need for more accurate information for policy purposes, such as assessing land use change, ecosystem status and habitat monitoring, more and more detailed data are needed (Weissteiner et al., 2016). As such, the Copernicus programme (formerly "Global Monitoring for Environment and Security"), at the request of the European Environment Agency (EEA), was launched during the period 2011-2013 and made it possible to obtain local components for riparian zones, providing precise information on these sensitive areas. The mapping of riparian areas using Copernicus data differs from the previous mapping, in particular by covering riparian areas in 39 countries with a minimum mapping unit of 0.5 ha. They have made it possible to delimit between 55,000 and 69,000 km^2 of existing riparian zones

(Weissteiner et al., 2016). These data provide information on the spatial extent of the riparian zone, and on the land cover land use at the local component.

As such, the expectation of these data is high and their potential usefulness is considerable. Riparian zones currently play a prominent role as components of the European Green Infrastructure which is a part of the Commission's Biodiversity Strategy 2020, whose objective is to restore these environments so that they can provide their ecosystem services. The Copernicus Riparian Layers should support MAES (Mapping and Assessment of Ecosystems and their Services) in order to assess ecosystem services at the European level. They can also be linked to the Water Framework Directive which has to promote sustainable water resources management through a catchment approach, by improving the ecological status of waters, by limiting pollution in groundwater and water surfaces. As riparian areas are the refuge of many bird populations, they can be linked to the Habitats and Birds Directive in the Natura 2000 network. (Weissteiner et al., 2016)

Following all the issues to which riparian zones are linked, it is important to evaluate the quality of these data in order to promote decision-making at the European level with a view to sustainable management of these environments.

1.1.5 Objectives

The main objective of this work is to (i) assess the potential of Copernicus data to characterize the ecological integrity of riparian areas, using a landscape approach. Second (ii), to assess the influence of spatial scale on the ecological integrity of riparian areas and finally (iii), to analyze the sensitivity of landscape metrics to three-dimensional variables.

This study is being conducted in parallel in Wallonia and Portugal. The aim will be to compare the results obtained for the potential of the Copernicus data for these two areas.

2. Material and methods

2.1 Study area

2.1.1 Description

Europe is a continent characterized by a wide variety of bioclimatic regions (Olson et al., 2001 ; Weissteiner et al., 2016). These are characterized by different climatic, geomorphological, geological, soil, and vegetation conditions (Metzger et al., 2005), ranging from the Arctic region to the Mediterranean region.

The study area is part of the central Baltic hydroregion, which, along with the Mediterranean hydroregion, is the most populated (Ferreira et al., 2019). The concept of hydroregion refers to a spatial entity formed by the aggregation of watersheds and decomposed on the continent according to bioclimatic conditions (Meybeck et al., 2013). This hydroregion covers an area of more than 2 450 000 km^2 and is highly disturbed, with by mining activities and urbanization (Ferreira et al., 2019).

Within the Baltic Central Hydroregion, the study will focus on Wallonia (Figure 1), which is the part located in the south of Belgium and covers an area of 16,903km^2 (Portail Wallonie, 2019). This region is composed of 5 natural regions with different climatic and soil conditions (Claessens et al., 2009) as well as a positive altitude gradient from west to east. Lower Wallonia reaches an altitude of 50 metres and Upper Wallonia reaches an altitude of 694 metres (Wallonia Portal, 2019).

The entire Walloon territory is mainly composed of agricultural land (51%), located mainly in the north of the region, and wooded areas (29%), located mainly in the east of the territory. Artificial zones represent 8% and other areas 12% (Wallonia Portal, 2019).

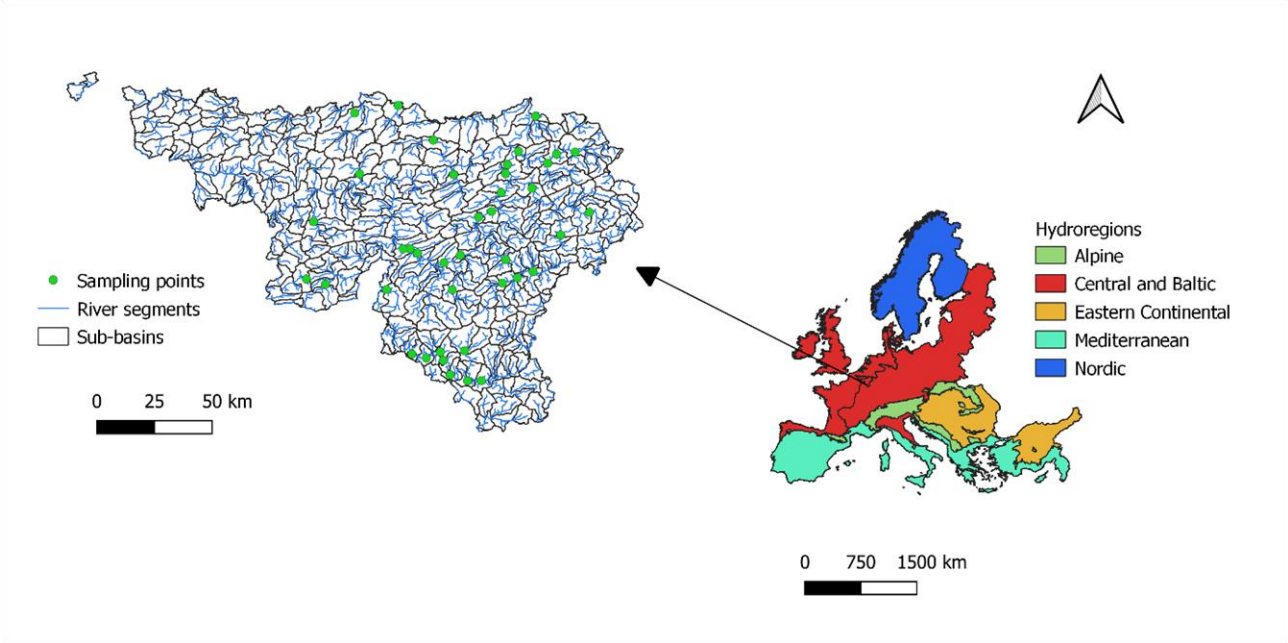

Figure 1 - Broad European hydroregions and study area (Wallonia, Belgium).

Wallonia is covered by more than 12,000 km of classified watercourses (i.e. catchment area > 1 km^2) in navigable and non-navigable watercourses (Georges, 2017). These are distributed in 4 river basins (Meuse, Escaut, Rhine, Seine) (Debruxelles et al., 2009).

The Meuse basin covers an area of approximately 36,000 km^2 (12 283 km^2 in Wallonia) and crosses 5 countries (Belgium, Grand Duchy of Luxembourg, France, Germany, Netherlands). It is of considerable importance in north-western Europe because 9 million people live in this basin and depend on it for their water supply (Bauwens et al., 2011). The Scheldt is the second largest hydrographic basin in the Walloon region (3770 km^2) and is located in the west part of Wallonia, essentially composed of agricultural land (Brogna et al., 2017).

As regards the composition of the riparian strips in Wallonia, Glutinous alder (*Alnus glutinosa*, Gaertn.) is the most common species in the tree stratum, followed by willows (*Salix caprea* L., and *Salix alba* L.), maples (mainly *Acer Pseudoplatanus*, L.) and ash trees (*Fraxinus excelsior* L.) respectively. The shrub stratum is mainly composed of hazelnut (*Corylus avellana* L.), hawthorn (*Crataegus* spp.) and elderberry (*Sambucus* spp).

2.1.2 Sampling approach

We selected 40 reference river reaches which were field surveyed by (Claessens et al., 2009). For these reference river reaches, we will use different approach of delineation (section 2.3) which will be analyzed using a landscape metrics approach.

In Portugal, 38 sampling points were selected from field monitoring carried out in 2005 in the Tagus basin and will be compared at a later date.

This field survey (Debruxelles et al., 2009) was designed with the objective of monitoring the riparian strips of Wallonia's watercourses in order to provide a basis for reflection on their management. In their work, 1071 sampling points were randomly distributed over the territory, proportional to the surface area of each catchment, in order to give more importance to the small number of large watercourses.

Each sampling unit is 50 metres long (2 sections of 25 metres are distributed on either side of the centre of the unit). The width is variable and is measured from the bottom of the bank (corresponding to the average water level) to two metres beyond the top of the bank (Claessens et al., 2009) (Figure 2). Several types of data could then be collected on each plot; location information (coordinates), landscape observations (land use, description of the riparian zone), hydromorphological information (height, depth, bed width,...) and a vegetation survey for the 3 strata (grass, shrubs, trees).

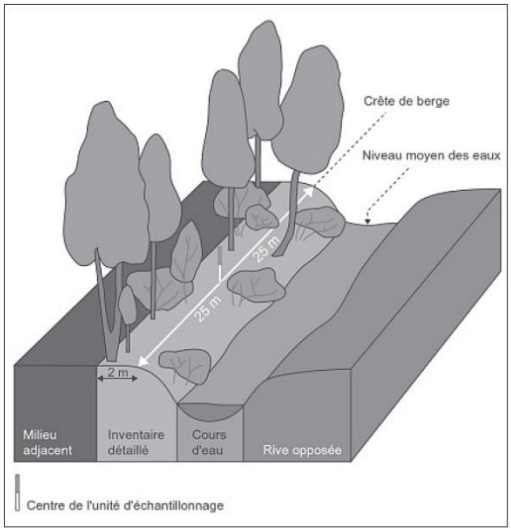

Figure 2 - Diagram of the sampling unit set up during the 2009 field campaign (Claessens & al., 2009)

The 40 sampling points were chosen on the basis of several conditions from the 1071 points previously explained. Have been removed ;

- Plots other than categories C1 (whose management is ensured by the Public serve of Wallonia).

- Plots whose names begin with channels and which are visually channels.

- Points with a sub-basin area of less than 100 km²

- Plots with a large part of the catchment area outside Wallonia

After this selection, the 40 most distant points were chosen (Figure 3) on the basis of their presence in the Potential Riparian zone (PRZ).

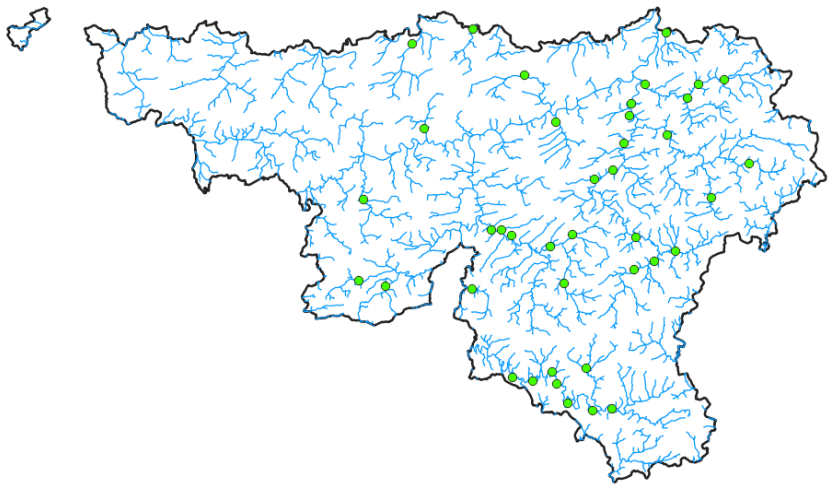

Figure 3 - Selection of the 40 sampling points (green) in Wallonia (Belgium)

2.2 Scale of analysis

Several studies have reported that land use influences spatial patterns of riparian vegetation (Aguiar and Ferreira, 2005; Fernandes et al., 2011). Some authors have compared the influence of land use by increasing the distance from the watercourse to show which spatial scale has the greatest influence on riparian vegetation structure (Fernandes et al., 2011) and stream integrity (Allan et al., 1997). Generally, the proximal scale has the greatest influence (Aguiar et al., 2005; Fernandes & al., 2011). This is why we will characterize land use at 2 scales; the segment scale (proximal) and the catchment scale (distal).

2.3 Remote sensing data and hydrological datasets

Copernicus Riparian Layers allow the delimitation of riparian zones on a European scale (Strahler order > 3), covering 39 countries. Designed in 2012, they delimit the **Potential Riparian Zone** (PRZ), the Observable Riparian Zone (ORZ) and the **Actual Riparian Zone** (ARZ) with a spatial resolution of 25m (Land Copernicus, 2019a).

The **PRZ** delineates riparian zones, forming a buffer of variable width around the watercourse, and is defined as the area that can support riparian forest. The PRZ layer is constructed from hydrological data, land-use/land-cover LCLU of the "Water" class, topographic variables such as slope, obtained from a Digital elevation Model (DEM), floodplain areas and soil properties and covers an area of more than 340,000 km² (Weissteiner et al., 2016).

The ORZ represents the observed riparian areas and is an intermediate output between the PRZ and the ARZ. It results from VHR satellite observations, combining Normalized Difference Vegetation Index (NDVI) and the Nprmalized Difference Water Index (NDWI).

The **ARZ** results from the intersection of the PRZ and ORZ. The development of the ARZ layer ensures a high degree of reliability since PRZ and ORZ are the result of independent inputs. For the 39 countries covered by the data, the ARZ covers about 69,000 km². (Weissteiner et al., 2016).

