KNOWLEDGE CONVERSION FOR ENHANCING MANAGEMENT OF EUROPEAN RIPARIAN ECOSYSTEM AND SERVICES

COST ACTION **CONVERGES**

DELIVERABLE 1.1.: GUIDANCE TO IMPLEMENT THE PROTOCOL FOR THE STATUS/PRESSURES ASSESSMENT

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This report is based upon work from COST Action CONVERGES (www.converges.eu), supported by COST (European Cooperation in Science and Technology ; www.cost.eu). COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. COST Actions help connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. This boosts their research, career and innovation. Funded by the Horizon 2020 Framework Programme of the European Union.

Citation: González del Tánago M., V. Martínez-Fernández, D. García de Jalón, P.M. Rodríguez-González, S. Dufour, V. Garófano Gómez (2020). KNOWLEDGE CONVERSION FOR ENHANCING MANAGEMENT OF EUROPEAN RIPARIAN ECOSYSTEM AND SERVICES: GUIDANCE TO IMPLEMENT THE PROTOCOL FOR THE STATUS/PRESSURES ASSESSMENT. Report, COST Action CA16208 CONVERGES, 60 pp. (https://converges.eu/resources/guidance-to-assess-riparian-vegetation-status-and-pressures/)

1. INTRODUCTION AND OBJECTIVES

This document, as Deliverable 1.1 of CONVERGES COST ACTION (https://converges.eu/), discusses procedures for characterizing and assessing riparian vegetation status in European rivers in the context of the European Union (EU) Water Framework Directive (WFD). Although the general degradation of riparian zones is widely recognized in European countries (Tockner *et al*., 2009), relatively little effort has focused on characterizing them accurately at the national scale, which is essential to assess and manage them appropriately.

Riparian vegetation is a key element in riparian-zone and fluvial-system ecosystems due to its fundamental influence on fluvial dynamics. In general, management of riparian corridors has not addressed targets beyond flood control, which often involves removing vegetation or conserving specific habitats (i.e., Natura 2000 sites), the latter of which cover only relatively small sections of river lengths and sometimes have emerged under human pressure.

Given the vast amount of literature on the essential influence of riparian vegetation on observed river adjustments and trajectories, and the relative lack of consideration of riparian vegetation in the most frequently used hydromorphological protocols that consider riparian zones, we have two main objectives. The first is briefly to review the hydromorphological context of the WFD to promote its revision and updating. We call for including riparian vegetation explicitly as an additional hydromorphological element when classifying the ecological status of rivers, as well as considering knowledge about the influence of riparian vegetation on the functioning of river ecosystems. Consequently, the second objective is to promote a multi-scale procedure to characterize and assess the status of riparian corridors. This involves improving the understanding of riparian vegetation trends in the context of natural and human-induced disturbances to support suitable management practices and conservation policies.

The document is structured in three parts. The first part highlights the relevance of riparian vegetation in river hydromorphology and the use of riparian plants and communities as useful indicators of river pressures and impacts. In the second part, we briefly discuss the traditional approaches to river morphology that have likely influenced the hydromorphological context of the WFD. This section discusses the little or no consideration of riparian vegetation as an element to classify the ecological status of rivers. The third part discusses ideas and guidelines for characterizing and assessing the status of riparian vegetation to consider multiple spatio-temporal scales, which should be tested in rivers across European countries, from distinct hydrological and biogeographical contexts.

2. RELEVANCE OF RIPARIAN VEGETATION IN RIVER FUNCTIONING AND ENVIRONMENTAL ASSESSMENTS

2.1. Role of riparian vegetation in river hydromorphology

In this document, “riparian vegetation” refers to vegetation whose establishment, growth and survival depends greatly on fluvial processes (Naiman *et al*., 2005; Dufour *et al*., 2019). Once established, riparian vegetation interacts with these fluvial processes (mainly flooding and sediment erosion, transport and deposition), becomes a key component of all of them, and has an increasing influence throughout its growth and development (Gurnell, 2014, Corenblit *et al*., 2007, 2009).

Riparian vegetation usually forms corridors along both sides of river channels. Within these corridors, vegetation species and communities are strongly subjected to and interact with river hydromorphology. Patterns in magnitude, frequency and timing of fluvial disturbances are crucial for plant dispersal, establishment and survival, and for community succession (Steiger *et al*., 2005; Corenblit *et al*., 2009a.b; Greet *et al*., 2011; Gurnell, 2014). Landscape properties (e.g., elevation, topography), along with the influence of hydrological and geological features, determine temperature and soil moisture availability, which control vegetation growth. Accordingly, vegetation growth, species succession and rejuvenation processes influence local temperature and soil moisture availability. Vegetation growth and succession gradually reinforce the stability of soil on channel banks and may modify flow velocity and flooding frequency. The influence of riparian plants as river engineers (Jones, 1994) that influence the physical context of river channels has been widely documented (Camporeale *et al*., 2013; Gurnell, 2014). Riparian vegetation successively creates and modifies river landforms. Canopy and root architecture, along with the spatial distribution of plants, strongly influence flow resistance and the direction of flows. Additionally, vegetation height and density (i.e., “biovolume” of plants) have a great capacity to retain sediment, which can be frequently reinforced by large woody debris (Gurnell *et al*., 2001; 2006; Corenblit *et al*., 2009b; Politti *et al*., 2018). Due to these reciprocal interactions that riparian vegetation maintains with water flow and fluvial landforms (Figure 1), this vegetation may be considered a major influence on geomorphic changes in river channels and floodplains (Tal *et al*., 2004; Corenblit *et al*., 2007; 2011).

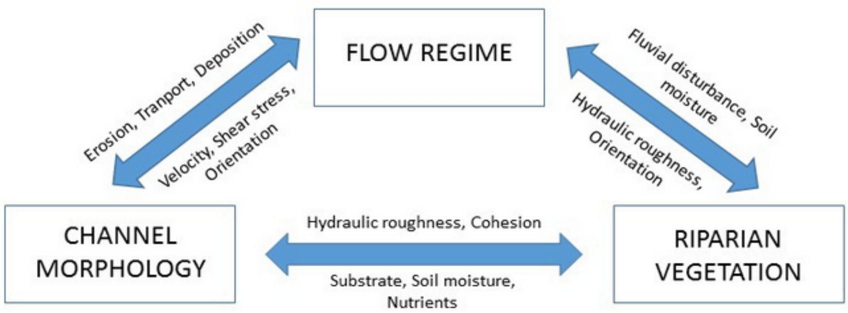

Figure 1. Mutual interactions between flow regime, channel morphology and riparian vegetation that determine fluvial dynamics (adapted from Corenblit *et al*., 2007).

The role of riparian vegetation in river hydromorphology is widely accepted. Consequently, advances in modelling river dynamics have indicated the relevance of including the successive phases of vegetation development to predict channel behaviour and river trajectories over time (García-Arias *et al*., 2013; Van Oorschot *et al*., 2016; Martínez-Fernández *et al*., 2018).

2.2. Riparian vegetation as an indicator of hydromorphological status: Vegetation responses to pressures and impacts

Riparian vegetation is frequently included in environmental river studies as it responds closely to pressures and impacts and may be a good indicator of changes over time. A large body of literature exists on biogeomorphic adjustments to multiple stressors, especially articles that document vegetation responses to flow regulated by dams and reservoirs (Merrit and Cooper, 2000; Williams and Cooper, 2005; Stromberg *et al*., 2007; Bejarano *et al*., 2011; Takahashi and Nakamura, 2011; Aguiar *et al*., 2014; González del Tánago *et al*., 2015; 2016b; Martínez-Fernández *et al*., 2017a; Kui *et al*., 2017; Sanchís-Ibor *et al*., 2018; Yi *et al*., 2019). More recently, an increasing amount of research in applied river science has focused on predicting riparian vegetation trends under different climate change scenarios, considering vegetation as a priority sentinel of future changes in rivers (Politti *et al*., 2014; Rivaes *et al*., 2014; Martínez-Fernández *et al*., 2018).

Basically, riparian vegetation responds to climate (e.g., precipitation, temperature), moisture availability, fluvial disturbances (Stella *et al.*, 2013; Gurnell *et al*., 2015a) and changes in land use (Dufour *et al*., 2019). Environmental changes (e.g., global warming, renaturalization of catchments) and direct human pressures (e.g., flow regulation, groundwater overexploitation, urbanization, floodplain occupation) modify the hydroclimate and fluvial hydromorphology context, and thus trigger changes in riparian communities via species composition, diversity, functional structure and landscape arrangement (Aguiar *et al.,* 2009: Rivaes *et al*., 2013). Changes in the extent of areas vegetated with woody plants at large scales may have hydrological implications by decreasing the magnitude of annual runoff and thus affecting soil moisture and extreme high and low flows (García-Ruiz and Lana-Renault, 2011; Qiao *et al*., 2017).

Vegetation encroachment is one of the most common responses to damming rivers, and an increase in vegetation growth and coverage below dams is often observed (Cooper *et al*., 2003; González del Tánago *et al*., 2015; Räpple *et al*., 2017; Kui *et al*., 2017). The reduction in flood magnitude and frequency due to dams likely promotes channel narrowing, which also increases the area of dense riparian vegetation and decreases the active channel area (Graf, 2006; Takahashi and Nakamura, 2011). However, García de Jalón *et al*. (2020) hypothesized that vegetation encroachment may be a convergent biogeomorphic response to multiple pressures and impacts at different spatial scales, which could occur in both regulated and non-regulated rivers due to different environmental and human-induced disturbances. Vegetation encroachment is also associated with river channelization and dredging and always follows channel narrowing (Stecca *et al*., 2019) and changes in land use (Liébault and Piégay, 2002; Kondolf *et al*., 2007; Dufour *et al*., 2015). Serlet *et al*. (2018) documented vegetation colonization of previously bare gravel bars after channelization along the Isère River (France). In this case, vegetation development decreased the initial instability of the bare gravel bars, which created a new dynamic equilibrium in the channelized river reach.

Replacement of riparian species and terrestrialization effects were observed in response to a generalized decrease in water resources (Santos, 2010; Garófano-Gómez *et al*., 2013). Additionally, altering the timing and frequency of groundwater pumping and the magnitude of flows in arid-zone rivers may induce changes in riparian vegetation by replacing wetland pioneer trees with more drought-tolerant shrubs (Stromberg *et al*., 2007). Chemical water quality can influence riparian vegetation features such as species composition (Salinas *et al*., 2000). Macrophytes and bank vegetation overgrowth are frequently observed in response to an excess of nutrients due to urban or agricultural land use (Grabowski *et al*., 2016; Ochs *et al*., 2018). In addition, nutrient levels in the substrate can significantly influence the survival and growth of seedlings in riparian systems (Adair and Binkley, 2002).

Bejarano *et al*. (2017) observed simpler and most likely fewer riparian vegetation guilds because of flow regulation. Similarly, Aguiar *et al*. (2014) observed changes in riparian functional trade-offs after land-cover changes and hydropower flow regulation, which shifted riparian communities from obligate riparian competitors, with hydromorphic leaves and high tolerance to waterlogging, to facultative riparian species, with physical defences, tap roots and high drought tolerance.

In addition to the studies mentioned, a large amount of literature addresses threats to riparian ecosystems worldwide (e.g., Poff *et al*., 2011) and vegetation responses to global (i.e., environmental) and more local (i.e., human-induced) hydromorphic changes (Stella *et al*., 2013). This emphasizes and supports the use of riparian vegetation as a suitable indicator of channel adjustments (Gumiero *et al*., 2015), potential future stream conditions (Ringold *et al*., 2009), flow conditions (Pike and Scatena, 2010) and riparian and stream conditions (Macfarlene *et al*., 2017). An extended review of the influence of different pressures and impacts on riparian vegetation characteristics and responses is included in Appendix I.