In parallel, the Copernicus data made it possible to establish a local component of land use, with a minimum mapping unit of 0.5 ha. This Land-Cover/Land-use (LCLU) layer is based on the specific MAES (Mapping and assessement of ecosystems and their services) nomenclature and will be used to characterize land use at the segment scale.

In order to delimit the upstream sub-basins and the river segments (Catchment scale), the Catchment Characterisation Model (CCM) data providing a delimitation of catchment areas and river system, available at European level, will be used. (Data Europa, 2019) These layers are generated from a 100 meters resolution digital terrestrial elevation model and characterize catchments and rivers by their Strahler order, « which reflects the level of each river in the hierarchy of the network » (Vogt et al., 2007).

In order to characterize the land-use at the catchment scale, the 2012 Corine Land Cover (CLC 2012) layer will be used. This layer is composed of 44 land use classes and characterizes land use on a European scale with a spatial resolution of 100m (Land Copernicus, 2019b). The choice to take the 2012 layer and not the most recent (2018) layer is justified by the fact that the Copernicus data were obtained between 2011 and 2013, which makes it possible not to combine several temporal scales.

At the segment scale, the Walloon hydrographic network was used to characterize the watercourse. This network is based on IGN maps and is more accurate than the CCM dataset. The choice of river segments was made from the position of the sampling unit. They are

delineated by the intersection between the PRZ and the CCM sub-basin. At this scale of study, land use will be characterized from the local component (LCLU) of the Copernicus Riparian Layers. An example of delimitation and characterization of land use for both scales is presented in Figure 4 & Figure 5.

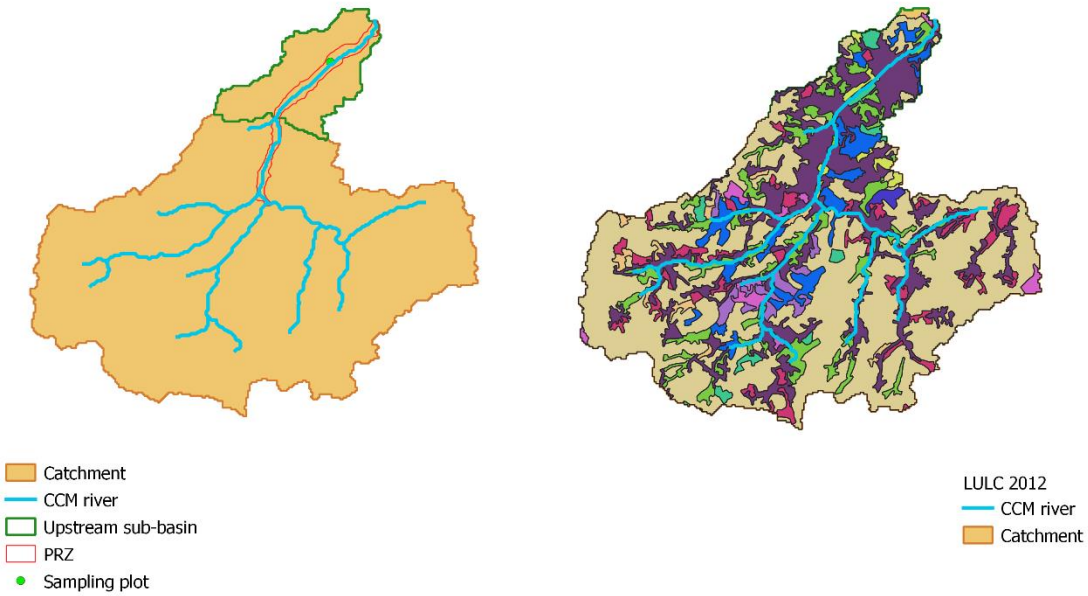

Figure 4 - Example of delimitation of a catchment area (brown), a sub-basin (green) and characterization of land use at the catchment scale with the LULC 2012.

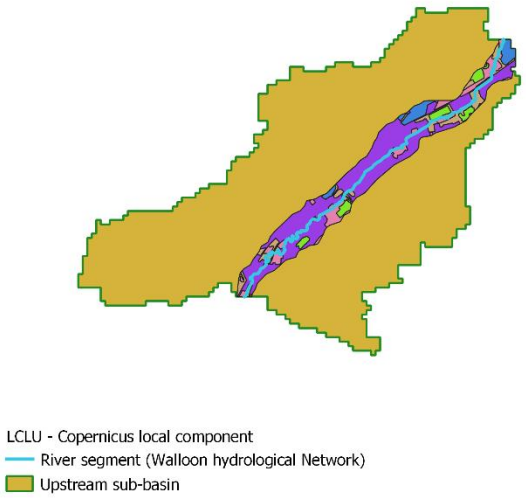

Figure 5 - Example of delimitation of a sub-basin and characterization of land use within the PRZ, using the local LCLU component of the Copernicus dataset.

For the two scales of analysis (Catchment scale and segment scale) and the two LULC datasets, the proportion of the different land use classes was calculated using Qgis software. Beforehand, these have been grouped into 6 new classes (Appendix 1 and Appendix 2) ;

- Artificial surfaces, Intensive agriculture, Extensive agriculture, Managed forests, Unmanaged and Unclassified.

Then, to assess the degree of human disturbance, 3 levels of disturbance were assessed based on the proportion of each land use (Table 1).

Table 1 - Classification of the human disturbance according to the land-use proportion.

Land-use proportion		Gradient of human disturbance
Artificial surfaces **Intensive agriculture** **Managed forests**	**> 70%**	Very disturbed
Unmanaged **Extensive agriculture**	**> 70%**	Least disturbed
Artificial surfaces **Intensive agriculture** **Managed forests**	**50% - 70%**	Mid disturbed

The gradient was represented in a Principal Component Analysis (PCA) to determine the land uses that are the main drivers of riparian change at the catchment and at the segment scales. It is also used to evaluate the correlation between the variables and to detect differences between sites. Each variable was standardized.

2.4 Assesment of the Riparian integrity

To determine whether Copernicus data are adequate to assess the ecological integrity of riparian vegetation, a landscape analysis, based on landscape metrics, will be conducted as it has already described the structural and functional attributes of riparian areas (Constança Aguiar et al., 2011; Fernandes et al., 2011) and can be used to assess their ecological integrity. Usually, well preserved riparian galleries exhibit large woody patches, highly connected, with complex shape configurations while degraded riparian systems are characterized by a reduce number of small and homogenised patches, often fragmented and with simple configurations (Fernandes et al., 2011 ; Magdaleno and Fernández-Yuste, 2013).

In order to delimit riparian vegetation within the potential riparian zone (PRZ), only the tree structure will be considered because it has been shown to provide most of the information and this reduces the time of analysis (Fernandes et al., 2011). Three data sets with different spatial resolution will be used ;

- The local component of the riparian zones of the Copernicus Riparian dataset, including the Actual Riparian Zone layer (ARZ), having a spatial resolution of 25 metres.

- The manual digitalization of woody patches from the Esri World Imagery map, with a spatial resolution of 60 cm, used as a reference

- The "Ecotope" layer 2015 obtained from LidaR 2012-2013 data (0.8 pts/m) and orthophotos (25 cm resolution). These data were resampled at 2m resolution. This layer includes the delimitation and characterisation of ecologically homogeneous units throughout the Walloon territory (Portail Wallonie, 2019). Within this layer, the "hardwood forest" class has been extracted.

Also, Polygons larger than 200 m² will be considered for the analysis (Figure 6)

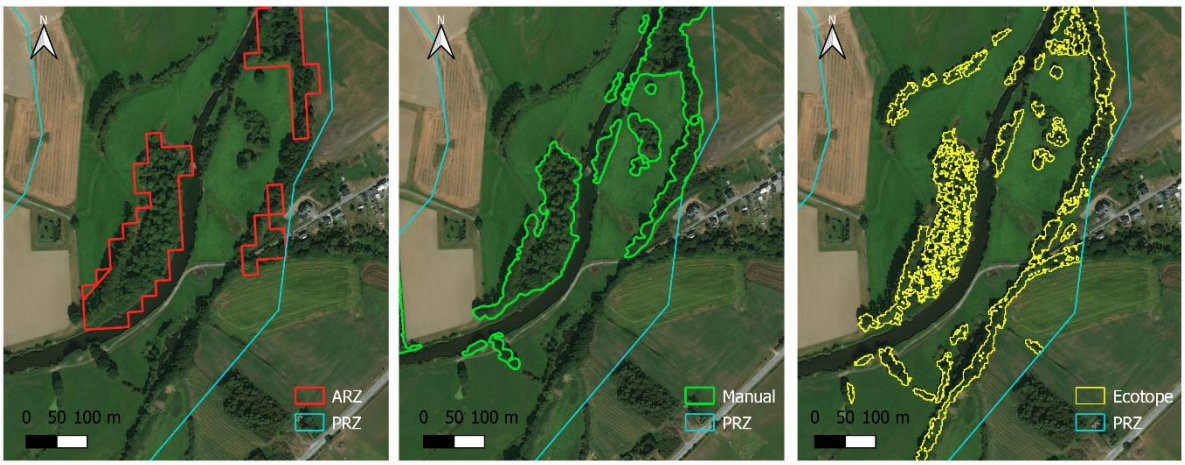

Figure 6 - Example of woody delineation for the three resolutions (Polygons > 200 m²). In red : ARZ layer, in green : Manual layer, in yellow : Ecotope layer

In order to distinguish the left bank from the right bank, the polygons of the woody patches were split by the rivers from the CCM dataset for the ARZ layer and by the Walloon hydrological network for the Manual digitalization and Ecotope layers. All the data used for the delineation of riparian vegetation are represented (Table 2).

Table 2 - The 3 datasets used for segment scale riparian vegetation delineation and the hydrographic dataset associated with each resolution.

Dataset	Spatial resolution	River used for the delineation
Actual Riparian Zone layer	25 m	CCM dataset
Ecotope layer	2 m	Walloon hydrological network
Manual digitalization (ESRI World Imagery)	60 cm	Walloon hydrological network

2.4.1 Landscape metrics and connectivity

In order to obtain an accurate assessment of riparian integrity, it is necessary to use several categories of landscape metrics capable of quantifying the configuration of the patches and the spatial relationships between them. They were chosen because they are linked to different ecological processes and allow the ecological integrity of riparian areas to be assessed (Fernandes et al., 2011) (Table 3).

These are divided into several categories;

- Area/density (Number of Patches, Patch density, Mean Patch Size, Patch Size Coefficient of Variation, Largest Patch Index),
- Shape (Mean Shape Index)
- Area/Edge (Mean Fractal Dimension Index),
- Isolation (Mean Nearest-Neighbor Distance, Proximity Index)

Table 3 - List of landscape metrics used, their ecological implications and potential application for riparian vegetation, from (Constança Aguiar et al., 2011 ; Fernandes et al., 2011).

Structural category	Landscape metrics	Acronym	Units and range	Description	Main ecological implications	Applications for riparian woods
Area/density	Number of Patches	NP	None [1,∞]	Basic statistics of the spatial configuration	Productivity, biogeochemical cycling and species dynamics	Simple indicators of riparian fragmentation
	Patch density	PD	None NP/100 ha			
	Mean Patch size	MPS	hectares [0,∞]			
	Patch Size Coefficient of Variation	PSCV	Percentage [0,∞]	Variability in the size of the patches	Biological diversity	Heterogeneity in the structure of riparian vegetation
Shape	Mean Shape Index	MSI	None [1,∞]	Complexity of shapes. Approaches 1 for shapes with simple perimeters	Interactions with the adjacent matrix-edge effects	Spatial configuration of riparian vegetation, in terms of complexity of riparian patches
Area/edge	Mean Fractal Dimension Index	MPFD	None [1,2]	Fractal dimension: ratio of perimeter per unit area. Increases as patches become more irregular	Lateral connectivity	
Isolation/proximity	Mean Nearest-Neighbor Distance	MNN	Meters [0,∞]	Minimum distance between patches of the same class, based on the shortest distance between their edges	Flows of energy and biomass and biological diversity, connectivity effects	Isolation of riparian patches, inter-connectivity
	Mean Proximity Index	MPI	None [0,∞]	Increases as the patch type become less isolated and less fragmented	Ecological neighborhood	Degree of isolation and fragmentation of riparian patches

The loss of longitudinal connectivity of riparian areas, as a result of habitat fragmentation, is a central concern for biodiversity conservation policies and landscape planning (Saura and Pascual-Hortal, 2007). To assess connectivity, the integral index of connectivity index (IIC) developed by Saura and Pascual-Hortal, (2007) will be used . This index, developed in 2006, is considered one of the best and has already been used on many occasions, particularly in France for the « Trame verte et bleue » and for the study of landscape graphs (Minor and Urban, 2007 ; Pascual-Hortal and Saura, 2007) :

$$IIC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i a_j}{(1+nl_{ij})}}{A_L^2}$$

Where n is the total number of patches in the landscape, a_i and a_j are the attribute (generally area) of patches *i* and *j*, « nl_{ij} represents the number of links in the shortest path (topological distance) between patches *i* and *j* » and A^2_L L is the attribute value of a patch that would cover all the landscape. This index is also threshold dependent ; two patches are linked if the distance between them is less than a certain threshold dispersion distance, This index makes it possible to integrate both the quality and the measurement of habitat availability (Saura and Pascual-Hortal, 2007).

The landscape metrics were calculated using *Fragstats* software at the landscape level. For the Mean Proximity Index, a distance of 5 metres was chosen because it has already been used to characterize riparian environments (Fernandes & al., 2011). This index was chosen in addition to the Mean Nearest Neighbor because it provides information on the degree of fragmentation, as well as the distance between patches.

In order to demonstrate a significant difference in mean for each of the landscape metrics between the 3 resolutions, a Repeated Measures ANOVA with 1 factor (Resolution) will be used. In order to validate this model, a Mauchly sphericity test was performed. Sphericity is a parameter ranging from 0 and 1. The null hypothesis of this test assumes that the variances between all possible pairs of intra-subject conditions are equal. Then, a Tukey test was performed to obtain a mean structuring for each landscape metrics according his resolution. All landscape metrics have undergone a logarithmic transformation in order to perform these treatments.

In order to evaluate the differences between each class of disturbance (Least Disturbed, Mid Disturbed, Very Disturbed), a one-way independent ANOVA with the factor Disturbance Class (least disturbed, mid disturbed, very disturbed) was performed. A Shapiro and Wilk test to verify normality and a Bartlett test were done to respect the homogeneity of the variances.

These statistical procedures were performed with the Rstudio software.

The integral connectivity index (IIC) was calculated using the "lconnect" package with *Rstudio* software. Its value was determined for 36 distances between 5m and 15km. The average obtained for each distance for each segment was calculated to create the IIC evolution curve based on the

threshold distance. A first evaluation will be made considering only the resolution. A second graph will be created showing all resolutions and disturbance classes.

2.4.2 Influence of land use and other environmental variables on the riparian structure.

Environmental variables influence the distribution of vegetation (Aguiar et Ferreira, 2005) and were selected for their relevance in explaining the structure of riparian vegetation and and for their availability at the scale of Wallonia (Table 5):

- The sinuosity of the stream corresponds to the ratio of the length of the river and the mean axis (Malavoi & Bravard, 2010). Several categories of sinuosity exist (table 4) ;

Table 4 - Sinuosity classes and morphology of the watercourse

Sinuosity class	Morphology of the watercourse
SI < 1.05	Straight
1.05 < SI < 1.25	Winding
1.25 < SI < 1.5	Very twisty
SI > 1.5	Meandriform

- The width of the channel was calculated from the relationship established by (Michez & al. 2017) on the scale of Wallonia (equation 2) :

$$\text{Channel width (m)} = 0{,}63 * CA^{0{,}55} \quad (2)$$

Where CA represents the Catchment area (km^2). The catchment area was calculated with the *QGIS* software.

The average height, the height variation coefficient, the altitude and median slope (in percentage) were extracted from the digital elevation model obtained from the Lidar 2013-2014 data. The median slope was preferred because it is less sensitive to extreme values. The heights and the altitude were extracted with the « Zonal Statistics tool » in the Arcmap 10.4.1 software. The slope was created from the Arcgis Slope tool and the slope's values were also extracted with the "Zonal Statistics" tool.

Tableau 5 - Groups of variables analyzed, variables included in each group, the spatial scale of analysis and bibliographic references showing the interest in studying these variables.

Group of variables	Variable	Spatial scale	Bibliography
Land use	proportion of land use classes (%)	Segment and Catchment	(Dufour et al., 2015) (Fernandes et al., 2011) (Martins et al., 2018)
Hydromorphological	Channel width (m) Catchment area (km^2)	Segment scale	(Aguiar and Ferreira, 2005a)
Topographical	Altitude (m) Median slope (%) Height Height coefficient of variation	Segment scale	(Hoechstetter et al., 2006) (Aguiar and Ferreira, 2005a) (Blaschke et al., 1995)

In order to assess the importance of land use classes on the ecological integrity of riparian areas, a first redundancy analysis (RDA) was conducted for the two scales of analysis and for each of the metrics separately, with the Ecotope layer. The RDA establishes linear relationships between several variables to be explained and several explanatory variables (Legendre and Legendre, 2012). The first RDA will make it possible to quantify the variability of landscape metrics explained by land use classes. This analysis will determine which catchment scale or segment scale has the greatest influence on the structure of riparian vegetation.

In order to evaluate the variability of landscape metrics explained by environmental variables (land-use, topographical, hydromorphological) at the segment scale, a second RDA was carried out for each of the landscape metrics. This second analysis will make it possible to evaluate the part of the structure of riparian vegetation explained by all the variables considered in addition to land use. This will also allow to judge the two-dimensional approach of landscape metrics.

Redundancy analyses were performed using the "Vegan" package on the R software. In order to avoid multicollinearity, the scores of the first 2 axes of the 2 PCAs performed before were taken. Environmental variables and landscape metrics have been standardized.

3. Results

3.1 Characterization of land use at the catchment and segment scales

At the catchment scale, the main land use classes are unmanaged areas (31.95%), followed by intensive agriculture (27.52%) and extensive agriculture (19.41%) (Table 6).

Table 6 - Average of the proportion (in %) and the coefficient of variation of each land use class at the segment and catchment scales.

		Artificial surfaces	**Intensive agriculture**	**Managed forest**	**Unclassified**	**Unmanaged**	**Extensive agriculture**
Segment scale	% average	29,13	29,70	0,09	6,72	34,36	/
	Coeffient of Variation	0,93	0,87	3,71	0,89	0,82	/
Catchment scale	% average	8,87	27,52	11,19	1,07	31,95	19,41
	Coeffient of Variation	0,65	0,56	0,64	2,29	0,43	0,45

At the segment scale, on average, the proportion of unmanaged areas is dominant (34.36%), followed by intensive agriculture (29.70%) and artificial surfaces (29.13%), which shows a significant anthropogenic disturbance. It should also be noted that no extensive agricultural land has been delimited at this scale level.

The coefficient of variation makes it possible to compare the proportions of land use between the two scales. Overall, the segments have a higher coefficient of variation for all land uses except for the "Unclassified" class. This shows that, on average, the segments show more variability in land use classes than the basins. At the segment scale, managed forests have the highest coefficient of variation, due to the fact that many segments do not have this land use class. Based on the proportion of each land use class in each catchment and segment (Appendix 3 and Appendix 4), the degree of anthropogenic disturbance was determined for each site (Table 7).

Table 7 - Distribution of 40 sampling points in disturbance classes, for both scales. Many watersheds are moderately disturbed (29) while more segments are highly disturbed

Level of disturbance	Number of catchments	Number of segments
Least disturbed	6	7
Mid disturbed	29	11
Very disturbed	5	22

We note that the number of segments and basins with little disturbance is casi-similar (6-7). The difference is noticeable in the level of disturbance "Mid disturbed". More segments are moving from Mid disturbed to Very disturbed. This is due to the fact that at the segment scale, the proportion of artificial surface is more than 3 times higher than that of the basin.

3.1.1 Human disturbance gradient at the catchment scale

PCA results at the catchment scale show that the first two axes (Dim1 and Dim2) of the PCA explain 85.7% of the variability of the dataset (Figure 7). The first dimension (Dim1) explains 59.2% of the variability of the dataset and mainly contrasts the proportions of intensive agriculture, artificial surfaces and unmanaged and managed forests.

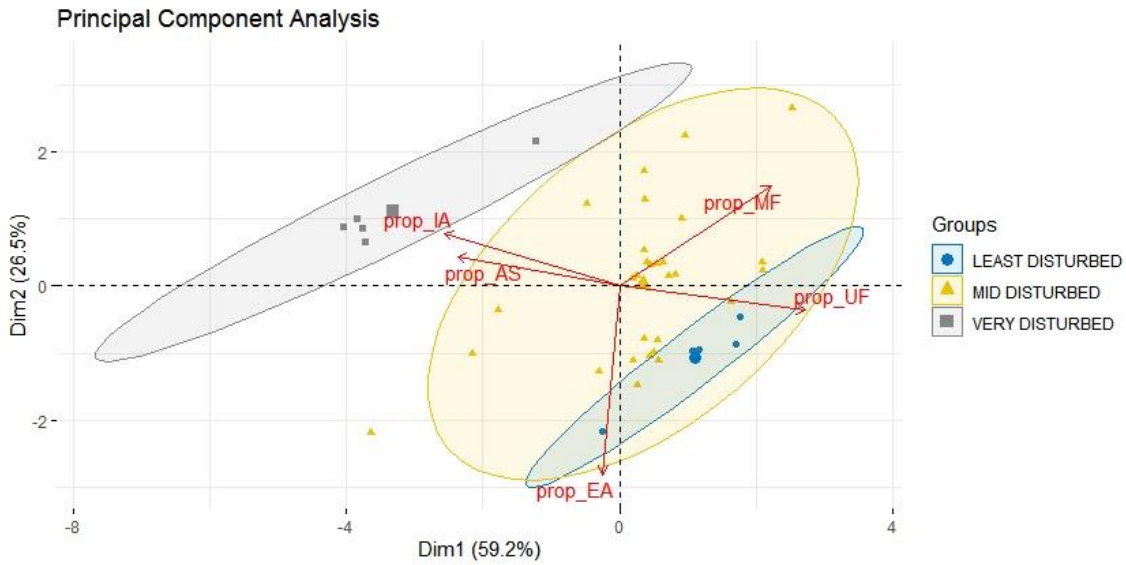

Figure 7 - Biplot of the PCA with the land uses at the catchment scale and whose catchments are grouped into clusters representing the disturbance level ; Least disturbed (grey), Mid disturbed (yellow), very disturbed (grey)

The first two axes (Dim1 and Dim2) of the PCA explain 85.7% of the variability of the dataset. The first dimension (Dim1) explains 59.2% of the variability of the dataset and mainly contrasts the proportions of intensive agriculture, artificial surfaces and unmanaged and managed forests.

The second axis explains 26.5% of the variability of the dataset and mainly contrasts the proportion of extensive agriculture with the proportion of managed forests.

The gradient is therefore strongly pronounced in one direction, marked by the negative correlation between the proportion of unmanaged forests and the proportions of artificial surfaces and intensive agriculture. It is also possible to observe the almost absence of correlation between unmanaged forests and extensive agriculture.

3.1.2 Human disturbance gradient at the segment scale

At the segment scale, results show that the first two axes (Dim1 and Dim2) explain 67.9% of the variability of the data set (Figure 8)

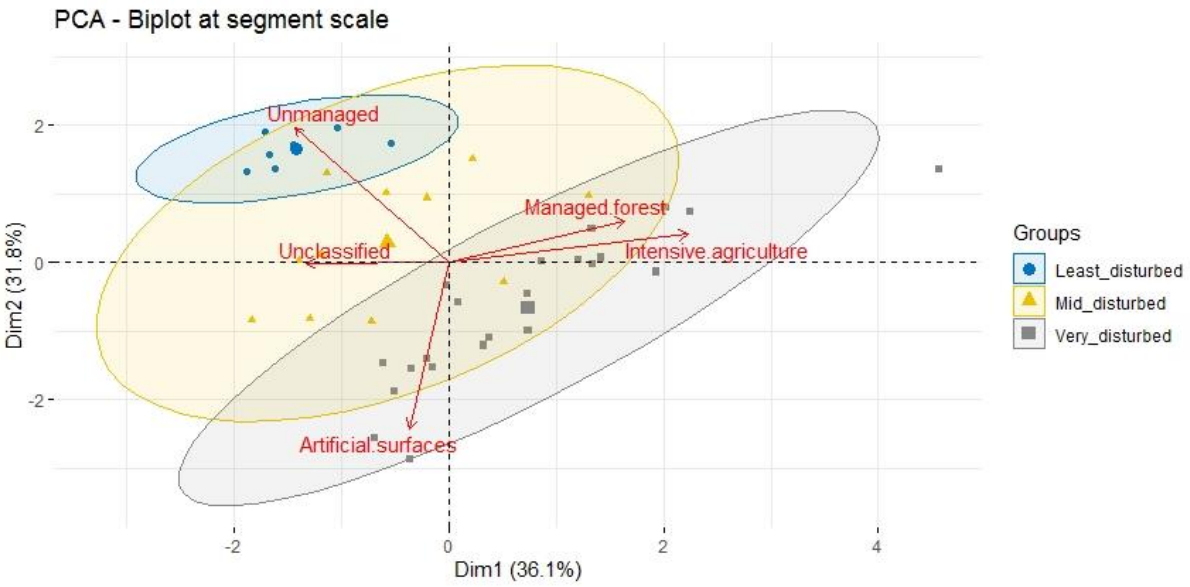

Figure 8 - Biplot of the PCA with the land uses at the segment scale and whose segments are grouped into clusters representing the disturbance level ; Least disturbed (grey), Mid disturbed (yellow), very disturbed (grey)

The first dimension (Dim1) explains 36.1% of the variability of the segments. The first axis essentially opposes the proportions of Unmanaged and Unclassified surfaces to Managed forest and Intensive agriculture.

The second axis, which explains 31.8% of the variability of the dataset, is mainly based on an opposition between artificial surfaces and unmanaged forests.

It should also be noted that the "Extensive Agriculture" class is not available at the segment level. This can be explained by the fact that 2 different datasets are used to characterize land use at these two scales (Appendix 3 and Appendix 4).