3. RIPARIAN VEGETATION IN HYDROMORPHOLOGICAL ASSESSMENTS AND THE CONTEXT OF THE WATER FRAMEWORK DIRECTIVE

Riparian vegetation is widely accepted as a key element of river functioning. However, the hydromorphological protocols used most frequently to assess the ecological status of rivers, which EU countries must perform to implement the WFD, do not include riparian vegetation descriptors that are adequate for assessing the quality of riparian corridors. In this section, we briefly review the traditional approach used to analyse and classify river systems, which is strongly based on the channel forms and processes created by water and sediment flows, without considering the influence of riparian plants. We then review the hydromorphological context of the WFD and the protocols that are currently used in hydromorphological assessments in European countries.

3.1. Riparian vegetation in traditional fluvial geomorphological assessments

Traditionally, the morphological conditions of rivers were assessed by considering channel forms and fluvial processes but not the presence of riparian corridors (traditional approaches of Leopold *et al*. (1964) and Schumm (1977), or the *Stream Reconnaissance Handbook* by

Thorne (1998)). Consequently, riparian corridors were frequently analysed separately from river channel morphology (e.g., Malanson, 1993), and their assessment addressed mainly riparian zone management (e.g., USDA, 1998; Winward, 2000; NRC, 2002) and did not consider channel morphology and river dynamics.

This traditional approach of analysing river morphology based primarily on channel forms, water and sediments (i.e., hydraulic variables and physical processes) has prevailed until recently. This approach is included in the most frequently used fluvial geomorphology textbooks, in which riparian vegetation is not mentioned for characterizing and classifying river typologies or for predicting river responses and changes in rivers over time (Knigton, 1984; Rosgen, 1994; Brierley and Fryirs, 2005; Charlton, 2008). Although the importance of riparian zones was recognized since the beginning of the development of river ecology concepts (Hynes, 1970; Vannote *et al*., 1980; Junk *et al*., 1989), the traditional channel morphological approach, based only on physical geomorphic features, prevailed in river assessment protocols and river habitat surveys (Thorne, 1998).

This is indicated by the extensive revision of hydromorphological methods by Belletti *et al*. (2015), who compare the smaller number (15) of methods used to assess conditions of riparian corridors to the large number of methods worldwide that explored the physical habitat (73) or channel morphology conditions (22), based solely on flow and channel morphological features. Many of these methods were developed before the WFD was approved, and some of them that were used for several years (e.g., the River Habitat Survey (RHS), Raven *et al*., 1998) seem to have influenced formulation of the hydromorphological context of the WFD strongly.

3.2. Riparian vegetation in the hydromorphological context of the WFD

The WFD considers three hydromorphological elements when assessing the ecological status of rivers:

i) the hydrological regime, more specifically, the quantity and dynamics of water flow
ii) river continuity
iii) morphological conditions, which include variations in river depth and width, structure and substrate of the river bed, and structure of the riparian zone

In this way, riparian vegetation is not explicitly mentioned among the hydromorphological quality elements that support the biological elements, or among the biological elements that are used to classify the ecological status of rivers, which include macrophytes.

Assessment of riparian zone structure should consider the status of riparian vegetation, but the WFD does not specify further details about riparian zones. Consequently, in practice, the EU countries do not have to monitor or assess conditions of riparian vegetation within riparian zones. Consequently, current protocols for assessing the hydromorphological conditions of rivers across many EU countries usually avoid mentioning riparian vegetation as an element to characterize and assess.

Many reasons could explain why riparian vegetation is excluded from the river elements that must be monitored to apply the WFD. Understanding about the interactions between vegetation and water/sediment flows that determine the form and dynamics of river channels has increased since the 1980s (Dufour *et al*., 2019). However, some of the most relevant results, widely disseminated by Gurnell *et al*., (2002 a,b), Corenblit *et al*. (2007, 2009a,b, 2011) and other authors, appeared several years after the WFD. Consequently, we argue that the

WFD was conceived under the traditional geomorphological approach, based on water and sediment interactions, without including vegetation as a third essential element of river dynamics. Therefore, we also argue that the WFD should be reviewed and updated to incorporate knowledge about the influence of riparian vegetation in river hydromorphology that has emerged since its approval.

3.3. Main hydromorphological protocols applied at the national level across EU countries

Each EU country can select its own set of protocols to assess the hydromorphological conditions of rivers. However, several EU countries have maintained the traditional morphological approaches and seem to have a strong influence on the official hydromorphological protocols that have been adopted across EU countries.

We highlight the influence of the RHS, which was developed, tested and has been implemented in the United Kingdom (UK) since 1993. After implementation of the WFD, it was adopted in many other EU countries as the official protocol to assess hydromorphological conditions and has been adapted to local contexts (e.g., Portugal, Ferreira *et al.*, 2011; Slovenia, Tavzes and Urbanic, 2009) and incorporated in specific approaches (e.g., Scotland, www. sepa.org.uk). The RHS is based on the traditional channel morphology survey developed by Thorne (1998). It includes observations of channel features (e.g., substrate, flow, erosion, deposition), bank features (shape and vegetation structure) and land use in the adjacent river corridor (Raven *et al.*, 2002). With this information, the RHS scores habitat quality based on comparisons with benchmark sites the experts judged as the best river habitats in the UK. The RHS also considers modifications to the channel and bank structure and gives penalty points to the resulting habitat quality based on the physical changes observed. The vegetation structure considered in the RHS is based on the following categories: (1) vegetation height (i.e., Bryophytes, short/creeping herbs or grasses, tall herbs or grasses, scrub or shrubs, and saplings and trees), and (2) the variety of existing vegetation types (i.e., Bare soil or artificial bank material; Uniform, which means only one vegetation type; Simple, which means mainly 2-3 vegetation types; Complex, which means 4 or more vegetation types; and Not visible, when the bank is obscured) (www.riverhabitatsurvey.org/manual/rhs-manuals). The method is used extensively in the UK and in other countries, but the information collected on riparian vegetation composition, structure and dynamics is inadequate.

Other hydromorphological methods widely recognized and applied in EU countries have the same limitations for characterizing and assessing riparian vegetation. For example, the LAWA system used in Germany addresses physical habitat assessments and uses 25 attributes that focus mainly on channel morphology and riverbank modifications. Vegetation structure and species composition are only qualified (i.e., ranging from “unchanged” to “completely changed”), based on the German concept of “leitbild” (i.e., natural state that would establish itself in the absence of human interventions). Under the LAWA approach, and for the same reasons as for the RHS, the information on riparian vegetation used in hydromorphological assessments is clearly insufficient. Similarly, the SEQ-PM (Système dÉvaluation de la Qualité du Milieu Physique) in France, or more recently the SYRAH or CARHYCE systems (Gob *et al.*, 2014), record many physical features of channel morphology and riverbanks. However, only the structure using qualitative or semi-quantitative classes, and the longitudinal continuity and coverage of riparian vegetation are assessed (Raven *et al*., 2002; Belletti *et al*., 2015) which do not characterize or assess riparian vegetation conditions adequately.

Rinaldi *et al*. (2013, 2015) developed the Morphological Quality Index (MQI) to assess stream morphological conditions in Italian rivers. Attributes for assessing geomorphological features, artificiality and channel adjustments were considered to score the MQI, but only a few of these attributes were related to the status of riparian vegetation. Geomorphological features were based on 13 indicators related mainly to the longitudinal and transversal continuity of water and sediment flows, natural channel forms and bed substratum. Of these 13 indicators, only 2 were related directly to riparian vegetation, and they considered only its spatial dimensions: i) width of connected functional vegetation in relation to channel width and channel pattern and ii) proportion of the maximum available length that is covered by the linear extension of functional vegetation. Twelve indicators were developed to assess channel artificiality, which were related to the presence of barriers or structures that alter flows and sediments or channel revetments. Only 2 of the 12 indicators were related to riparian vegetation management: i) intensity of woody debris removal in the past 20 years and ii) type of cutting interventions for riparian vegetation. Only channel planform, channel width and bed-level changes were included to assess changes in the channel over time. Changes in riparian vegetation were not considered when evaluating river adjustments. The MQI represents an advanced, process-based approach for assessing river hydromorphology compared to other methods. Nevertheless, it is strongly based on channel morphology and water and sediment flows, and does not adequately consider riparian vegetation as a third essential element of river dynamics and hydromorphological status.

3.4. Current situation of hydromorphological assessment and riparian vegetation monitoring in EU countries

To understand how riparian vegetation is currently monitored and assessed across EU countries, we developed a questionnaire for members of the COST Action CONVERGES to collect information on riparian vegetation. The questions were simply phrased to obtain information on topics related to ownership, legal delineation of riparian zones, main management objectives, official protocols for characterization and assessment, typologies, reference conditions and main pressures and impacts that influence riparian vegetation.

Appendix II includes the questionnaire (Table A-1) and the answers (Table A-2) from Bosnia and Herzegovina (Rahman Nurkovic), Czech Republic (Jiri Jakubinski), France (Simon Dufour), Germany (Stefan Lorenz), Greece (Eva Papastergiadou), Hungary (Timea Kiss), Italy (Nicola La Porta, Andrea Andreoli), Lituania (Ligita Balezentiene), Portugal (Francisca Aguiar, Teresa Ferreira, Patricia María Rodríguez-González), Serbia (Jelena Milovanovic), Slovakia (MIchal Slezak, Maria Sibikova, Anna Kidova), Slovenia (Gorazd Urbanic), and Spain (Vanesa Martínez-Fernández, Idoia Biurrun). The answers to this general questionnaire are summarized in Table A-2 and incorporate additional information extracted from the review of Belletti´s *et al*. (2015).

In several countries (e.g., Greece, Germany, Spain, Czech Republic), the State owns riparian zones, while in others (e.g., France, Portugal, Slovenia, Slovakia) ownership can be shared with a few private landowners under certain conditions, including location, river size and river use. Several countries have laws for delineating riparian zones, such as a fixed width (e.g., France, Germany, Slovakia), a width relative to channel size (e.g., Portugal, Slovenia) or a width relative to ordinary flooding (e.g., Spain).

Ownership of riparian zones implies maintaining them, and both the State and private landowners are responsible for periodic upkeep. Flood control is the main management objective in many countries, and vegetation removal or growth control is a common practice in nearly all countries. Conservation of biodiversity is an objective for certain river reaches with valuable habitats included in the Natura 2000 network, with many sites devoted to conserving floodplain forests along the Danube River. Some countries conserve riparian vegetation as buffer strips to control non-point sources of nutrients and fine sediments from agricultural fields (e.g., France, Portugal).

The answers regarding the main pressures and impacts that influence riparian vegetation status vary among countries. Agriculture is most frequently considered the main driver of riparian zone degradation, followed by urbanization, navigation, grazing and recreational uses (Figure 2). The experts considered land-cover changes as the greatest pressures, followed by channelization, flow regulation, water pollution and groundwater depletion (Figure 3).

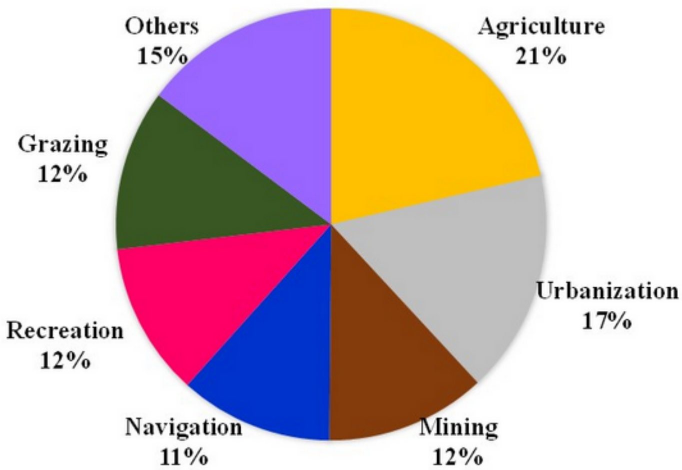

Figure 2. Relative importance (%) of human activities that contribute most to degradation of riparian vegetation in European countries (expert-based assessment; n =17).