3.2 Characterization of the landscape structure of riparian zones.

3.2.1 Comparison of landscape metrics for the 3 resolutions

Table 8 - Average of the landscape metric values obtained for the 3 resolutions and (+- standard error)

		Resolution	Resolution	Resolution
Landscape metrics	Acronym	Actual Riparian Zone	Manual Digitalization	Ecotope
Number of Patches	NP	19,02 (+- 14,66)	57,90 (+- 53,48)	121,78 (+- 123,38)
Mean Patch Size	MPS (ha)	2,13 (+- 1,41)	0,85 (+- 1,12)	0,40 (+- 0,39)
Patch size Coefficient of Variation	PSCV (ha)	138,21 (+- 37,73)	226,9 (+- 52,92)	259,59 (+- 91,40)
Largest patch index	LPI	37,96 (+- 19,56)	29,75 (+- 16,66)	24,16 (+- 15,74)
Patch density	PD	66,74 (+- 39,72)	262,84 (+- 192,67)	419,03 (+-257,15)
Mean Shape Index	MPI	1,6 (+- 0,278)	2,25 (+- 0,21)	2,925 (+- 0,24)
Mean Fractal Dimension Index	MPFD	1,089 (+- 0,026)	1,209 (+- 0,043)	1,282 (+- 0,0204)
Mean Nearest-Neighbor Distance	MNN	157,95 (+- 129,81)	22,099 (+- 11,09)	20,322 (+- 6,89)
Mean Proximity Index (5m)	MPI	0	1019,63	638,24

With regard to the area/density metrics (Figure 9), the ARZ layer delimits vegetation patches that are larger (p-value < 0,001), less numerous (p-value < 0,001) and more homogeneous (p-value < 0,001) than the Ecotope and Manual layers. In addition, this trend is confirmed by a higher LPI for ARZ compared to the Ecotope layer (p-value < 0.001) and to the manual (p-value < 0.01).

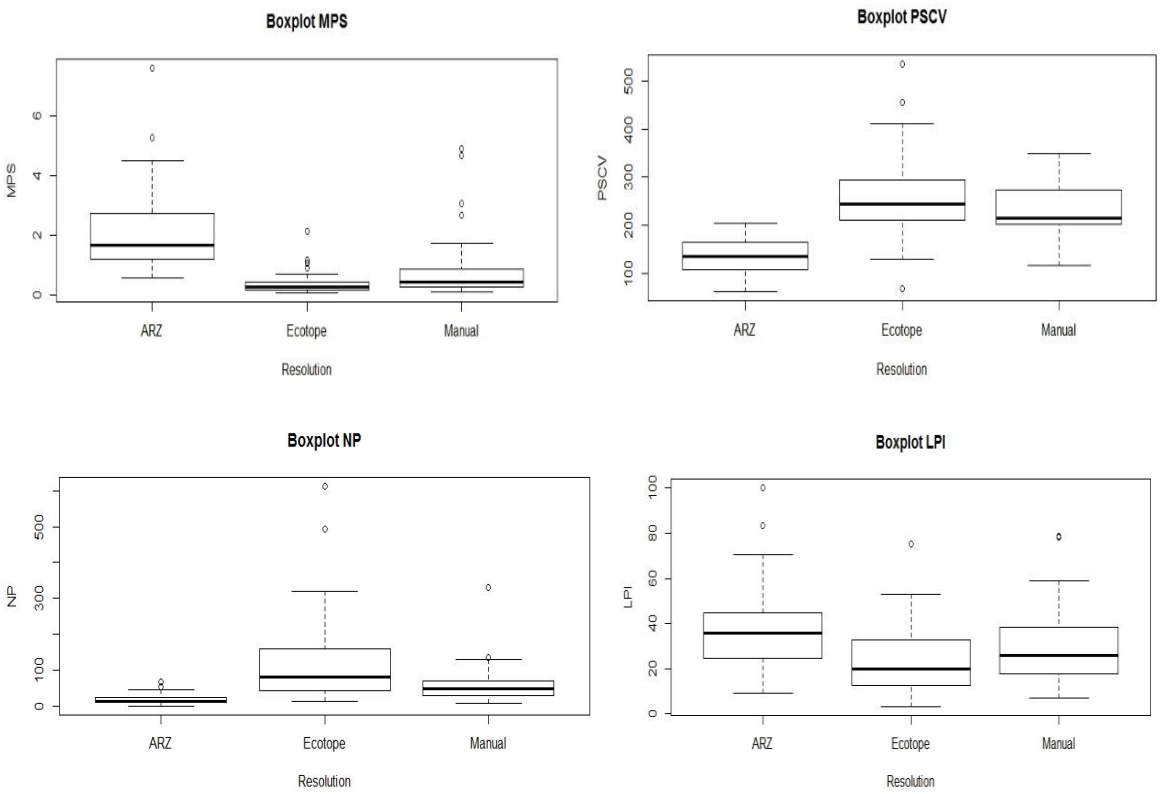

Figure 9 - Boxplots of the patch size (MPS), the patch size coefficient of variation (PSCV), the number of patches (NP) and the largest patch index (LPI), showing very significant differences between the ARZ layer and the manual and ecotope layers (p-value<0,001).

Comparison between the ecotope and manual layers indicates that the ecotope layer has a higher number of patches, a lower average area (p-value < 0.001). The ecotope layer also has a significantly larger PSCV than the manual layer (p-value < 0.05).

The Mean Patch Fractal Dimension (MPFD) and Mean Shape Index (MSI) shape indices differ very significantly between resolutions. The ARZ layer has the lowest index values (p-value <

0,001), and the ecotope layer the highest (p-value < 0.001) (Figure 10). The ARZ patches are therefore simpler, less elongated than those of the other two layers.

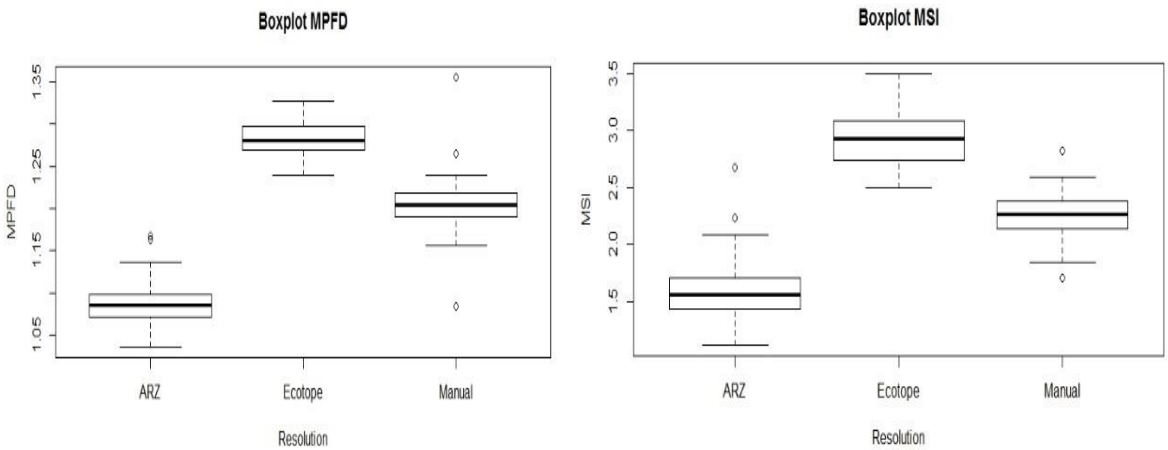

Figure 10 - Boxplots of Mean Patch Fractal Dimension (MPFD), The Mean Shape Index (MSI), showing very significant differences between the ARZ layer and the manual and ecotope layers (p-value<0,001)

For the indices relating to the isolation/proximity metrics, in the landscape, the MNN and MPI (evaluated at a distance of 5m), results show a very significant difference between the ARZ and the other two resolutions for the MNN (p-value < 0.001) (Figure 11). The segments of the ARZ and Manual layers do not show any significant difference in MNN. This result shows that the ARZ patches are further away than those of the other layers.

For MPI, the average value obtained for each segment of the ARZ layer is zero. It was therefore not possible to compare it statistically with the other two layers. For this index, there is no significant difference between the manual and ecotope layer. This index, between 0 and infinity, still shows that the ARZ patches are more isolated. All the results of the Statistical tests are provided in Table 9.

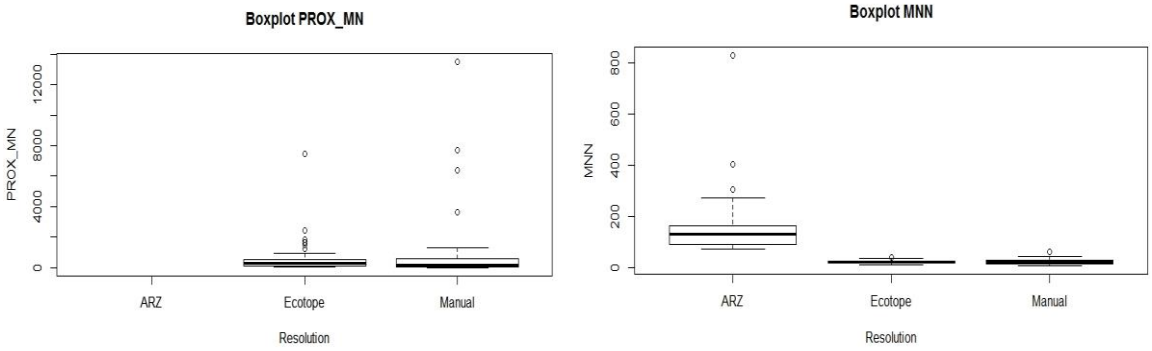

Figure 11 – Boxplots of Mean Proximity index (PROX_MN) and Mean-Nearest Neighbor (MNN). MNN shows a very highly significant difference between the ARZ and the other two resolutions (p-value < 0.001) and the MPI showing no significant difference between the Manual and Ecotope layers (p-value > 0.05)

Table 9 - Statistical ANOVA multipeared with the factor resolution and Tukey test associated (* : significant, **, highly significant, *** ; very highly significant).

Test ANOVA multi peared	**p-value**	**Tukey test**
NP ~ resolution	< 0,001 ***	Ecotope > Manual *** Manual > ARZ ***
PD ~ resolution	< 0,001 ***	Ecotope > Manual *** Manual > ARZ ***
LPI ~ resolution	< 0,001 ***	ARZ > Manual ** ARZ > Ecotope ***
MPS ~ resolution	< 0,001 ***	ARZ > Manual *** Manual > Ecotope ***
PSCV ~ resolution	< 0,001 ***	Ecotope > Manual* Ecotope > ARZ*** Manual > ARZ***
MSI ~ resolution	< 0,001 ***	Ecotope > Manual *** Manual > ARZ ***
MPFD ~ resolution	< 0,001 ***	Ecotope > Manual *** Manual > ARZ ***
MPI ~ resolution	0.15 (comparison between manual and Ecotope layer)	/
MNN ~ resolution	< 0,001 ***	ARZ > Manual*** ARZ > Ecotope***

3.2.2 Evolution of the structure of riparian zones according to the disturbance gradient.

The MPS decreases with increasing disturbance; the MPS varies very significantly for the 3 resolutions between the least and very disturbed segments (p-value < 0,001) (Figure 12)

The ARZ layer tends to overestimate the MPS in highly disturbed areas. Indeed, there is no significant difference between the least and mid disturbed classes (p-value > 0,05), while the MPS of the manual and ecotope layers varies between these two classes in a highly significant (p-value < 0,01) and significant way (p-value < 0,05), respectively.

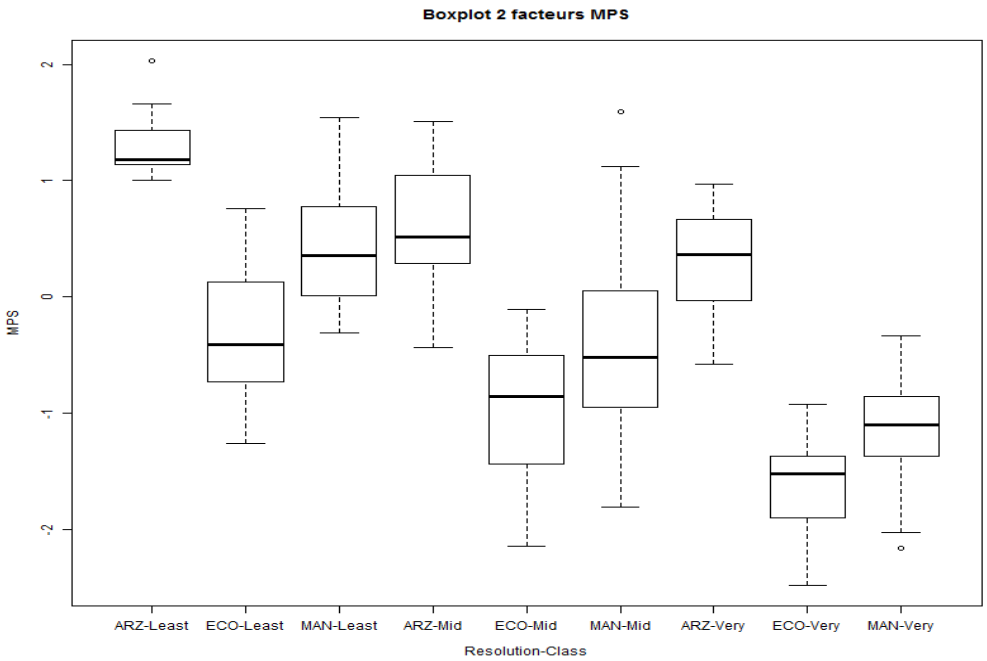

Figure 12 - Boxplot of the Mean Patch Size (MPS) for the 3 resolutions according to the disturbance gradient showing very highly significant differences (p-value<0.001) between very disturbed and least disturbed gradients, for the 3 resolutions

This is also shown by the LPI (Figure 13). For the ARZ layer, this result shows that there is no significant difference in the area of the largest patch between the 3 classes while for the ecotope layer, the LPI value is smaller for highly disturbed environments than for disturbed environments (p-value = 0,074).