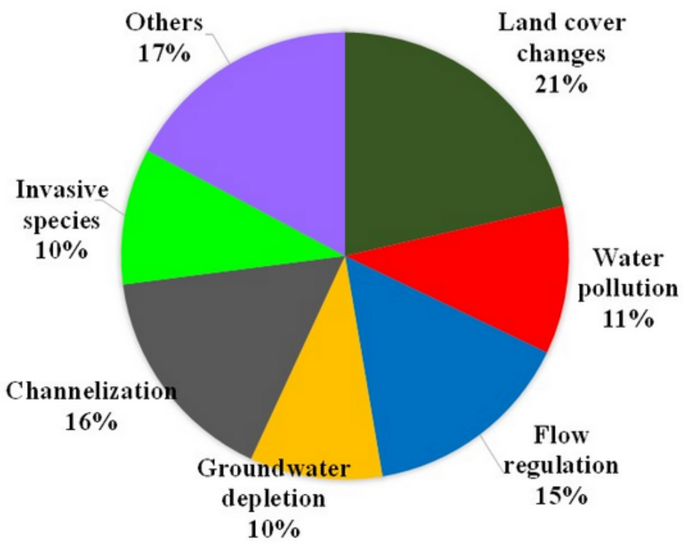

Figure 3. Relative importance (%) of impacts that contribute most to degradation of riparian vegetation in European countries (expert-based assessment; n =17).

The protocols used to characterize and assess riparian vegetation at the national level differ among countries. In general, most collect qualitative information mainly related to the type and structure of vegetation, following the qualitative classes established by the RHS. Nevertheless, other attributes of riparian corridors are sometimes assessed, such as longitudinal continuity, vegetation cover, size and shape of vegetation patches and the presence of woody debris. Most protocols exclude species composition, and additional information such as age structure, distribution along functional zones or data on functional traits is not required.

Based on this information (Table A-2 of Appendix II), we conclude that the official protocols of hydromorphological assessments do not characterize riparian vegetation adequately. As mentioned, this could be because the WFD does not explicitly mention riparian vegetation as a key hydromorphological element. Consequently, the available data on riparian vegetation status at the national scale is inadequate. The data are not valid for explaining trends in riparian degradation, predicting future riparian status or designing riparian restoration actions within European countries.

4. NEED FOR MULTI-SCALE CHARACTERIZATION OF RIPARIAN VEGETATION STATUS

4.1. Riparian vegetation dynamics across spatial scales: A multi-scale approach

The dynamics of riparian vegetation are influenced by a complex combination of reciprocal interactions between water and sediment flows, which interact within the fluvial landscape (e.g., valley settings, land cover and uses of the valley floor) and ultimately depend on the external hydrological context of the catchment (e.g., runoff and sediment production, geology, land cover) (Gurnell *et al*., 2015a). These dynamic relationships are organized hierarchically in a nested way and respond to distinct fluvial processes and active forms that emerge at different spatial and temporal scales (Beechie et al., 2010; González del Tánago *et al*., 2016a). Although riparian ecosystems respond and change mainly across the transversal gradient of flood disturbance (Steiger *et al*., 2005), they also reflect hydromorphological constraints across the longitudinal and vertical gradients of river systems (Ward *et al*., 2002). Riparian vegetation species and communities are subjected to multiple hydromorphological features which occur over a range of spatial scales, from the large scale, i.e., region or catchment (e.g., climate and biogeographic contexts, topography and hillslope processes), to the more local scale, i.e., reach or geomorphic (e.g., moisture availability and fluvial disturbance constraints) (Gurnell *et al*., 2015a).

The hierarchical framework developed in the EU REFORM project follows a multi-scale conceptualization of river systems to characterize and assess river hydromorphology in European rivers (Gurnell *et al.*, 2015b; González del Tánago *et al*., 2016a) (Figure 4). Within a catchment, which is delineated by its water divide, different "landscape units", each with a relatively similar pattern of topography and land cover, may be identified following the traditional longitudinal zonation of river systems into zones with relatively homogeneous longitudinal slope and channel style. Within each landscape unit, different "river segments" may be identified along the main channel, each with a homogenous geological context, valley setting and patterns of flow and sediment regime, which likely correspond to river sections between confluences of significant tributaries. Within each river segment, different "river reaches" may be identified assuming relatively homogenous internal assemblages of geomorphic units and channel forms. In the other side, a larger scale than the catchment can be considered the biogeographic region, which would be determined by broad climate, geological and land-cover features, and would determine the potential pool of riparian species.

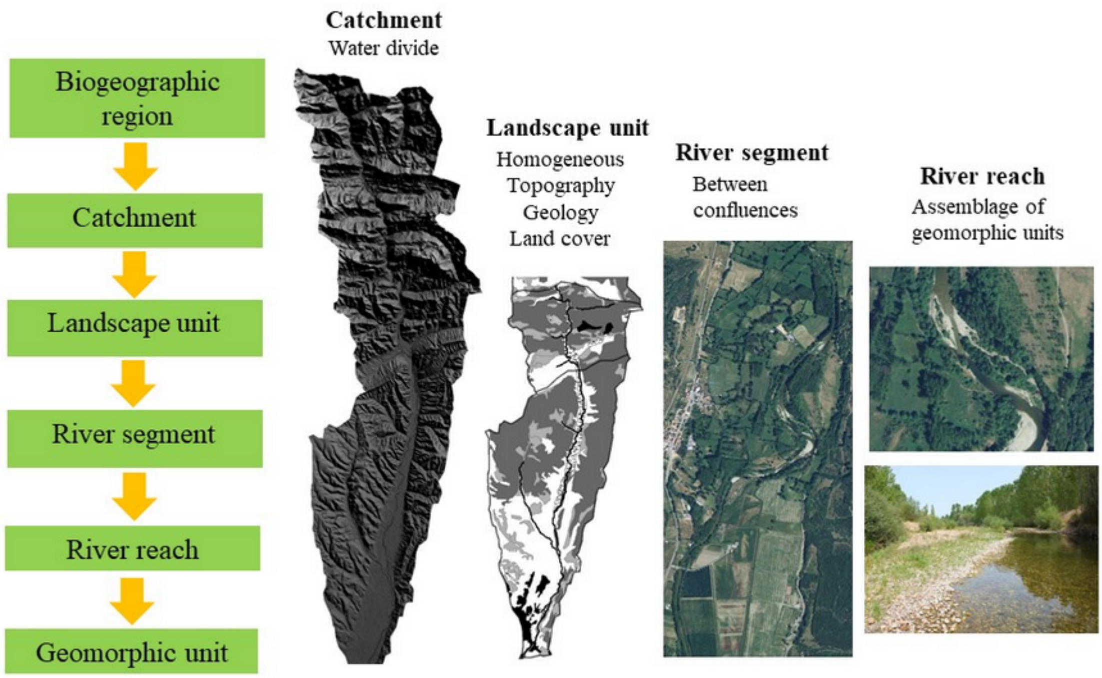

Figure 4. Multi-scale hierarchical approach for hydromorphological studies, which was developed within the REFORM Project (Gurnell et al. (2015b) and could be used to characterize and assess riparian vegetation at multiple spatial scales.

The cascade of hydromorphological processes and landforms that ultimately emerge along these spatial scales frame the conditions of riparian vegetation development and succession, as the result of continuous feedback mechanisms that determine recruitment, establishment, growth and mortality processes (Figure 5). Following an up-scaling approach from the reach to the catchment, we assume that the recruitment and establishment of pioneer species (e.g., Salicaceae species) that occur in certain bare gravel bars (i.e., habitat mosaics, geomorphic units) are promoted by flood disturbance and geomorphic unit re-creation at the local scale (e.g., site specific shear stress, flood frequency) (Karrenberg *et al*., 2002). The occurrence of bare gravel bars depends on the variability in the flow regime (e.g., high and low flows magnitude and frequency) and coarse-sediment availability (i.e., sediment supply, largewoody debris supply), which vary greatly among river segments. Both flow regime and sediment supply are related to runoff and erosion processes that result from the hydrological conditions of each landscape unit (i.e., hillslope processes) and are ultimately influenced by the climate, geology and land-cover and -use conditions in the catchment. Similarly, vegetation growth and development in certain river reaches is promoted by local soil-moisture availability associated mainly with riparian soil texture, nutrients and groundwater-surface water interactions. These local substrate and moisture conditions are determined by sediment supply and fluvial disturbance patterns in the river segment, which in turn are driven by the erosion processes and hydromorphological context of the respective landscape unit and catchment. Vegetation mortality, mainly due to continuous flooding, desiccation, or burial or scour forces, depends on the flood hydrograph, water depth and velocity thresholds exceeded at the local scale, which are determined by local topography and substrate conditions. Plant mortality is ultimately caused by interactions between water and sediment flow regimes and the channel morphology framed by the valley setting, which vary among river segments. Both water and sediment flows are created by runoff and erosion processes within the respective landscape units, which depend on climate, topography and land-cover conditions across the catchment.

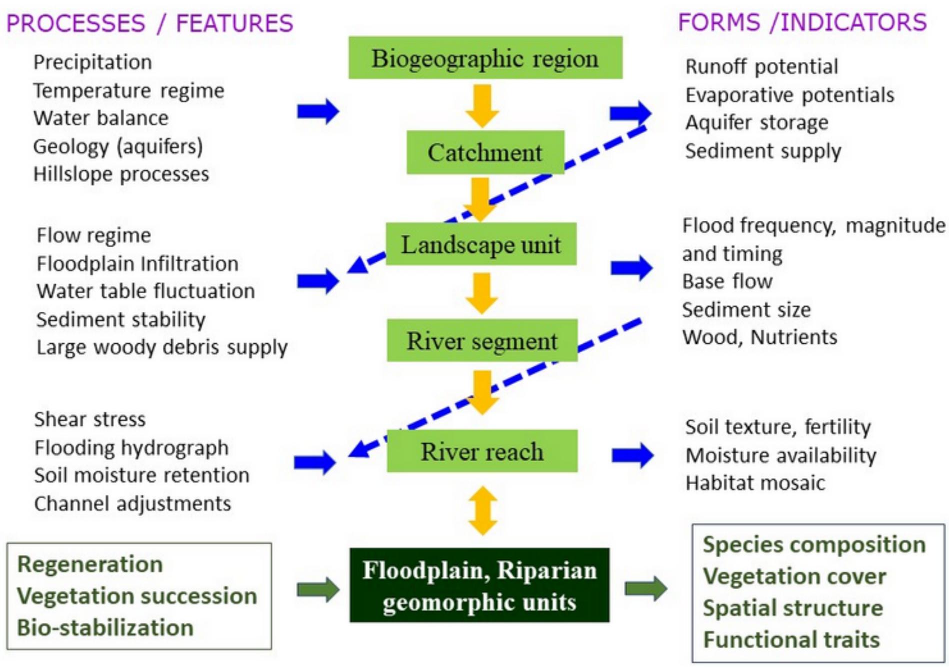

Figure 5. Hierarchical cascade of hydromorphological processes and forms that interact with seed dispersal, recruitment, growth and mortality of riparian vegetation and determine the coverage, composition and structure of riparian vegetation at certain time, and the succession of riparian communities overtime (adapted from González del Tánago *et al.*, 2016a).

4.2. Potential vegetation units, indicators and analysis approach for characterizing riparian vegetation at multiple scales

Different vegetation units can be used to characterize and assess the status of riparian vegetation at the spatial scales mentioned previously (i.e. from the local site to the catchment) and at different temporal scales (i.e., turnover ratios of the respective vegetation unit) (Figure 6).

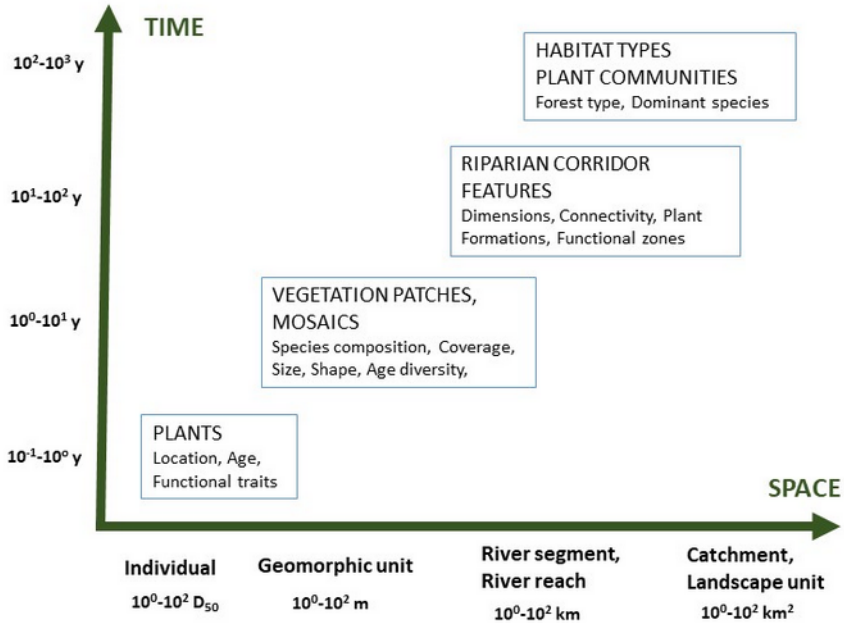

Figure 6. Vegetation units used to characterize riparian vegetation at different spatial scales (km^2 of catchment, km or m of river length, D_{50} cm of grain size) and approximate temporal (years) scales

Within vegetation units, many potential attributes can be used as indicators of the riparian vegetation status of rivers. In general, these attributes represent measures of how riparian vegetation is structured and provide insights into how river hydromorphology creates the spatial arrangement of habitats and vegetation forms (static perspective of riparian vegetation structure). The attributes can also indicate how riparian vegetation interacts within the river system and how river hydromorphology promotes fluvial processes and riparian vegetation dynamics (dynamic perspective of riparian vegetation behaviour).

The same attributes can be used to provide insights into changes in rivers over time by assessing past changes in riparian vegetation that resulted from natural or human-induced disturbances. They can also be used to predict future changes in riparian vegetation for expected vegetation trends under scenarios of river management practices or climate change.

From a practical viewpoint, three approaches can be used to assess riparian vegetation indicators: 1) plant taxonomy, 2) spatial landscape structure of vegetation mosaics and 3) dominant processes that create and maintain vegetation patterns (Table 1). Each approach requires different methods and expertise. Riparian analysis based on taxonomy requires expertise in botany and in identifying species to differentiate families, genera and species of the most common riparian species. Riparian studies based on landscape analysis require expertise in GIS and remote sensing, with the ability to quantify characteristics of spatial vegetation mosaics automatically. Riparian studies that focus on dynamics of riparian zones require expertise in fluvial geomorphology, as well as the ability to identify riparian species and basic knowledge on their hydromorphological requirements.

Table 1. Potential indicators used to characterize riparian vegetation at different spatial scales, under different analysis approach.

ANALYSIS APPROACH *(MAIN DATA SOURCE)*	PLANT / PATCHES RIVER REACH (0.1-1 km)	RIPARIAN CORRIDOR RIVER SEGMENT (1-10 km)	CORRIDOR / FOREST TYPES LANDSCAPE UNIT / CATCHMENT (10-100 km^2)
Taxonomy based *(field work)*	Species composition, Abundance, Diversity	Plant formations, Plant communities	Phytosociological classes, Habitat types, Dominant species
Landscape-mosaic approach *(GIS analysis)*	Size, Shape, Coverage, Relative location to channel, Spatial distribution	Riparian corridor width, overage, Connectivity, Fragmentation	Corridor types, Spatial assemblage of patches, Landscape diversity
Functional approach (process-based) *(field work + GIS analysis)*	Pioneer recruitment areas (size, location), Plant functional traits, Genetic diversity	Functional zones based on dominant fluvial processes, Vegetation guilds	Broad Longitudinal / Transversal zonation of Plant communities, Broad location of Pioneer / Late-seral species

Species composition.

Species composition should be the basic information used to describe existing riparian plants in an area; it can be used to infer riparian vegetation types, formations and associations, dominant species or phytosociological classes. Once species are identified, other quantitative attributes of riparian vegetation, such as species richness, diversity, and percentage of exotic species, can be calculated for each spatial unit in a catchment. Although some advances have been made in using remote sensing to identify species (e.g., Rodríguez-González *et al*., 2017), field work is usually required to describe plant communities at the local scale. However, at larger scales, existing maps and documents can be used to characterize phytosociological classes in riparian corridors.

Traditional approaches for environmental assessments are based on the indicator value of species according to their tolerance to pressures and impacts (Karr *et al*. (1986) for fish communities, Wright *et al*. (1988) and Smith *et al*. (1999) for macroinvertebrate fauna). The WFD includes species composition, along with abundance, as one of the quality elements needed to classify the ecological status of rivers, referred to as biological elements (i.e., aquatic flora, benthic invertebrate fauna and fish fauna). For riparian vegetation, the WFD does not require identifying species to describe riparian communities as a component of the quality of the riparian zone; consequently, species composition is not included in current monitoring protocols. This is a serious omission, not only due to the intrinsic ecological relevance of riparian vegetation, as mentioned previously, but also because restoration measures often include interventions that use riparian vegetation, which is not monitored or assessed.

Landscape mosaics.

Spatial metrics obtained by GIS based on aerial photographs or remote sensing sources (Fernandes *et al*., 2011; Dufour *et al*., 2012; Rodríguez-González *et al*., 2017) are an interesting approach to analysing riparian vegetation. They are frequently used to document changes in riparian corridors over time. At the large scale, total coverage is frequently reported as one of the easiest vegetation characteristics for tracking temporal changes over time via diachronic analysis (González del Tánago *et al*., 2015). Several authors have used other spatial measures that are relatively simple to obtain using GIS and can differentiate distinct vegetation structures likely related to pressures or impacts. They include the number of vegetation patches, the size and shape of patches, and distance among patches (Aguiar *et al*., 2011). These spatial measures require manual or automatic delineation of vegetation patches. As these measures can vary greatly along the river course, they normally represent riparian vegetation characteristics at segment or reach scales.

Functional zones.

Functional and process-based indicators of riparian vegetation status can be derived from the typology and dimensions of the functional zones defined by Gurnell *et al*. (2015a). These authors suggest considering five functional zones along river channels, with each zone typically created and maintained by different dominant fluvial processes. These five zones change along river corridors according to available space (i.e., valley confinement, human floodplain occupation) and river types (i.e., channel planform based on valley width, valley slope, sediment size, etc.). Zone 1 corresponds to the permanently flooded area, with high sediment dynamics, where aquatic plants are currently established. Zone 2 corresponds to the contiguous area which is frequently flooded but also has high sediment dynamics (coarse substratum). It typically contains emergent riparian macrophytes and pioneer woody species that tolerate frequent floods, scour and burial. Zone 3 is frequently flooded and has significant sediment deposition (fine substratum). It contains riparian plants that tolerate frequent flooding and moderate sedimentation. Zone 4 represents areas that are occasionally flooded, but have no significant sediment dynamics. It contains riparian plants that have varying flood tolerance depending on the local microtopography and are considered late-seral riparian species. Zone 5 corresponds to the more distal area of riparian corridors in which flooding is absent or extremely rare, soil moisture is fed mainly by subsurface or groundwater runoff and plants tolerate local soil moisture and the alluvial/groundwater regime, and connect with terrestrial hillslope species. The existence and dimensions of these five functional zones, along with their respective species composition and age structure, may closely reflect the effects of current hydromorphology in riparian corridors. For example, changes in the flow regime due to dams and reservoirs are likely to promote gradual disappearance of Zones 2 and 3 and trigger vegetation encroachment. This would result in extending Zone 4 to the channel banks and development of late-successional plant formations in the proximal riparian zones, which would replace the initial pioneer-species riparian formations (Martínez-Fernández *et al*., 2017b) (Figure 7).

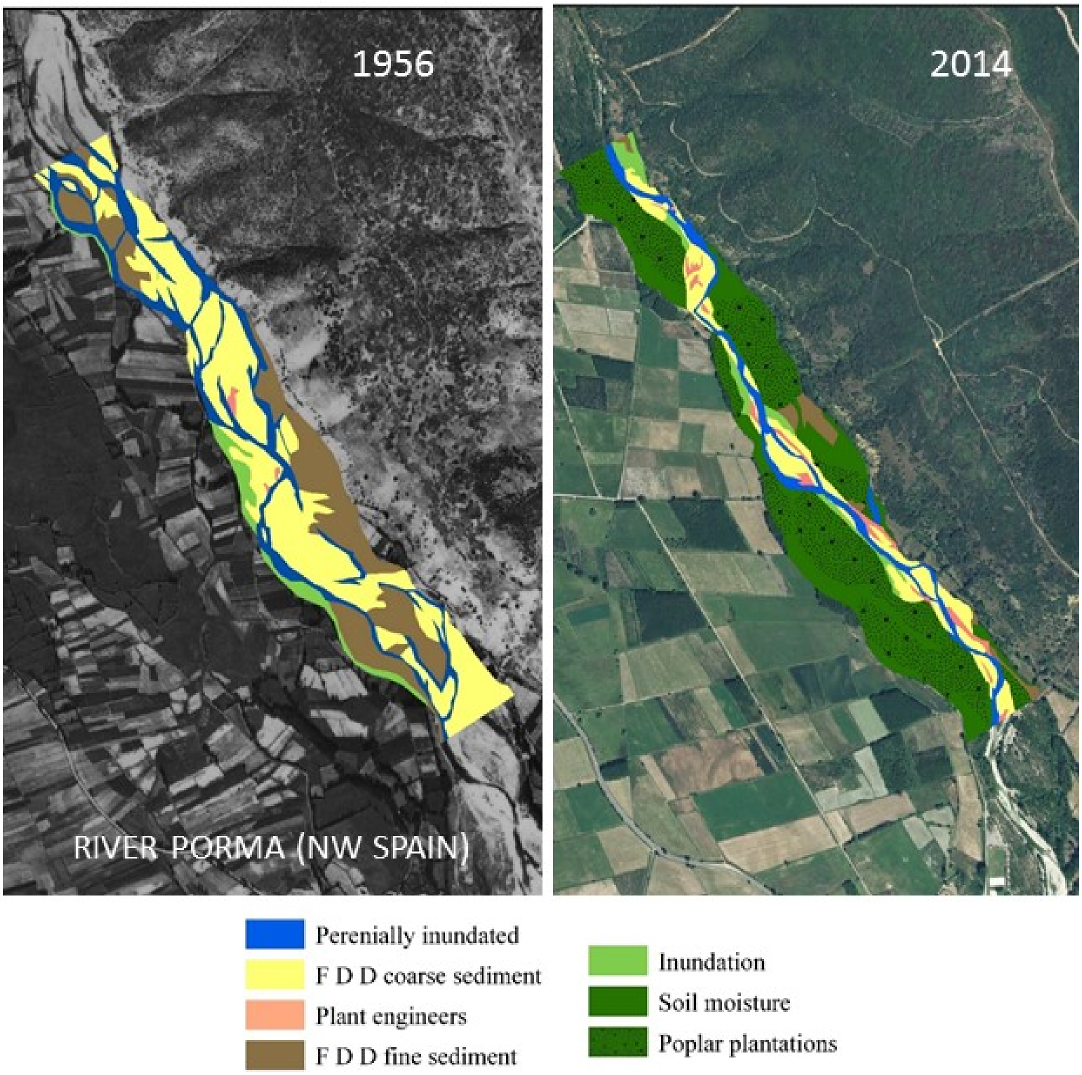

Figure 7. Example of identification of functional zones in the Porma River (Spain), based on dominant fluvial processes defined by Gurnell *et al*. (2015a) (i.e, perennially flooded, fluvial disturbance dominated (FDD) with coarse sediments, FDD with fine sediments, flooding dominated and soil moisture regime from subsurface runoff dominated).