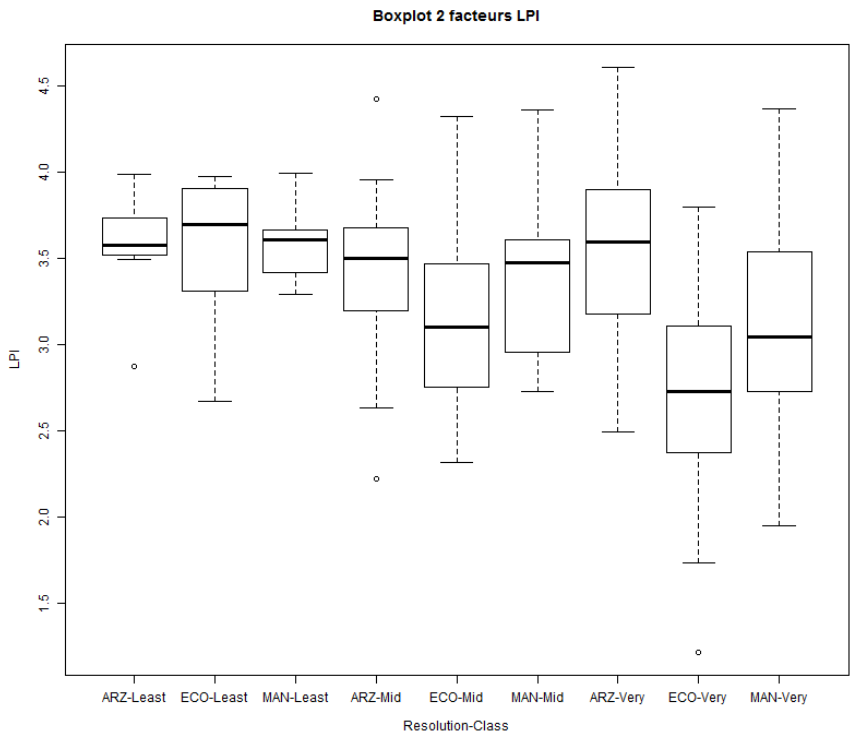

Figure 13 – boxplots of LPI showing no significant difference between the 3 disturbance classes for ARZ and Manual layers (p-value > 0.05) and showing a highly significant difference between least and very disturbed segments for the Ecotope layer (p-value = 0.0074)

For the 3 resolutions, the PSCV of the patches is not significant for the 3 classes. The 3 resolutions have patches whose size remains homogeneous between the 3 disturbance classes.

For the shape indices (MSI, MPFD), the ARZ and Ecotope layers have the MSI which decreases with increasing disturbance level (Figure 14). MSI decreases between the least disturbed and very disturbed classes for the ARZ (p-value = 0,0156) and the ecotope layer (p-value = 0,00105). The shapes of the patches are therefore simpler in highly disturbed environments. The ecotope layer is the only one to obtain a significant result for this index between the mid disturbed and the least disturbed environments (p-value = 0,02924). The MPFD index does not differ significantly between classes for the 3 resolutions.

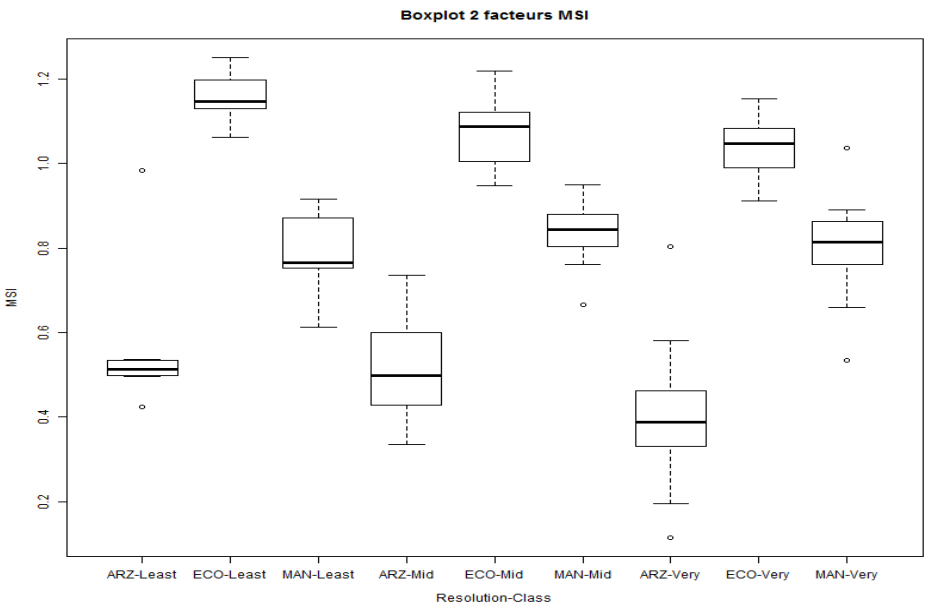

Figure 14 - MSI boxplots for the 3 resolutions and 3 disturbance classes showing a significant difference in the index between very disturbed and least disturbed environments for the ARZ layer (p-value= 0,0156) and highly significant for the Ecotope layer (p-value=0,00105)

The inter-connectivity index (MNN) increases significantly and highly significantly respectively between least and very disturbed segments for the ARZ (p-value = 0,00692) and Manual layers (p-value = 0,00617) (Figure 15). The ARZ MNN is also different between highly and moderately disturbed environments (p-value < 0.01). This shows that the distance between the patches increases with the degree of disturbance.

The ecotope layer does not show any significant difference in this index between classes. This may be explained by the fact that the ecotope layer delimits a large number of patches and are closer together because of the small size of the grain. The proximity index (MPI) evaluated at a distance of 5m equals 0 for the ARZ layer and could not be taken into account in the statistical analysis. Analysis of the MPI by class shows that there is no significant difference in this index in each of the classes for the ecotope and manual layers. The zero value of this index for the ARZ layer indicates that these, in addition to being distant, are also more fragmented. Statistical results are provided in Table 10.

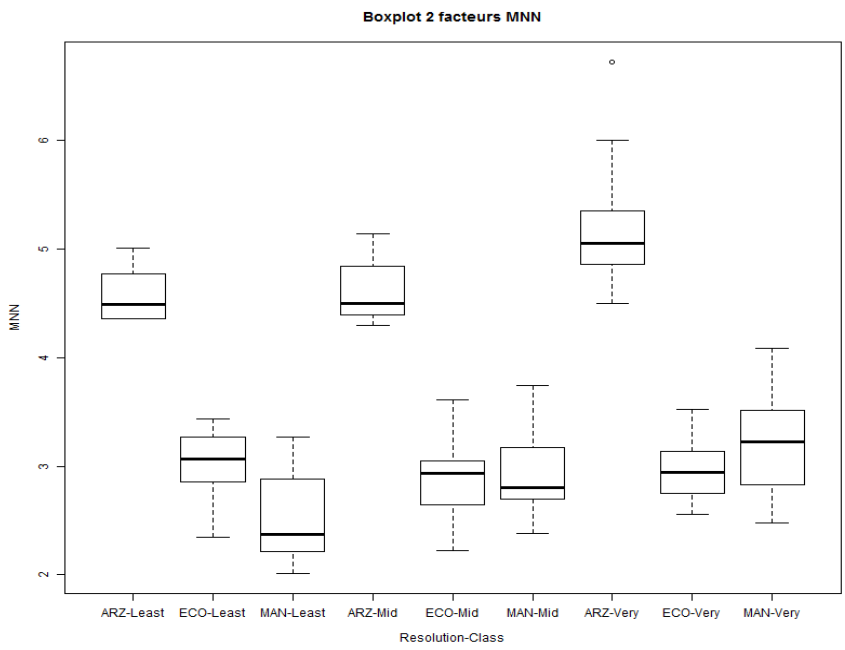

Figure 15 - MNN boxplots for the 3 resolutions and 3 disturbance classes showing a significant difference between very disturbed and least disturbed environments for the ARZ layer (p-value= 0,00692) and highly significant for the Manual layer (p-value=0,00617)

Table 10 - Statistical test Results (Independent Anova one way) with the factor "Class of disturbance", test significance and mean structure (VD = Very disturbed, MD ; Mid disturbed, LD ; Least disturbed), *: significant, **: highly significant, ***: very highly significant, '='means p-value >0,05.

INDEPENDANT ANOVA ONE-WAY	Resolution	p-value	Tukey
PD ~ Class	ARZ	6.179e-05 ***	VD = MD VD > LD *** MD > LD *
	Manual	9.628e-06 ***	VD > MD ** VD > LD *** MD = LD
	Ecotope	5.808e-06 ***	VD > MD * VD > LD *** MD > LD *
MPS ~ Class	ARZ	6.179e-05 ***	VD = MD VD < LD *** MD < LD *
	Manual	9.63e-06 ***	VD < MD** VD < LD *** MD = LD
	Ecotope	5.805e-06 ***	VD < MD* VD < LD *** MD < LD *
PSCV ~ Class	ARZ	0,9819	VD = LD = MD
	Manual	0.5521	VD=LD=MD
	Ecotope	0.9957	VD=LD=MD
MSI ~ Class	ARZ	0.01279 *	VD = MD VD < LD * MD = LD
	Manual	0,59	VD = LD = MD
	Ecotope	0.002416 **	VD = MD VD < LD ** MD < LD*
MPFD ~ Class	ARZ	0,1779	VD = LD = MD
	Manual	0,6384	VD = LD = MD
	Ecotope	0,9724	VD = LD = MD
MNN ~ Class	ARZ	0.000836 ***	VD > MD** VD > LD * MD = LD
	Manual	0,01257*	VD =MD VD > LD ** MD = LD
	Ecotope	0,7302	/
MPI ~ Class	ARZ	/	/

	Manual	0,4263	VD = LD = MD
	Ecotope	0,1274	VD = LD = MD
	ARZ	0,8093	VD = LD = MD
LPI	Manual	0,08732	VD=LD=MD
	Ecotope	0,0108*	VD > LD **

3.2.3 Evolution of the Integral Index of Connectivity (IIC)

3.2.3.1 Evolution of the IIC for the 3 resolutions

The integral index of connectivity (IIC) increases with threshold distance and varies with spatial resolution (Figure 16). For the 3 resolutions, it increases and stabilizes when the threshold distance corresponds to the maximum distance between the patches pairs, i.e. when all the patches are linked.

The shape of the curve differs according to the resolutions. The increase in the IIC as a function of threshold distance is softer for the manual and ecotope layers than for the ARZ layer, which is more stepped in shape.

The evolution of the IIC for ARZ indicates that the index increases very slightly between 5-20 meters because few patches are connected with these distances. From 20 meters, more patches are connected, which increases the index value. This is again constant between 40 and 50 meters because there are no more new patches that are linked. The curve follows the same trend as the manual for distances between 60 and 100 meters and then rises before stabilizing when all the patches are linked, around 4000m.

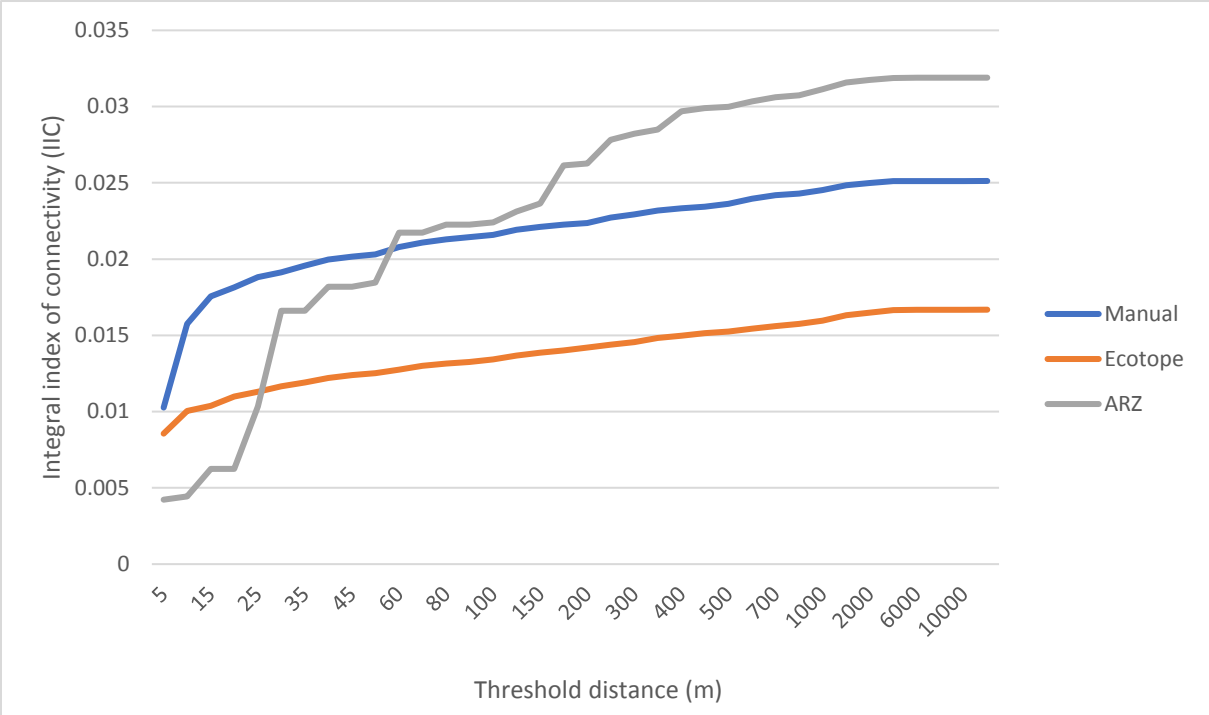

Figure 16 Evolution of the IIC (mean values for each of the 40 segments at distance threshold from 5m to 15 000m) for the 3 resolutions. The blue curve represents the IIC evolution of the Manual layer, the orange shows the IIC evolution for the Ecotope layer and the grey curve shows the IIC evolution for the ARZ.