Apart from the functional riparian zones, we also consider other riparian vegetation attributes that indicate their dynamics and river functioning. Floodplains and riparian zones are generally dynamic environments where erosion and deposition processes periodically remove older vegetation and create new bare locations for recruitment of pioneer species (Hughes *et al*., 2009). Thus, age diversity (i.e., frequency distribution of ages of a species in an area of habitat; Richards *et al*. (2002)), the extent and location of areas with pioneer recruitment, or percentage of area covered by late-seral species or mature forest compared to that covered by early-seral species or young stands, may be indicators of channel dynamics, heterogeneity of successional stages or temporal trends of riparian vegetation (Garófano-Gómez *et al*., 2017).

Functional traits.

Functional traits of riparian species have also been included in riparian vegetation assessments as a complementary approach to the species-based analysis, which may be relatively simple and inexpensive but does not adequately capture relevant underlying ecosystem processes

(Brooks *et al.*, 2002). A functional traits approach 1) relates riparian structure to ecological processes and 2) compares different bioclimatic contexts (related to biogeography and different regional pools of species).

Common functional traits of riparian species used in riparian forest studies include height, dispersal, diaspore characteristics, phenology in relation to flood-pulse timing, seed size and production, growth rate, tolerance to disturbance, etc. Species traits reflect different aspects of available resources and habitat requirements, and thus may be good indicators of complex patterns of hydromorphological changes (Kyle and Leishman, 2009). Seed and germination traits can determine plant distribution patterns (Leyer and Pross, 2009), while niche differentiation traits (e.g., flowering time) and competitive hierarchy traits (e.g., plant height, seed mass) can predict the potential coexistence of native species with invasive species (Fried *et al*., 2019). Functional diversity indices have been used more frequently in recent years to assess environmental and human-induced impacts on functional diversity in riparian forests (Bruno *et al*., 2016; Lozanovska *et al*., 2018). Among them, functional richness, functional evenness and functional divergence are used most frequently, although their ability to explain or predict riparian community responses to environmental or human-induced functional changes can vary greatly (Lozanovska *et al*., 2018).

4.3. Understanding riparian vegetation responses to multiple disturbances

The multi-scale approach for characterizing riparian vegetation using vegetation units and indicators shown in Figure 6 and Table 1 facilitates understanding of riparian vegetation responses to natural or human-induced disturbances. At each spatial scale, the main hydromorphological features and processes are likely to influence certain riparian vegetation features or attributes (Figure 8). Disturbances may alter these vegetation features and directly interact with riparian plants (e.g., plant removal and species replacement due to overgrazing) or indirectly alter riparian vegetation characteristics by modifying the respective hydromorphological processes (e.g., riparian plant desiccation or terrestrialization because of decrease in riparian soil moisture due to flow regulation or overexploitation of groundwater).

SPATIAL SCALE	HYDROMORPHOLOGICAL PROCESS/VARIABLES	VEGETATION INDICATORS	DISTURBANCES/ PRESSURES
CATCHMENT LANDSCAPE UNIT	Precipitation, Evapotranspiration Topography/Landforms Land Cover, Land Uses Hillslope runoff, Aquifer storage Erosion processes, Sediment supply	Phytosociological classes, Habitat types Dominant species Longitudinal /Transversal zonation of plant formations	Global (climatic) changes, Warming Land Cover changes Wildfires Road construction Irrigation, Overgrazing
RIVER SEGMENT	Valley-settings interactions Flow regime, Sediment budget Channel size and planform Channel adjustments Sediment size, Alluvial depth Floodplain sediment erosion /deposition Water table fluctuation	Plant communities Corridor width, coverage Connectivity, Functional zones based on dominant fluvial processes Patch structure Landscape complexity	River damming Flow regulation Water abstraction Channelization Dredging, Gravel mining Floodplain occupation Groundwater depletion
RIVER REACH	Flood frequency and duration Shear stress Riparian soil texture Soil moisture Burial and scour processes	Species composition, Diversity Size, Location to channel Recruitment areas Plant functional traits Genetic diversity	Embankments, Dredging Channel revetments Weirs, check-dams Floodplain sealing, Debris filling Plantations

Figure 8. Process-based summary of multi-scale vegetation indicators resulting from hydromorphological processes and the potential influence of disturbances at the respective spatial scales.

Characterizing riparian vegetation attributes at different spatial scales and different periods can detect changes over time (Figure 9). The observed changes could be associated with specific human-induced disturbances occurring at the reach or segment scale (e.g., construction of dams and reservoirs, channelization) or at larger scales (e.g., land-cover changes within a catchment, regional hydrological decrease). Detailed information on the magnitude and timing of disturbances at their respective scales, including biological invasions and pandemic pests/diseases, will give valuable insights to relate altered fluvial processes and vegetation changes. This could help to the diagnosis of riparian vegetation status, understand the trajectory from the past and predict the most likely future trends under different management scenarios and hydrological contexts (Figure 9).

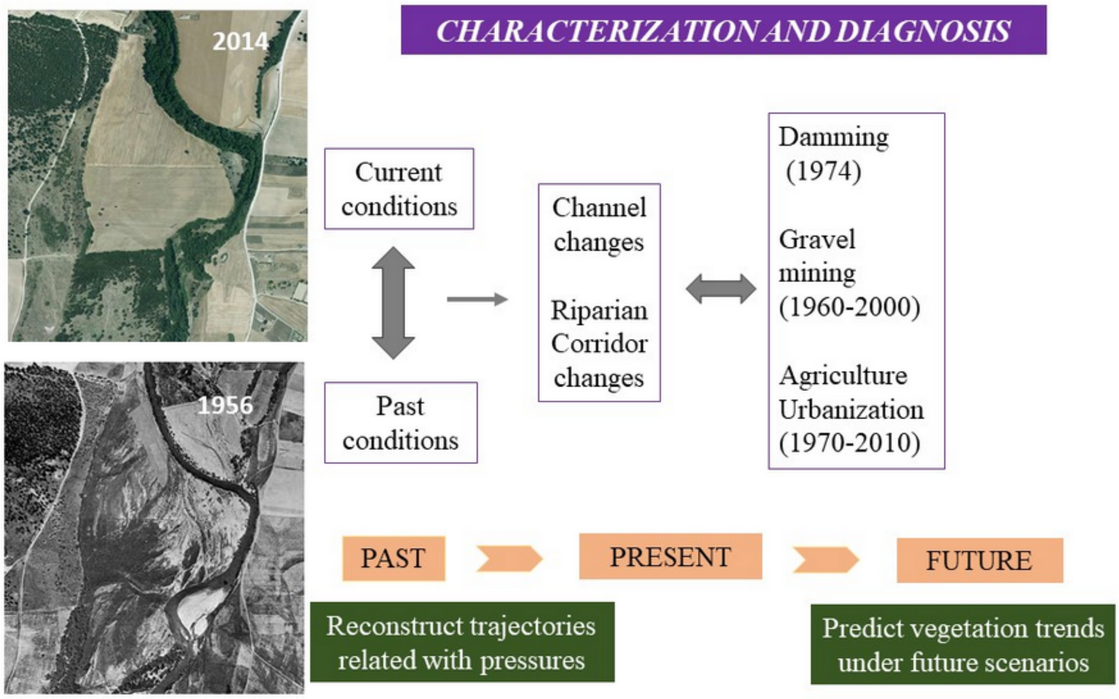

Figure 9. Conceptual diagram of characterization and diagnosis of riparian vegetation status based on changes related to disturbances at different spatio-temporal scales. Understanding trajectories from the past of the riparian corridor, as responses to disturbances, can help predict future trends under scenarios of river management practices and climate change.

4.4. Potential indicators for assessing riparian vegetation status in hydromorphology

Assessing the status of riparian vegetation is a further step from characterization and diagnosis (i.e., accurate statement of causes and effects) and requires additional information that is often complex and difficult to obtain. Riparian vegetation status is characterized using an objective quantitative or qualitative description of vegetation attributes that are relatively simple to verify. Assessing riparian vegetation status requires comparing the quality of vegetation conditions to a previously established reference or target condition, which can be difficult to describe. Once differences between the current status and reference status are quantified, thresholds between the classes of status quality (e.g., very good, good, fair, poor, very poor) are defined. This, along with the reference or target condition, may be subjective and usually has great uncertainty (Figure 10).

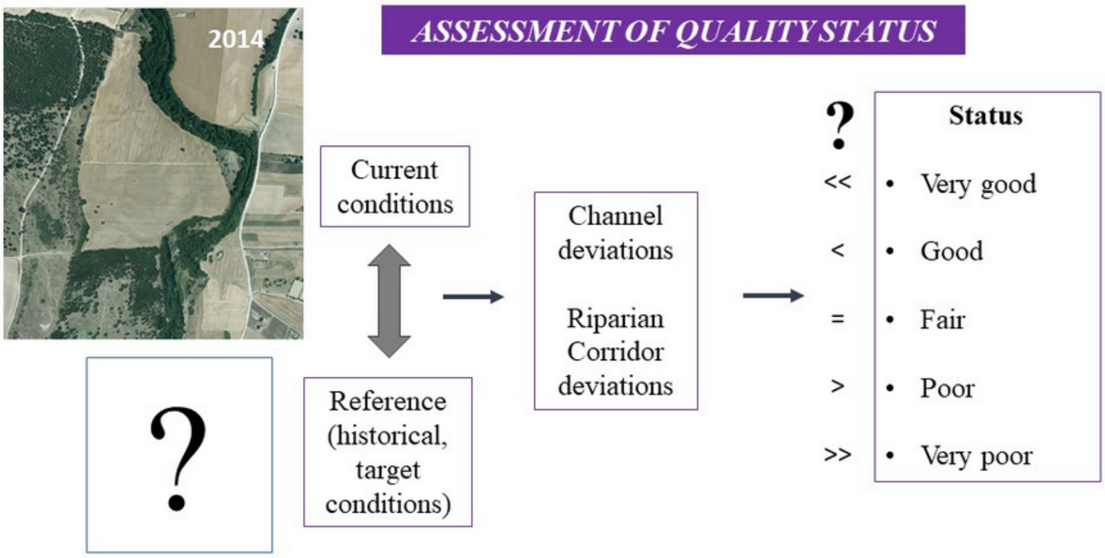

Figure 10. Assessment of the current riparian vegetation status, which is compared to reference conditions, based on natural, historical or target conditions, and according to thresholds of the quality status.

As mentioned, environmental assessments require knowing current conditions as well as defining conditions that correspond to similar sites, but in the absence of degradation, or correspond to the desired or targeted conditions. These theoretical "healthy" or reference conditions, which serve as controls that are compared to current conditions, may combine historical conditions and always consider unavoidable human influence (Dufour and Piégay, 2009) and the best possible conditions that are expected at a given site site (based on explicit quality objectives, section 5.4).

Defining references for riparian vegetation requires prior identification of river types based on geomorphological features. Rinaldi *et al*. (2016) developed a river classification system that could be useful for this purpose. It includes morphological features (i.e., valley confinement, planform pattern and bed material size), floodplain typologies based on formation processes (i.e., bankfull unit stream power, floodplain form and material size), flow regime types based on intermittency and prevailing type of flow source (i.e., hydrological regime based on magnitude, frequency, and timing of flows) and groundwater-surface water interactions.

Based on the river typology and hydro-geomorphic context of the catchments, theoretical riparian vegetation types and features can be predicted as "natural" communities (i.e., spontaneous in the absence of direct human interventions). At the catchment scale, biogeographical studies that provide information about spatial distribution patterns of species, along with advanced studies of vegetation functional traits, could be used to identify vegetation types, riparian plant formations and associations along the river corridor at the regional scale. Similarly, valley settings, the river planform and flow regime patterns can help to identify the species composition and structure of vegetation patches along river segments. Sediment size, channel geometry and flood disturbance regime at the reach scale can theoretically infer local riparian vegetation features based on species composition of functional zones, spatial distribution of pioneer species, or location and dimensions of dominant riparian guilds.

The second stage of the assessment entails establishing thresholds of deviations from the reference conditions that correspond to the discrete quality classes of vegetation status. This second stage may involve different approaches, such as considering individual criteria of artificiality vs. naturalness in taxonomic features (e.g., presence and abundance of obligate species, percentage of invasive alien species), landscape features (e.g., fragmentation, encroachment) or functional features (e.g., changes in functional diversity, riparian guilds, natural recruitment), or defining multicriteria indices whose combined quantitative range of values can be divided evenly into classes of quality status.

To explore which riparian vegetation indicators to include in river hydromorphological assessments, we distinguish vegetation attributes that are related more to riparian ecosystem "functionality" as a proxy of naturalness (assuring riparian functions and ecosystem services) from other attributes that are related more to riparian ecosystem "artificiality" (reflecting human pressures and impacts that induce changes in riparian vegetation not observed in reference conditions). A variety of potential indicators of functionality and artificiality can reflect the status of riparian vegetation at different spatial scales (Table 2). These indicators are selected according to several criteria: quantifiable, with the highest values corresponding to the highest functionality (i.e., best status) or highest artificiality (i.e., worst status), independent and not inter-correlated (i.e., functionality attributes independent from artificiality attributes). In general, high values of functionality are expected to occur with low values of artificiality. Measuring these attributes provides qualitative assessment of vegetation responses to fluvial processes induced by natural or human-induced disturbances. A future list would need to be supplemented and validated for a wide range of geographical conditions.

Table 2. Potential indicators to assess the status of riparian vegetation as responses to pressures and impacts at the respective spatial scales. Applicability must be adjusted to bioclimatic/geographic contexts, river types and other specific features which could determine the status of riparian vegetation at certain spatial scales (i.e., assessment of each indicator is always based on what is expected to be "natural" or spontaneous at each river site).

<table>
<tr><th rowspan="2">SPATIAL SCALE</th><th colspan="2">RIPARIAN VEGETATION INDICATOR</th><th rowspan="2">PRESSURES / IMPACTS</th></tr>
<tr><th>FUNCTIONALITY</th><th>ARTIFICIALITY</th></tr>
<tr><td>CATCHMENT

LANDSCAPE UNIT</td><td>Native[1] riparian plant formations:
• Dominant species
• Diversity</td><td>Human-induced plant formations:
• % exotic species
• % valley floor occupation</td><td>Land-cover changes at larger scales:
Agriculture
Grazing
Urbanization
Groundwater overexploitation
Mining</td></tr>
<tr><td>RIVER SEGMENT</td><td>Riparian corridor features:
• % floodplain with native riparian communities
• Diversity of vegetation patches (landscape complexity)
• % of functional zones dominated by fluvial erosion and deposition processes, according to valley settings</td><td>Alteration of riparian corridors:
• % artificially fragmented or disconnected corridor
• % forest plantations (e.g., poplars) or managed vegetation
• % functional zones dominated by fluvial processes that do not correspond to the respective location according to river typology</td><td>Flow regulation
Water abstraction
Channelization
Dredging
Floodplain occupation
Gravel Mining</td></tr>
<tr><td>RIVER REACH</td><td>Riparian vegetation mosaics:
• % expected species composition and abundance depending on river typology and site
• Diversity of age classes
• % area of pioneer species recruitment</td><td>Alteration of riparian vegetation mosaics:
• Coverage of late-seral species[2]
• % of terrestrial species
• % of nitrophyllous and ruderal species
• % dead trees[3]
• % artificial vegetation reproduction or plantations</td><td>Flow regulation
Channelization
Channel revetments
Pavements
Bank elevation
Fillings
Excavations
Water pollution
Local grazing</td></tr>
</table>

[1] Native for the given biogeographic region and river typology

[2] To use in artificially stabilized or regulated rivers

[3] To use when high mortality is related to human influence

5. GUIDELINES FOR IMPLEMENTING THE PROTOCOL TO CHARACTERIZE RIPARIAN VEGETATION AT MULTIPLE SCALES SUPPORTING ITS FURTHER ASSESSMENT

This section includes guidelines for implementing the multi-scale characterization of riparian vegetation status, as a basic step for its diagnosis and further assessment. Our final objective would be to encourage the full incorporation of riparian vegetation as a third hydromorphological element considered in the context of the WFD, along with flow regime and channel morphology, supporting the biological elements for the classification of ecological status of rivers.

5.1. The river reach as the basic unit of study

Following the general criteria for river hydromorphological assessments (Rinaldi et al, 2013; Gurnell et al., 2015b; Rinaldi et al., 2016), we assume that the river reach is the initial and basic unit of study for characterizing and assessing riparian vegetation. Characterizing the reach requires additional information about influences at larger scales. To do so, it is necessary to consider the nested hierarchical influence of the river segment in which a river reach is located (i.e., flow regime and valley settings); the influence of the landscape and drainage area, which represent the ultimate water and sediment sources for the reach (i.e., based on precipitation regime, topography, geology, land cover); and the influence of the bio-climatic region, which determines the potential plant species and vegetation types that inhabit the reach. Multiple criteria are used to delineate river reaches, river segments and landscape units (Figure 11).

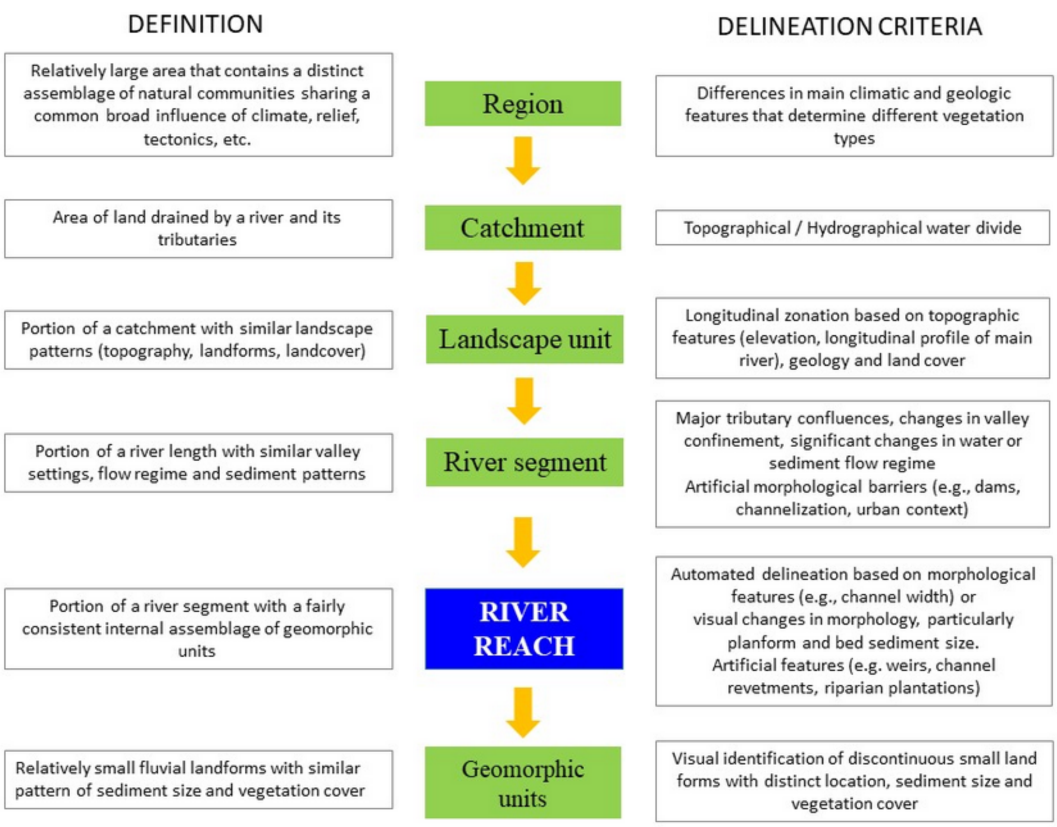

Figure 11. Definitions and delineation criteria for understanding and characterizing riparian vegetation at multiple spatial scales.

5.2. Measuring riparian vegetation indicators in the field and in the office: Characterization of current and past conditions

The spatial scales used to characterize and assess riparian corridors should reflect the purpose of the riparian vegetation study. Nevertheless, up-scaling analysis of indicators is required to understand the cause and effects of the observed features adequately (Table 1 and Figures 6 and 8). At the catchment scale, information on riparian vegetation types and dominant plant formations provide basic information on riparian zones. However, riparian zones are usually monitored at the river-segment scale (e.g., the "water body" scale in the context of the WFD), which requires more detailed information on plant communities of vegetation patches and their spatial arrangement. Use of remote sensing data (e.g., aerial photographs, LIDAR) can help estimate attributes of riparian vegetation, such as average riparian corridor width, height, coverage, continuity vs. fragmentation, and the location and dimensions of functional zones.

At the scale of reaches within river segments, additional information on riparian vegetation can be obtained on composition and abundance of species, from which complementary metrics can be estimated (e.g., species richness, diversity, % exotic species, % obligate vs. facultative riparian species, functional trait diversity). For riparian vegetation dynamics and succession, information on age structure (e.g., pioneer recruitment, age diversity, % mature forest) and its relation to hydrological processes (e.g., dimensions and species composition of functional zones, main location of species, distance and elevation from the bank channel, pioneer recruitment areas related to recent flooding events) is necessary to understand and predict future trends of riparian corridors.

The same approach for characterizing riparian vegetation should be applied to both current vegetation conditions (section 5.2) and conditions in the past (e.g., pre-pressure/pre-impact periods) using the information available for this purpose (e.g., aerial photographs, documents).

5.3. Identification of temporal changes and related pressures and impacts: Riparian vegetation diagnosis

Comparing past conditions to current ones can identify and quantify the magnitude and relevance of temporal changes. It can also identify the spatial and temporal scale at which these changes occur, including potential delay in vegetation responses and turnover ratios of vegetation units (Figure 6). Knowing the pressures and impacts that occurred during previous periods and quantifying the resulting hydromorphological changes could provide valuable insights into the changes observed and explain the current status (Figures 5 and 8). Understanding the potential relationships between pressures and impacts and changes in riparian vegetation over time will lead to a proper diagnosis of the state of riparian vegetation and help to formulate efficient management practices.