The Manual and Ecotope layers have higher IIC values than the ARZ at short distances because their woody patches are closer and more numerous. Once the maximum threshold distance is reached, the ARZ has a higher IIC value because it delineates larger areas.

The observed IIC is also higher for the manual layer than for the ecotope layer because the average area of patches obtained by manual digitization is larger. Indeed, the calculation of this index takes into account the area of the patch in the numerator and the number of links existing between two patches in the denominator. As there are more of them for the ecotope layer, more bonds exist between the i and j patches, which decreases the value of the index.

3.2.3.2 Evolution of the IIC as a function of the disturbance gradient.

The IIC increases with threshold distance but differently with the anthropogenic disturbance gradient (Figure 17). As previously, it increases and stabilizes when all pairs of patches are linked. For the 3 resolutions, a first trend shows that the IIC is lower in the highly disturbed segments than in the least disturbed segments.

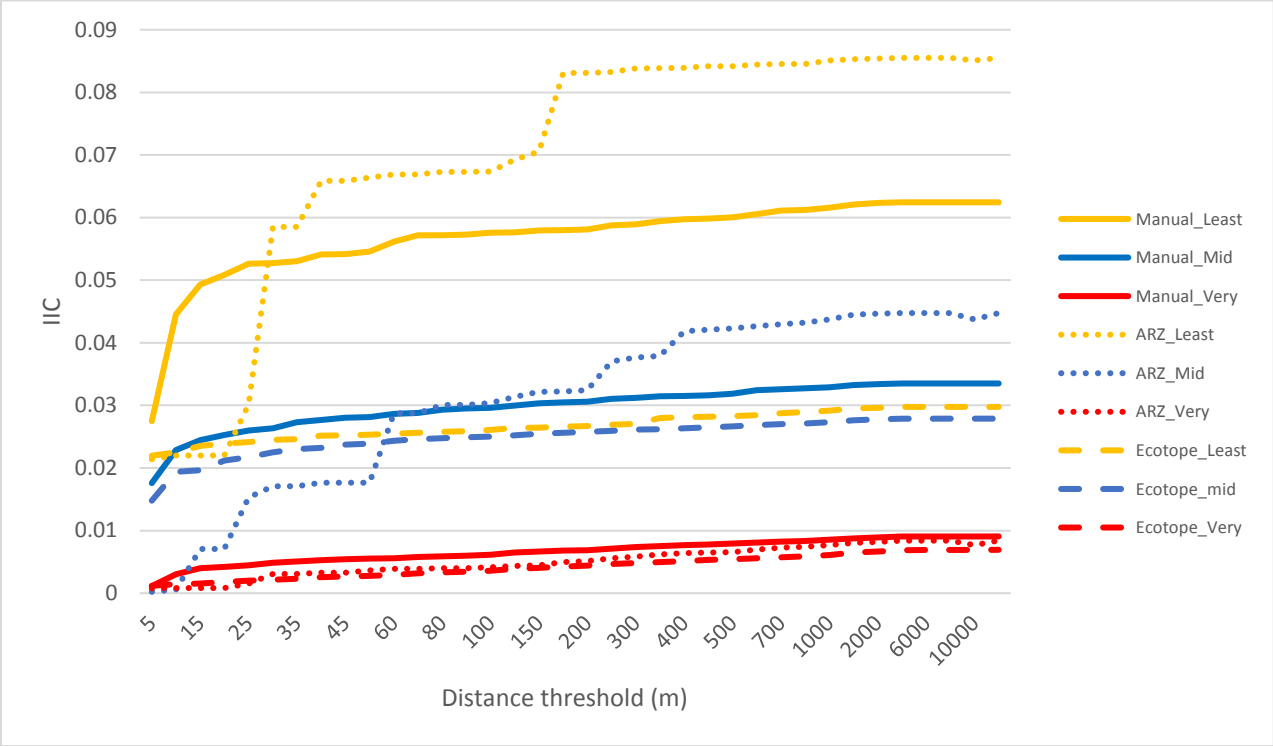

Figure 17 - evolution of the IIC (average values for each segment for each threshold distance from 5m to 15 000m) for each resolution and each disturbance class. The evolution of the IIC is represented in yellow for the least disturbed environments, in blue for the moderately disturbed environments and in red for the most disturbed segments.

For each of the disturbance gradients, the IIC curve for the ARZ has a stepped structure relative to the others that are smoother. This stepped structure is characterized in each disturbance class by an underestimation of connectivity at short distances. This underestimation is reduced in the very disturbed segments and increases when the segments have better ecological integrity (in the mid and least disturbed segments). Over longer distances, the ARZ overestimates connectivity except for very disturbed environments.

For the Very disturbed segments, the Manual layer has on average a higher IIC value, followed by ARZ and Ecotope layers. For this disturbance class, the ARZ underestimates connectivity in short distances, between 5 and 25m. In the mid disturbed segments, the ARZ underestimates

connectivity over a distance of 60 meters compared to the Ecotope and Manual layers before overestimating it beyond this distance.

The "Least disturbed" segments show quite large disparities between resolutions. The ARZ has the lowest IIC values up to 20m compared to Ecotope and up to 30m compared to the manual layer. Beyond these distances, the ARZ has the highest IIC value and therefore overestimates connectivity.

The Manual layer systematically has a higher value than the ecotope layer. As explained above, the patches obtained by manual digitization are larger than those of ecotope and the index gives more importance to large patches.

3.3 Influence of environmental variables on riparian vegetation structure.

3.3.1 Influence of land use variables at the segment and catchment scales.

The first redundancy analysis conducted on land use variables (Table 11) at the segment and catchment scales shows that the local scale has a greater influence on the variability of riparian vegetation structure than the catchment scale for each of the 3 resolutions. The results are presented for the ecotope layer because it provides the most significant results in term of landscape metrics analysis.

Table 11 - RDA results assessing the percentage variability of landscape metrics explained by land use classes at the segment and catchment scale, as well as the associated p-value.

	Segment scale		**Catchment scale**	
Metrics	% of variance explained	p-value	% of variance explained	p-value
MPS	66,96%	0.001***	24,69	0.006**
NP	23,08%	0,009**	23,85	0,005**
PSCV	13,10%	0,088	4,07	0,44
MSI	25,19%	0,005**	0,114	0,108
MPFD	16,17%	0,041*	12,3	0,091
MPI	23,51%	0,009*	3,1	0,558
MNN	8,87%	0,167	12,9	0,086
LPI	33,48%	0,001***	16,56	0,02*

At the segment scale, land use variables explain 66,96% of the variability of the mean patch size (MPS) (p-value < 0,001), unlike 24.69% at the catchment level (p-value = 0,006). The dominance index (LPI) is also better explained by local land use variables (p-value < 0,001). Shape metrics such as MSI and MPFD are explained by 25% (p-value < 0,005) and 16% (p-value = 0,041) at the segment scale while they are not significant at the catchment scale. The degree of patch isolation and fragmentation (MPI) is also significantly explained by the land use variables at the segment level (p-value < 0,009).

3.3.2 Influence of environmental variables on riparian vegetation structure

The results of the 2nd redundancy analysis (Table 12) which takes into account all environmental variables (land use, hydromorphological variables, topographical variables), show that in all cases, the percentage of variability explained increases but is not significant for all landscape metrics (PSCV, MPFD, MNN). Compared to the first redundancy analysis, the degree of significance increased for MPI (p-value < 0,002), showing that other environmental variables, in addition to land use, influence the degree of isolation and fragmentation of patches. It is also noted that these variables do not significantly influence the PSCV, which shows that the landscape approach does not take into account topographical variables.

Table 12 - Redundancy analysis results (RDA) showing the percentage of variances of landscape metrics by all environmental variables and the associated p-value

Metrics	% of variance explained	p-value
MPS	80,34%	0.001 ***
NP	80,83%	0,001***
PSCV	36,46%	0,061
MSI	44,35%	0,009**
MPFD	33,85%	0,091
MPI	52,76%	0,002**
MNN	31,48%	0,125
LPI	58,03%	0,001***

4 Discussion

4.1 Potentiality of the Copernicus Riparian Layer for the characterization of riparian zones

The results confirmed that the structure of riparian areas could be assessed on the basis of landscape metrics of different categories (Aguiar et al., 2011 ; Fernandes et al., 2011). Landscape metrics such as MPS, MPI and MNN can be used to characterize the width, longitudinal continuity and fragmentation of corridors and thus assess the ecological integrity of riparian areas (Fernandes et al., 2011)

However, the results showed that the assessment of ecological integrity by landscape metrics varied very significantly with spatial resolution. These results are in line with other studies that have shown that most landscape metrics vary with the grain (Turner et al., 1989; Wu, 2004; Ostapowicz et al., 2008). The comparison between the 3 spatial resolutions showed that the ARZ layer, with a medium spatial resolution, delimits larger, more homogeneous, simpler, less numerous and more isolated patches. When the spatial resolution is finer, for the Manual and Ecotope layers, the patches are smaller but more heterogeneous, more complex, more numerous and closer together. A finer grain provides more detail on the complexity of the shapes and the number of patches is logically higher because a coarser resolution can mask some habitats (Turner et Gardner, 2015).

However, the ARZ layer reacts positively according to the pressure gradient. In the least disturbed environments, for all 3 resolutions, riparian vegetation has larger, more complex and better connected patches. When the riparian envelope is mainly composed of an agricultural and artificial matrix, patches are smaller and more numerous while Fernandes et al., (2011) observed a decrease in the number of patches for Mediterranean ecosystems (Tagus basin, Portugal) when the proportion of agricultural land increases. It is therefore necessary to qualify that plant formations differ according to the bioclimatic region studied. Mediterranean riparian vegetation forms narrow strips around the river, while vegetation in temperate regions can extend over a width of more than 150m (Aguiar and Ferreira, 2005a). This implies that the integrity of riparian areas differs according to the region studied and that conservation measures to determine the minimum width of the corridor must be studied locally (Aguiar & al., 2005). Also, the influence of the disturbance gradient on the evolution of the IIC was marked by a decrease in connectivity values for the 3 resolutions. This trend was observed by García-Feced et al., (2011), who determined significant differences in the IIC between landscapes composed mainly of forests and those with a higher proportion of agricultural land .

Consequently, these results show that ARZ, by responding positively to a pressure gradient, can be used for management purposes by identifying disturbed segments for which vegetation needs to be preserved and where connectivity is poor, and providing the necessary conservation measures. Management measures for these environments aim to restore them by creating corridors (Apan et al., 2002). In this case, the Copernicus data and other resolutions provide a different interpretation. Since the patches delineated by the ARZ are more isolated and have lower connectivity over short distances, management measures would aim to "overestimate" the need to create corridors, which may result in additional costs.

In addition, Weissteiner et al., (2016) observed several sources of overestimation in the ARZ classification that could be observed in this study. Overestimations are found in predominantly agricultural and urbanized areas. Underestimates are generally found near the watercourse (Figure 18) where corridors are present. This is a bias in the estimation of the number of patches, and in the total area delineated. This problem can lead to errors in restoration budgets as shown by Gergel et al., (2007), who developed a cost error matrix based on the results obtained with the confusion matrix in order to demonstrate the implication it has for decision makers.

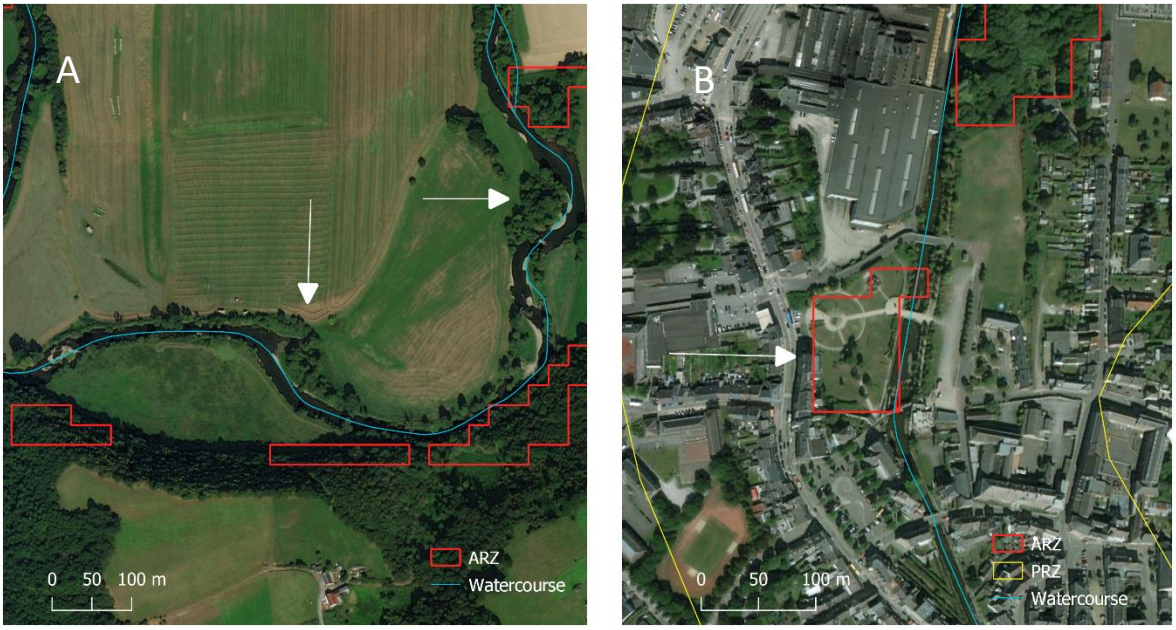

Figure 18 - ARZ misclassification; A represents underestimations (along the river) and B overestimations (in urban areas).

Misclassification errors should not be overlooked as they are biases to be taken into account when using Copernicus data. Riparian vegetation forms linear corridors. A few missing pixels can change the interpretation of the longitudinal continuity of the corridor, by interpreting a fragmented landscape when in reality there is no disturbance (Langford et al., 2006)

4.2 Impact of the resolution on the assessment of ecological processes.

Depending on the spatial resolution of the data sets, the assessment of the ecological processes that result from the landscape pattern will vary.

A patch is a resource area for species (Forman, 1995). Resource quantity and habitat availability increase with patch size and a change in area can influence species abundance (Turner et al., 1989). By overestimating areas, the ARZ overestimates the amount of resources available for species.

Several ecological processes are linked to the shape of the patch. This influences the diversity of the species present (Turner et al., 1989) by conditioning the edge-interior ratio, which is all the greater when the shape of the patch is complex (Collinge, 1996). The edges influence with the landscape matrix and promote the role of forests as a well for nutrients (Clément et al., 2017). In addition, complex woody patches located near the watercourse have a positive impact on water quality (Clément et al., 2017). As a result, these processes are more accurately evaluated by the Ecotope and Manual layers than by the ARZ, although their shape is cut by the PRZ.

Indeed, the patch area, shape index and fractal dimension are underestimated for the Manual and Ecotope layers. This can be explained by the delimitation of the sub-basins and the PRZ. This one delineates a buffer zone around the watercourse and forms the boundary of the study area at the segment scale. This layer cuts the patches of the Manuel and Ecotope layers quite clearly when the wooded areas extend beyond the PRZ (Figure 20). A change in the extent therefore results in a bias in the shape, complexity and mean area of the patches (Turner et Gardner, 2015). In addition, this problem is more pronounced in areas of low extent (Turner and Gardner, 2015). Since the width of the PRZ is dependent on the width of the watercourse, this results in a greater bias for riparian areas with a low watercourse width.

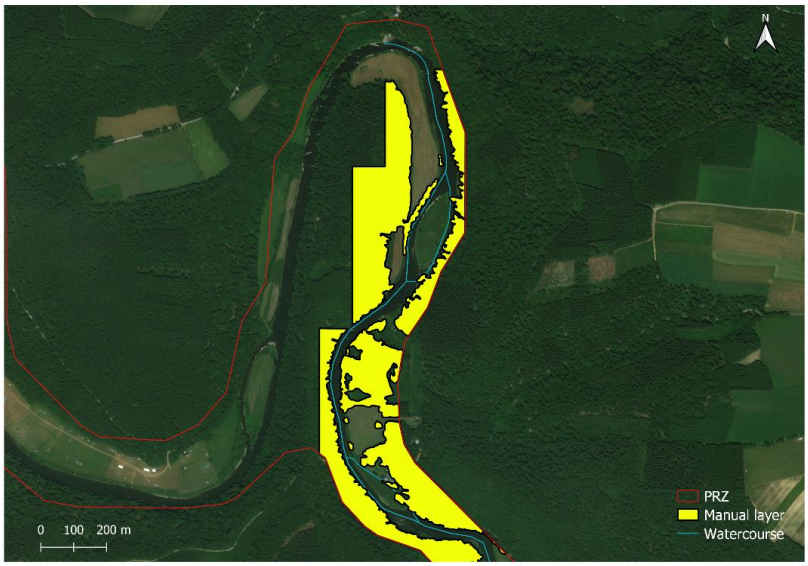

Figure 19 - Cutting of the manual layer (yellow) by PRZ and sub-basin limits.

The average distance between the ARZ patches is greater than for the Manual and Ecotope. Because the patches of ARZ are more isolated, this one overestimates processes such as loss of genetic diversity, loss of mobility for organisms and underestimates the longitudinal aspect of the corridor.

These trends show that, depending on the resolution under consideration, the assessment of the structure of the riparian landscape is modified and some ecological processes may be over- and under-evaluated and these observations should be taken into account in the management of these environments.

4.3 Influence of environmental variables on riparian vegetation structure

The results showed that land use at the segment scale better assessed the variability of the riparian structure than the catchment scale. This result was expected and has already been suggested by several authors (Von Schiller et al., 2008; Fernandes et al., 2011; Nicol et al., 2017) and reinforces the need to protect the riparian buffer.

The second redundancy analysis adding all environmental, topographic and hydromorphological variables explained an additional percentage of the variability in riparian zone structure but low compared to land use. Aguiar et Ferreira, (2005) also obtained low values for the influence of environmental variables on the integrity of riparian environments. Other variables such as dams (Aguiar et al., 2016), floristic composition (Aguiar et al., 2011) and substrate could provide additional information on ecological integrity assessment.

The absence of a statistical link between the PSCV and all environmental variables shows that landscape metrics do not take into account height and height variation. It points to a problem that is observed in the two-dimensional patch corridor matrix approach (Drăguţ et al., 2010). By neglecting these variables, the assessment of landscape structure is erroneous (Hoechstetter et al., 2006) given that riparian environments are dynamic.

4.4 Management tools

On a continental scale, the Copernicus Riparian Layers have already provided a general overview of the state of riparian zones on a European scale (Weissteiner et al., 2016). The ratio of ARZ/PRZ surfaces provides an indicator of their ecological status. A high ratio is observed in the Scandinavian countries. A weak ratio shows a deficiency that is mainly marked in Eastern European countries, Germany and the Netherlands. In analysing the cause of ARZ deficiency with land use (LCLU Riparian Layer), Weissteiner et al. (2016) noted that the European-wide pressure on these areas was mainly due to agriculture.

Also, at the segment level, riparian areas could be studied using landscape graphs. Indeed, the method of landscape graphs to characterize ecological networks has recently emerged (Foltête et al., 2012). These techniques are used to support landscaping. In this approach, a graph is composed of nodes, corresponding to habitat patches and connected by links, which are paths allowing the flow of individuals. Through this method, it is also possible to identify the critical patches (patch scale) to be preserved as a priority in order to maintain connectivity and implement conservation policies (Saura et Pascual-Hortal, 2007). However, in assessing the influence of spatial resolution on the location of priority sites for conservation, Pascual-Hortal and Saura, (2007) shows that some connectivity indices are very sensitive to spatial resolution and therefore do not define the same priority patches according to resolutions. In landscape graph analyses for riparian areas, it is therefore important to select the metrics that are most robust to a variation in spatial resolution. In addition to the IIC, the probability of connectivity (PC) could be used. It is a functional connectivity index based on the probability of species dispersal from one patch to another (Foltête et al., 2012) and has shown the same prioritization of patches according to resolutions (Saura and Pascual-Hortal, 2007). This aspect could therefore be studied with the Copernicus data and compared with the other resolutions used in this work, in order to analyse whether the ARZ defines in the same way the priority patches as the finer resolutions.

5 Conclusion

Riparian structure can be assessed from a combination of landscape metrics. The results showed that the ecological integrity assessment varied with the spatial resolution used. The finer spatial resolutions show that they more accurately represent the structure of riparian vegetation, both in terms of number of patches, mean area, shape and distance between patches.

Although ARZ differs significantly from finer resolutions, the Copernicus data reacts positively to a disturbance gradient. As with other resolutions, patches are larger, more complex in shape and closer in the least disturbed environments and in the very disturbed segments, patches are smaller, simpler and more distant. This would allow this data to be used for riparian area management by identifying river segments to be safeguarded and restored as a priority, although it is necessary to take into consideration the overvaluation of landscape metric values and its impact on the assessment of riparian integrity.

Local land use has the greatest influence on the structure of riparian vegetation. This result reinforces the need to limit human activity within the buffer delimiting the riparian zone and to set up more protection zones and reform the longitudinal continuity of the corridors.

The two-dimensional approach of landscape metrics has shown that it does not take into account the height of vegetation, which is a variable to be taken into account when assessing the ecological integrity of these environments, given that they are dynamic and characterized by different stages of plant succession.

Copernicus Riparian Layers delimit watercourses with a strahler order greater than 3. With anthropogenic pressure and the consequences on these environments, it would be interesting to extend this dataset to all Strahler orders in order to better manage these ecosystems. The study focused on the Centro-Baltic hydroregion. It would be interesting to observe how Copernicus data would react in other environments, such as Mediterranean areas, as the dynamics of riparian areas differ from one bioclimatic region to another.

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7 Appendix

7.1 Appendix 1 - Land cover reclassification for the Corine Land Cover layer (LULC 2012) used to characterize land cover in the watershed into 6 classes (Artificial surfaces, Intensive agriculture, Extensive agriculture, Managed forests and Unmanaged)

GRID_CODE	CLC_CODE	LABEL	Land-use classification system
1	111	Continuous urban fabric	Artificial surfaces
2	112	Discontinuous urban fabric	Artificial surfaces
3	121	Industrial or commercial units	Artificial surfaces
4	122	Road and rail networks and associated land	Artificial surfaces
5	123	Port areas	Artificial surfaces
6	124	Airports	Artificial surfaces
7	131	Mineral extraction sites	Artificial surfaces
8	132	Dump sites	Artificial surfaces
9	133	Construction sites	Artificial surfaces
10	141	Green urban areas	Artificial surfaces
11	142	Sport and leisure facilities	Artificial surfaces
12	211	Non-irrigated arable land	Intensive agriculture
13	212	Permanently irrigated land	Intensive agriculture
14	213	Rice fields	Intensive agriculture
15	221	Vineyards	Intensive agriculture
16	222	Fruit trees and berry plantations	Intensive agriculture
17	223	Olive groves	Intensive agriculture
18	231	Pastures	Intensive agriculture
19	241	Annual crops associated with permanent crops	Intensive agriculture
20	242	Complex cultivation patterns	Extensive agriculture
21	243	Land principally occupied by agriculture, with significant areas of natural vegetation	Extensive agriculture
22	244	Agro-forestry areas	Extensive agriculture
23	311	Broad-leaved forest	Unmanaged Forest
24	312	Coniferous forest	Managed forest
25	313	Mixed forest	Unmanaged Forest
26	321	Natural grasslands	Unmanaged Forest
27	322	Moors and heathland	Unmanaged Forest
28	323	Sclerophyllous vegetation	Unmanaged Forest
29	324	Transitional woodland-shrub	Unmanaged Forest

30	331	Beaches, dunes, sands	UNCLASSIFIED
31	332	Bare rocks	UNCLASSIFIED
32	333	Sparsely vegetated areas	Unmanaged Forest
33	334	Burnt areas	UNCLASSIFIED
34	335	Glaciers and perpetual snow	UNCLASSIFIED
35	411	Inland marshes	UNCLASSIFIED
36	412	Peat bogs	UNCLASSIFIED
37	421	Salt marshes	UNCLASSIFIED
38	422	Salines	UNCLASSIFIED
39	423	Intertidal flats	UNCLASSIFIED
40	511	Water courses	UNCLASSIFIED
41	512	Water bodies	UNCLASSIFIED
42	521	Coastal lagoons	UNCLASSIFIED
43	522	Estuaries	UNCLASSIFIED
44	523	Sea and ocean	UNCLASSIFIED
48	999	NODATA	UNCLASSIFIED
49	990	UNCLASSIFIED LAND SURFACE	UNCLASSIFIED
50	995	UNCLASSIFIED WATER BODIES	UNCLASSIFIED

7.2 Appendix 2 - Land cover reclassification for the LCLU layer of the local Copernicus Data component, used to characterize land cover at the segment scale in 6 classes (Artificial surfaces, Intensive agriculture, Extensive agriculture, Managed forests and Unmanaged forests).