The analysis of riparian vegetation pressures and impacts requires detailed information of multi-scale potential drivers:

(1) flow regime changes due to dams and reservoirs, water transfers and groundwater depletion (e.g., changes in timing, magnitude and frequency of high and low flows)
(2) intensity of channelization (i.e., realignment, channel revetments and dredging)

(3) changes in land cover and use in riparian and floodplain areas (i.e., expansion of agriculture, forestry, grazing)
(4) significant changes in land cover and land use (i.e., renaturalization) at landscape or catchment scales
(5) significant changes in runoff and sediment production associated with reforestation, erosion control, a decrease in grazing, or larger-scale global changes

A parallel analysis of channel morphology and riparian vegetation responses is also required to quantify:

(1) changes in active channel morphology and dimensions (e.g., changes in channel typology due to changes in channel sinuosity, braiding index or channel width)
(2) river adjustments (e.g., narrowing, widening, incision, aggradation)
(3) changes in riparian corridor dimensions, coverage, continuity or encroachment
(4) changes in riparian vegetation plant formations, functional zones or mosaics
(5) changes in riparian vegetation species composition and population structure (e.g., age structure, genetic diversity, sex ratios).

5.4. Identifying deviations from reference or target conditions: Riparian vegetation status assessment

Riparian vegetation assessment compares the current status to a reference status, which is considered natural or slightly modified by human interventions, or affordable and realistic (i.e., what should exist). The theoretical reference or target conditions can be based on past or historical conditions that existed before pressures and impacts, or from predicted, simulated or target conditions that are considered to have “good” or “very good” ecological status. The difference between the current and “good” or “very good” conditions can indicate the current status, which is always expressed relative to the reference conditions (Figure 10). Indicators of artificiality (Table 2) can also help assess deviations from the reference or slightly human-modified riparian conditions.

A final step in the riparian vegetation assessment procedure can be to apply quantitative scores to classify deviations from reference conditions and rank current statuses (e.g., from best to worst). Differences between current and reference statuses can be scored according to quantitative criteria (e.g., percentage deviation) or qualitative criteria (e.g., in relation to thresholds of specific features).

Given the purpose of monitoring and assessment, attributes of ecological functioning of riparian vegetation can be assessed separately from attributes of artificiality (Table 2). Similarly, other approaches for assessing riparian vegetation status such as those based on ecosystem services (based mainly on ecological and socio-economic criteria) could yield different values than assessment of riparian vegetation attributes related to naturalness (based only on ecological criteria). Nevertheless, assessment procedures must be related to reference or target conditions that are based on specific objectives (e.g., to have good status within the WFD) of the strategic and planning process (e.g., Programme of measures in the river basin management plans within the WFD). Results of assessment procedures are useful only when they are based on clearly defined process-based reference conditions, detailed characterization of the current status of riparian vegetation and adequate understanding of past trends in riparian vegetation in response to disturbances.

6. CONCLUSIONS AND FINAL REMARKS

We conclude the following:

a) Riparian vegetation is a key element of river hydromorphology that closely interacts with water and sediment flows. A vast scientific bibliography exists that supports riparian vegetation as a major influence on changes in the geomorphic evolution patterns of river channels and floodplains.

b) In EU countries, the WFD has been a major challenge for developing hydromorphological studies since its approval in 2000. Under it, monitoring the hydromorphological status of water bodies is mandatory when designing measures in river basin management plans to improve the ecological status of water bodies.

c) The most relevant scientific insights into the importance of riparian vegetation in river hydromorphology emerged in the late 2000s, after approval of the WFD. Thus, the WFD should be reviewed and updated as the hydromorphological context benefits from knowledge obtained on river dynamics associated with riparian vegetation development and succession.

d) Hydromorphological features induce and interact with riparian vegetation features in a hierarchical cascade of processes, initially influenced by factors at larger scales (e.g., region, catchment, landscape unit) and successively influencing smaller river-system scales (e.g., river segment, reach, geomorphic unit).

e) A multi-scale approach to characterize riparian vegetation that is consistently based on hydromorphological processes is useful for understanding riparian vegetation status in relation to past and present pressures and impacts, and for designing future management options for different scenarios and targets.

f) EU countries have different hydromorphological protocols, which results in frequent misunderstandings between characterization (i.e., description of features) and assessment procedures (i.e., definition of quality classes according to deviations from reference conditions).

g) Considering the indicator value of riparian vegetation as a key hydromorphological element of rivers helped to generate guidelines for a multi-scale approach to characterize and assess riparian vegetation. Additionally, we suggested indicators of the functionality and artificiality of riparian vegetation, which may differ greatly from those used to assess ecosystem services of riparian vegetation.

h) The overall consideration of the available literature, management and policies on riparian vegetation among EU countries identified important issues, such as:

i. The traditional background of the hydromorphological context of the WFD, which should be updated to include knowledge obtained on the influence of riparian vegetation on river dynamics and status
ii. The inadequate consideration of riparian vegetation within the more frequently used river hydromorphological protocols

i) Additionally, we identified scientific gaps in establishing adequate riparian vegetation assessment procedures, such as:
   I. Definition of process-based river hydromorphological typologies in EU countries
   II. Agreement on criteria used to define reference conditions of riparian vegetation based on established river hydromorphological typologies and differences in biogeographic regions.

AKNOWLEDGEMENTS

We thank Virginia Garófano for her comments on and suggestions for the document.

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ANNEXE I

RIPARIAN VEGETATION AS AN INDICATOR OF HYDROMORPHOLOGICAL STATUS: VEGETATION RESPONSES TO PRESSURES AND IMPACTS

1 INTRODUCTION

Inland aquatic ecosystems have been recognised as some of the most threated by human pressures in the world (Saunders et al. 2002). This fact is especially relevant in Europe, where the degradation of its rivers is widespread and nearly all river basins are heavily affected by human activities (Tockner et al. 2009). Recently, Schinegger et al. (2012) conducted a high-resolution data analysis of human pressures at the European scale and they found that more than 79% of the sites analysed (for a total of 9330 sampling sites in 14 European countries) were impacted. However, the same authors also pointed out that little is known about the prevalence, spatial patterns, interactions with natural environment and co-occurrence of pressures.

The identification of significant anthropogenic pressures is an important part of river basin planning and particularly for implementing the EU Water Framework Directive (WFD) (2000/60/EC). All Member States are obliged not only to estimate these pressures within their river basin districts (in a consistent and comparable way), but also to assess the consequent potential impacts on the ecological status of water bodies and, based on this, the susceptibility of the water bodies, i.e., if the impacts potentially lead to a risk of non-compliance with the environmental quality objectives set for the water bodies.

Following the **DPSIR framework**, promoted by the European Environmental Agency (Nixon 2003), the **driving forces** are human activities (e.g. agriculture, urbanisation, industry, tourism…) generating a combination of **pressures** (e.g. water abstraction, physical alterations, pollution discharges, climate change…), which alter the **state** of the abiotic components of the ecosystem (e.g. physico-chemistry, hydro-morphology…). These alterations **impact** biological communities and thus ecological status, eventually resulting in a **response** at the water policies level (e.g. water use restrictions, wastewater treatment…) (Friberg 2010, Wasson et al. 2010).

In the general approach of the WFD, pressures are defined as alterations of the water regime (water abstraction, water flow regulation), uses which lead to morphological alterations of the water bodies, and pollution (from point and diffuse sources); and impacts are those modifications of the quality elements resulting from one or a number of pressures, which potentially leads to a failing of the environmental objectives set under Article 4 of the WFD (Borchardt and Richter 2003). Nevertheless, different authors have categorized pressures in different ways and have evaluated their impacts on organism groups according to specific ranges of pressure severity, for example see Hering et al. (2006); or Schinegger et al. (2012), who categorized pressures into four groups: hydrology, morphology, water quality and connectivity.

Different biological communities can show different responses to a certain pressure depending on the nature of the disturbances, the spatial scale considered and the specific indicator or metric used as response variable (Bruno et al. 2014a). For example, the effect of certain anthropogenic pressures on vegetation could vary depending upon the function and features of the type of vegetation considered (Bunn and Arthington 2002, González et al. 2018).

Here, pressures have been categorized into several groups: hydrological pressures, morphological pressures, pollution, land uses and others (multiple pressures). The specific impact of these pressures on riparian vegetation is explained, as well as the main responses of vegetation features and the scale and metrics that should tackle the pressure and impact assessment.

2 HYDROLOGICAL PRESSURES

Hydrological pressures cover impoundments and other infrastructures that affect natural water and sediment fluxes. Some examples of hydrological pressures are reduction of the natural flow velocity, hydropeaking, water abstraction (water flow alteration/minim flow), reservoir flushing, seasonal hydrograph modification (because of water storage for irrigation, hydropower, etc.). Artificial alterations in hydrological features are considered one of the major stressing impacts in many river types (Hooke 2006) that cause modification and impoverishment of aquatic biota (Schinegger et al. 2012), both upstream and downstream of the infrastructure causing the alteration (Nilsson et al. 2005).

Riparian vegetation consists of a group of species highly dependent on fluvial processes, but particularly they depend on the hydrologic regime of rivers and associated geomorphic adjustments to complete their life cycles (Karrenberg et al. 2002). When fluvial processes are affected by human pressures, different types of vegetation and different stages of their life cycles can be compromised (González et al. 2018). Not only riparian and floodplain woodlands can be disfavoured by river regulation and human pressures, but also non-woody wetlands (Weisberg et al. 2013).

Recruitment of new individuals is a disturbance-dependence process (Scott et al. 1996, Cooper et al. 2003) and therefore is episodic (Mahoney and Rood 1998). Mature riparian woodlands in good ecological status are composed of a shifting steady state mosaic of patches that established in different years (Johnson et al. 1976, Stanford et al. 2005). Different types of human pressures produce a simplification and homogenization in hydrogeomorphic processes (Shafroth et al. 2002) that involve a decrease (or even suppression) in the creation of safe-sites, suitable for the regeneration of new individuals, at spatial and temporal scales enough to maintain the shifting steady state mosaic. The bare areas that remain expose after the reduction in flooding disturbance, are colonized by pioneer vegetation in a first phase, and then these species are progressively replaced by early successional species and finally by late successional species, properly terrestrial or even invasive ones. This encroachment, species replacement and eventual "terrestrialization" of the riparian corridors (Stella et al. 2011) is a direct consequence of the floodplain disconnection and general reduction in the hydrogeomorphic dynamism (Garófano-Gómez et al. 2013, Garófano-Gómez et al. 2017). Many studies have verified the sharp decline in regeneration after floodplain disconnection, while established populations age and are replaced by less disturbance-dependent species (Merritt and Cooper 2000, González et al. 2010, Martínez-Fernández et al. 2017).

In some other cases of hydrological alteration, the annual flow magnitude is not heavily modified but the seasonal hydrograph. Regeneration will not take place if floods able to do geomorphic work (creating moist and bare surfaces), are not timed with seed release (Karrenberg et al. 2002, Wilcox and Shafroth 2013). Dispersal season and high (Spring) flows must be coupled.

The sediment regime has also been highly altered by human pressures (Wohl et al. 2015), and as well as the flow regime, it is also very important to create bare surfaces and maintain the shifting steady state mosaic. Reservoirs trap sediments, reducing the sediment load and modifying the type of sediments downstream of these infrastructures (Scott et al. 1997, Johnson 1998). The sediment deficit affects the potential of large flows to induce geomorphic dynamism; consequently, sediment releases should be a necessary component of environmental flows (Wohl et al. 2015).