GRID_CODE	MAES4_CODE	LABEL	Land-use classification system (Option 1)
2	1111	Continuous urban fabric (in-situ based or IM.D. >80-100%)	Artificial surfaces
3	1112	Dense urban fabric (IM.D. >30-80% + industrial, commercial, public, military and private units)	Artificial surfaces
4	1113	Industrial or commercial units	Artificial surfaces
5	1121	Low density urban fabric (IM.D. 0-30%)	Artificial surfaces
6	1211	Road networks and associated land	Artificial surfaces
7	1212	Railways and associated land	Artificial surfaces
8	1213	Port areas	Artificial surfaces
9	1214	Airports	Artificial surfaces
10	1311	Mineral extraction, dump and construction sites	Artificial surfaces
11	1321	Land without current use	Artificial surfaces
12	1411	Green urban areas T.C.D. ≥ 30%	Artificial surfaces
13	1412	Green urban areas T.C.D. < 30%	Artificial surfaces
14	1421	Sports and leisure facilities T.C.D. ≥ 30%	Artificial surfaces
15	1422	Sports and leisure facilities T.C.D. < 30%	Artificial surfaces
25	2321	Complex cultivation patterns	Extensive agriculture
26	2331	Land principally occupied by agriculture with significant areas of natural vegetation	Extensive agriculture
27	2341	Agro-forestry T.C.D. ≥ 30%	Extensive agriculture
28	2351	Agro-forestry T.C.D. < 30%	Extensive agriculture
16	2111	Non-irrigated arable land	Intensive agriculture
17	2121	Greenhouses	Intensive agriculture
18	2131	Irrigated arable land and rice fields	Intensive agriculture
19	2141	Complex patterns of irrigated and non-irrigated arable land	Intensive agriculture
20	2211	Vineyards	Intensive agriculture
21	2221	High stem fruit trees (extensively managed)	Intensive agriculture
22	2222	Low stem fruit trees and berry plantations	Intensive agriculture
23	2231	Olive groves	Intensive agriculture
24	2311	Annual crops associated with permanent crops	Intensive agriculture
34	3151	Highly artificial broadleaved plantations	Managed forest
38	3241	Highly artificial coniferous plantations	Managed forest
42	3341	Highly artificial mixed plantations	Managed forest
44	3412	Lines of trees and scrub	Managed forest
45	3511	Forest damaged by fire	Managed forest
46	3512	Other damaged forest	Managed forest
48	4111	Managed grasslands without trees and scrubs (T.C.D. < 30%)	Managed forest
49	4112	Managed grasslands without trees and scrubs (T.C.D. ≥ 30%)	Managed forest
1	0	Urban Atlas not available	UNLCASSIFIED
81	9000	Urban Atlas: Rivers and lakes	UNLCASSIFIED

82	9111	Permanent interconnected running water courses	UNLCASSIFIED
83	9112	Intermittently running water courses	UNLCASSIFIED
84	9113	Highly modified natural water courses and canals	UNLCASSIFIED
85	9121	Permanent separated water bodies belonging to the river system	UNLCASSIFIED
86	9122	Temporary separated water bodies belonging to the river system	UNLCASSIFIED
87	9211	Permanent natural water bodies	UNLCASSIFIED
88	9212	Temporary natural water bodies	UNLCASSIFIED
89	9213	Ponds and lakes with completely man-made structure	UNLCASSIFIED
90	9214	Intensively managed fish ponds	UNLCASSIFIED
91	9215	Standing water bodies of extractive industrial sites	UNLCASSIFIED
92	10111	Marine (other)	UNLCASSIFIED
47	4000	Urban Atlas: Grassland	Unmanaged
50	4211	Dry grasslands without trees (T.C.D. < 30%)	Unmanaged
51	4212	Mesic grasslands without trees (T.C.D. < 30%)	Unmanaged
52	4213	Alpine and subalpine grasslands without trees (T.C.D. < 30%)	Unmanaged
53	4221	Dry grasslands with trees (T.C.D. ≥ 30%)	Unmanaged
54	4222	Mesic grasslands with trees (T.C.D. ≥ 30%)	Unmanaged
55	4223	Alpine and subalpine grasslands with trees (T.C.D. ≥ 30%)	Unmanaged
56	5000	Urban Atlas: Heathland and scrub	Unmanaged
57	5111	Heathlands and Moorlands	Unmanaged
58	5112	Other scrub land	Unmanaged
59	5211	Sclerophyllous vegetation	Unmanaged
60	6111	Sparsely vegetated areas	Unmanaged
61	6211	Beaches	Unmanaged
62	6212	Dunes	Unmanaged
63	6213	River banks	Unmanaged
64	6221	Bare rocks and rock debris	Unmanaged
65	6222	Burnt areas (except burnt forest)	Unmanaged
66	6223	Glaciers and perpetual snow	Unmanaged
67	7000	Urban Atlas: Wetland	Unmanaged
68	7111	Inland freshwater marshes without reeds	Unmanaged
69	7112	Inland freshwater marshes with reeds	Unmanaged
70	7121	Inland saline marshes without reeds	Unmanaged
71	7122	Inland saline marshes with reeds	Unmanaged
72	7211	Exploited peat bog	Unmanaged
73	7212	Unexploited peat bog	Unmanaged
74	8111	Salt marshes without reeds	Unmanaged
75	8112	Salt marshes with reeds	Unmanaged
76	8113	Salines	Unmanaged
77	8121	Intertidal flats	Unmanaged
78	8211	Coastal lagoons without reeds	Unmanaged
79	8212	Coastal lagoons with reeds	Unmanaged
80	8221	Estuaries	Unmanaged
29	3000	Urban Atlas: Woodland and forest	Unmanaged
30	3111	Riparian and fluvial Broadleaved forest	Unmanaged
31	3121	Broadleaved swamp forest	Unmanaged

32	3131	Other natural and semi natural broadleaved forest	Unmanaged
33	3141	Broadleaved evergreen forest	Unmanaged
35	3211	Riparian and fluvial coniferous forest	Unmanaged
36	3221	Coniferous swamp forest	Unmanaged
37	3231	Other natural and semi natural coniferous forest	Unmanaged
39	3311	Riparian and fluvial mixed forest	Unmanaged
40	3321	Mixed swamp forest	Unmanaged
41	3331	Other natural and semi natural mixed forest	Unmanaged
43	3411	Transitional woodland and scrub	Unmanaged

7.3 Appendix 3 - Proportion of land use (%) for each catchment, with «AS » : Artificial surfaces, « EA » : Extensive agriculture, « IA » : Intensive agriculture, « MF » : Managed Forests, « Unclass » : Unclassified, « Un_forest » : Un_forest and the class of disturbance.

ID	AS	EA	IA	MF	Unclass	Un_forest	Class
1	0,09953	0,19583	0,45784	0	0,02327	0,22352	Mid_disturbed
2	0,05999	0,15862	0,27709	0,12373	0,00111	0,37947	Mid_disturbed
3	0,06124	0,1557	0,28614	0,11896	0,00117	0,37678	Mid_disturbed
4	0,06279	0,24481	0,23531	0,09267	0,00204	0,36238	Mid_disturbed
5	0,19595	0,11388	0,1965	0,15655	0,04792	0,28919	Mid_disturbed
6	0,12218	0,10251	0,22975	0,18075	0,03626	0,32855	Mid_disturbed
7	0,06009	0,00735	0,06984	0,31361	0,12138	0,42772	Mid_disturbed
8	0,12211	0,02967	0,18402	0,2276	0,08589	0,35071	Mid_disturbed
9	0,0612	0,15721	0,27016	0,12882	0,00106	0,38155	Mid_disturbed
10	0,05787	0,16558	0,24262	0,11993	0,00089	0,41311	Mid_disturbed
11	0,05863	0,16836	0,25109	0,12	0,00093	0,40098	Mid_disturbed
12	0,06166	0,12591	0,31918	0,09676	0,00127	0,39521	Mid_disturbed
13	0,08408	0,31873	0,24572	0,08746	0	0,26401	Mid_disturbed
14	0,23722	0,14249	0,58576	0	0	0,03452	Very_disturbed
15	0,06047	0,26596	0,21647	0,09059	0,00158	0,36494	Mid_disturbed
16	0,05951	0,26335	0,21308	0,09487	0,00165	0,36753	Mid_disturbed
17	0,04835	0,29112	0,21318	0,11983	0,00249	0,32504	Mid_disturbed
18	0,05746	0,3086	0,23776	0,1322	0	0,26398	Mid_disturbed
19	0,04548	0,32482	0,23171	0,10954	0	0,28845	Mid_disturbed
20	0,03703	0,28684	0,24663	0,14091	0	0,28859	Mid_disturbed
21	0,07377	0,18285	0,28006	0,12509	0,00574	0,33249	Mid_disturbed
22	0,07639	0,18485	0,28033	0,12179	0,00557	0,33108	Mid_disturbed
23	0,27008	0,41546	0,29916	0	0	0,0153	Mid_disturbed
24	0,129	0,26998	0,43193	0,00642	0,00003	0,16265	Mid_disturbed
25	0,1516	0,1543	0,67598	0,00149	0	0,01663	Very_disturbed
26	0,07689	0,33685	0,20292	0,00231	0,00931	0,37172	Least_disturbed
27	0,0463	0,21326	0,10033	0,10452	0	0,53559	Least_disturbed
28	0,06333	0,161	0,29703	0,12257	0,0013	0,35478	Mid_disturbed
29	0,05982	0,19587	0,11578	0,15367	0,00156	0,4733	Mid_disturbed
30	0,05795	0,23842	0,14473	0,09345	0,00057	0,46488	Least_disturbed
31	0,05879	0,23683	0,15159	0,08885	0,00054	0,4634	Least_disturbed
32	0,05549	0,19682	0,14297	0,13702	0	0,46769	Mid_disturbed
33	0,06339	0,19229	0,07854	0,23852	0,00465	0,42261	Mid_disturbed
34	0,04524	0,1909	0,06972	0,15972	0,00702	0,5274	Least_disturbed
35	0,05769	0,24002	0,14036	0,09806	0,00059	0,46327	Least_disturbed
36	0,15107	0,12541	0,70826	0	0	0,01526	Very_disturbed
37	0,24814	0,13921	0,52954	0,01802	0	0,06509	Very_disturbed
38	0,05087	0,14696	0,27445	0,21028	0,03356	0,28389	Mid_disturbed
39	0,08312	0,03322	0,53117	0,14218	0,01597	0,19435	Very_disturbed
40	0,07543	0,08179	0,34326	0,1956	0,01271	0,29122	Mid_disturbed

7.4 Appendix 4 - Proportion of land use (%) for each segment, in Artificial surfaces, Intensive agriculture, Managed forest, Unclassified and Unmanaged and their class of disturbance

ID	Artificial surfaces	Intensive agriculture	Managed forest	Unclassified	Unmanaged	Class
1	0,39171	0,28517	0,00152	0	0,3216	Mid_disturbed
2	0,03393	0,10651	0	0,15245	0,70711	Least_disturbed
3	0,06155	0,36084	0,00123	0,12062	0,45575	Mid_disturbed
4	0,47252	0,37249	0	0,06841	0,08658	Very_disturbed
5	0,87854	0,01954	0	0,08444	0,01749	Very_disturbed
6	0,70863	0,04417	0	0	0,24719	Very_disturbed
7	0,18855	0,62397	0	0	0,18747	Very_disturbed
8	0,97466	0	0	0,02534	0	Very_disturbed
9	0,32658	0,42039	0	0,13025	0,12278	Very_disturbed
10	0,23179	0,20912	0	0,19346	0,36562	Mid_disturbed
11	0,02093	0,20639	0	0,13352	0,63916	Mid_disturbed
12	0,04911	0,73992	0,00495	0,05133	0,1547	Very_disturbed
13	0	0,64696	0	0	0,35304	Mid_disturbed
14	0,48354	0,3782	0	0,00264	0,13562	Very_disturbed
15	0,05725	0,30199	0	0,10812	0,53264	Mid_disturbed
16	0,02671	0,74202	0	0,07702	0,15425	Very_disturbed
17	0,50175	0,03518	0	0,13295	0,33012	Mid_disturbed
18	0,05522	0	0	0,03553	0,90925	Least_disturbed
19	0	0	0	0,0773	0,9227	Least_disturbed
20	0,15039	0,66498	0	0,06785	0,11677	Very_disturbed
21	0,58555	0,17772	0	0,13235	0,10438	Very_disturbed
22	0,2733	0,42056	0	0,14122	0,16492	Very_disturbed
23	0,19631	0,73228	0,00053	0,00525	0,06562	Very_disturbed
24	0,78389	0	0	0,01215	0,20396	Very_disturbed
25	0,13213	0,68621	0,01913	0,00431	0,15822	Very_disturbed
26	0,061	0,25136	0,00294	0	0,6847	Mid_disturbed
27	0	0,06902	0	0	0,93098	Least_disturbed
28	0,17037	0,66735	0	0,04817	0,11411	Very_disturbed
29	0,23985	0,48451	0	0,00984	0,26579	Very_disturbed
30	0,36582	0,00109	0	0,09543	0,53765	Mid_disturbed
31	0,0906	0	0	0,12973	0,77967	Least_disturbed
32	0,56976	0,24972	0	0,00032	0,1802	Very_disturbed
33	0,05697	0,00641	0	0,08516	0,85146	Least_disturbed
34	0,61333	0,16934	0	0,049	0,16833	Very_disturbed
35	0,018	0,74507	0,00373	0,05712	0,17608	Very_disturbed
36	0,31895	0,48113	0	0,0502	0,14971	Very_disturbed
37	0,62556	0,19024	0	0,05942	0,12478	Very_disturbed
38	0,47579	0,0151	0	0,21835	0,29076	Mid_disturbed
39	0	0,1936	0	0	0,8064	Least_disturbed
40	0,46181	0,18334	0	0,1302	0,22465	Mid_disturbed