Not only sediment texture is important, but also sediment moisture (Kranjcec et al. 1998, Cooper et al. 1999). Both are interconnected, as flow regulation promotes coarser textures that generate an increase in cohesiveness (bank hardening effect) and complementary a decrease in the soil water-holding capacity (González et al. 2010). Other factors that affect moisture in the riparian and floodplain zones are related to the rate of recession following floods, the base flows and the water table conditions (Mahoney and Rood 1998). All of them are determinant of both, the regeneration and survival of young seedlings and saplings (Guilloy-Froget et al. 2002, Guilloy et al. 2011), as well as of the maintenance of mature riparian ecosystems (Scott et al. 1999).

3 MORPHOLOGICAL PRESSURES

Morphological pressures refer to the alterations of the morphological condition of the streambed and banks as a consequence of the installation of artificial structures and barriers (e.g. dams, weirs, lateral protections…) causing breaks in longitudinal, transversal, vertical (and temporal) connectivity (Borchardt and Richter 2003, Wasson et al. 2010). Some examples of morphological pressures are channelization, alterations of the natural morphological channel plan form, alterations of the cross-section, alterations of instream habitat conditions, presence of artificial embankments and rip-rap of different levels that limit channel migration and dykes for flood protection (Van Looy et al. 2003, Dufour et al. 2007, Schinegger et al. 2012).

The reduction in the hydromorphological connectivity is one of the main causes of habitat degradation and loss in river channels and their floodplains for many riparian species, including other biota groups, like fish (Hughes and Rood 2003, Aarts et al. 2004). In this sense, habitat loss and reduced hydrological connectivity have been defined as the more frequent impacts nowadays in European rivers (Schinegger et al. 2012).

Reduction in channel widening and migration reduces the presence of safe sites for regeneration of riparian species (González et al. 2018). Artificial barriers that affect the natural movement of water and sediments in a river system may reduce the necessary genetic exchange between riparian species and also between the species of other organism groups, like fish or aquatic macroinvertebrates, along longitudinal and transversal gradients (Stromberg 1993). Reduction in both types of connectivity may affect the natural balance between riparian species in an ecosystem, as some species are more prone to vegetative reproduction than others.

Other human activities like mining (gravel extraction) alters channel topography, destroy habitats and regeneration sites for riparian species. However, if habitats remain hydrologically connected to the river and are regularly flooded, their restoration can be relatively easy and successful (González et al. 2017).

4 POLLUTION

Apart from alteration of river morphology and of water and sediment regimes, other ecological impacts in running waters result from various pressures acting simultaneously, like point sources discharges and diffuse pollution that can alter both water and soils (Borchardt and Richter 2003, Wasson et al. 2010). Although water quality has improved markedly in European rivers in the last decades (Aarts et al. 2004), this pressure is still present. It can be generated by non-treated stormwater, public sewage treatment plants, industries, croplands, livestock, etc. The chemical pollution generated covers acidification, artificial eutrophication or nutrient enrichment (P, N, C), heavy metals and organic pollution.

Water pollution is a key pressure in river ecosystems and impacts aquatic biota (Schinegger et al. 2012). Periphytic diatoms, macrophytes, benthic macroinvertebrates and fish are more responsive to nutrient enrichment (eutrophication) and organic pollution gradients than riparian vegetation (Hering et al. 2006). Riparian vegetation features like species composition can be affected by chemical water quality (Salinas et al. 2000), but in turn, riparian vegetation also protects streams from nonpoint source pollutants and improves the quality of degraded streams water (Dosskey et al. 2010).

Most riparian species are pioneer species adapted to poor soil conditions (Karrenberg et al. 2002). However, the nutrient levels in the substrate can affect significantly seedlings survival and growth in riparian systems (Adair and Binkley 2002). In this sense, sediment releases from dams have shown to be an important input of nutrients in the system triggering recruitment (Asaeda et al. 2015).

Sediment properties other than moisture and texture can also influence seedling establishment, such as salinity, that can increase as a result of human activities (Jolly et al. 1993). In rivers with an altered hydrology, lack of annual flooding can result in high soil salinity values that are stressful to riparian species, reduce germination rates (Shafroth et al. 1995) and compromise seedling survival (Bhattacharjee et al. 2008).

5 LAND USE PRESSURES

Land use covers industrial and urban areas, agriculture, irrigated croplands, fishery and forestry. Land use is one of the larger pressures on riverscapes (Allan 2004), and particularly on riparian vegetation (Bruno et al. 2014a), because many types of uses like urbanisation or agriculture occupy the riparian and floodplain areas, producing a complementary morphological pressure with the modification of the bank profiles and a pollution pressure with the input of sediments, nutrients and pollutants. For example, agricultural land uses near riparian forests are often associated with increased soil salinity due to irrigation (Jolly et al. 1993).

Wasson et al. (2010) pointed out that artificial land uses like urbanisation and industry represent the pressure with the most negative impact on aquatic biota, over those generated by agriculture, which can be more variable. But in all these cases, riparian forests can have an important protective or buffer effect mitigating the impacts from both agricultural and urban land uses at the basin and riparian corridor scales (Moore and Palmer 2005). Furthermore, the direct influence of riparian forest on invertebrate community structure is widely recognised (Naiman et al. 2005). However, riparian vegetation is not often evaluated in terms of ecological status. Riparian vegetation should have a relevance by itself and not only as a complement factor to other organism groups or status indices.

Livestock, in addition to wild animals, such as ungulates, can also produce an impact on riparian vegetation, for instance, affecting health plant condition and damage (Beschta and Ripple 2016).

6 MULTIPLE PRESSURES

Almost 90% of lowland European rivers are affected by a combination of multiple pressures. Many river sites are affected by hydromorphological pressures or a combination of water quality and hydromorphological pressures. However, there is still a lack of knowledge about the prevalence, spatial patterns, interactions with natural environment, co-occurrence of pressures and the ecological status of rivers at large scales (Allan 2004, Schinegger et al. 2012).

Hydrological alteration and land use changes (like agricultural intensification) can be considered the main human pressures modifying aquatic and riparian communities (Ward 1998). However, the natural constraints in certain ecosystems can make them more sensitive in combination with the nature of the human pressure, leading to different regional responses (Allan 2004). Specifically, this is the case in Mediterranean areas, where human pressures can interact or even exacerbate the pressures along with the proper natural stressors of these river ecosystems, like water salinity, water scarcity or temporality (Stella et al. 2013, Bruno et al. 2014a, Bruno et al. 2014b).

Natural stressors comprise wildfire, windthrow, insect outbreaks, snow loading, ice accumulation, snow avalanching, landslides, and debris flows, floods, bank erosion and avulsions, the last three unique to riparian zones. Furthermore, disturbance regimes vary with catchment scale and stream size (Johnson et al. 2000). Riparian zones exhibit a mosaic of patches at the landscape scale that reflect different local habitat conditions, disturbance histories and recovery trajectories (Naiman et al. 2010), which influence the resilience or the system to new disturbances. Apart from the specific disturbance agents, it is necessary to consider also their spatial extent, frequency, intensity and pattern of disturbance. Their characteristics may vary geographically as a function of climate, topography, vegetation, soil moisture and their interactions (Moore and Richardson 2012).

Multiple pressures act simultaneously in most cases, therefore, managers require to define a hierarchy amongst these to identify priority actions, particularly because pressures are predicted to intensify in the future because of an increase in extreme flow events and the growing water demand for agriculture and energy (European Commission 2009).

7 PRESSURE AND IMPACT ASSESSMENT DEPENDING ON THE SCALE AND METRICS

Human pressures can have a negative influence on aquatic and riparian communities regardless of the scale considered, as pointed out by some authors (Gregory et al. 1991, Allan 2004). However, others consider that the assessment of the impacts on a water body requires a defined area, i.e., the collected data and information have to be referred and aggregated to particular scales (Borchardt and Richter 2003).

The hydrological pressures are often evaluated at reach level or even microhabitat, while land use is evaluated at basin level (Hering et al. 2006). According to Wasson et al. (2010), the impact of a given land use can be different at the basin level compared to the riparian corridor (landscape) level, and the regional variability of these pressure-impact relationships has seldom been analysed at a large geographical scale.

Streams and their riparian and floodplain areas are subject to a wide variety of natural and anthropogenic disturbances across a range of spatial and temporal scales (Moore and Richardson 2012). Therefore, their response to impacts depends upon the nature of the pressures and the spatial scale considered (Richards et al. 1996, Ferreira and Aguiar 2006). Different studies, such as those developed by Salinas and Casas (2007), Aguiar et al. (2009) and Bruno et al. (Bruno et al. 2014a) have stated that human pressures acting at basin scale seem to play a major role in riparian vegetation. Aguiar et al. (2009) indicated the scale dependency of multi-metric plant-based indices, an important consideration in the development of typological-adapted systems for meeting WFD criteria or for other assessment and monitoring purposes.

Apart from the scale considered, the assessment of biological communities' responses can be different depending on the indicator or metric used (Bruno et al. 2014a). A "metric" is considered a measurable part or process of a biological system that changes in value across a human-disturbance gradient (Karr and Chu 1999).

The indicators of the ecological condition, such as the QBR (Munné et al. 1998, Munné et al. 2003) and the RQI (González del Tánago et al. 2006, González del Tánago and García de Jalón 2011) are more appropriate to assess river health (Karr 1999) and respond more clearly than biodiversity indices (such as species richness) to human pressures (Bruno et al. 2014a). Furthermore, they can be more integrative, as they consider different ecosystem components (e.g. composition, structure, functioning, diversity), what give them a more holistic nature, and they have been identified as sensitive to different types of disturbances including land use change and stream modification (Garófano-Gómez et al. 2011, Belmar et al. 2013). Despite many ecological studies regarding the influence of human pressures on biological communities continue using richness as a response variable (Birk et al. 2012), species themselves are not considered a good indicator of human pressures because the indicator taxa for different types of stressors differ geographically depending on the ecological amplitude of the species and species optima in each ecoregion (Aguiar et al. 2009). It is also relevant to consider the sampling season constraints and the inter-annual variability of plant structure and composition.

Apart from the indicators of the ecological condition, different structural and functional components of the riparian ecosystem can be used separately in bioassessments of ecological quality of Mediterranean-type streams (Aguiar et al. 2009), However, depending on the spatial scale of approach some components can be better than others.

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SHORT QUESTIONNAIRE ON RIPARIAN VEGETATION ASSESSMENT IN EUROPE

To answer the questions, please maintain the right answer for your case and remove all the indicated options not valid for you

I. **PERSONAL DATA**	
Name	
Country of work	
Affiliation	
Email	
What is you involvement in the study of Riparian vegetation?	Research: Public Universities / Scientific Centers / Consulting Public administration: Conservation / River Management / Water resources Other (please, specify)
	If Research, do you collaborate with river managers? YES / NO
	If Public administration, do you collaborate with research centers? YES / NO
Are you aware **o**f people (researchers, public administration, private company) working on riparian vegetation assessment at national/regional scale, within the context of the Water Framework Directive? **YES / NO**	
If you answered YES. Can you please provide the contacts: 1. Name……………………………………………………………………………Institution………………………………………………………………………………….. Contact email……………………. Another information………. 2. Name……………………………………………………………………………Institution………………………………………………………………………………….. Contact email……………………. Another information……….	
II. MANAGEMENT OF RIPARIAN ZONES	
1. Are you aware of any legal definition of riparian zone in your country (e.g., fixed width, some flooding return period, other …)? Could you indicate the criteria and the source where it is described?	
2. Is the riparian zone in your country : **PUBLIC / PRIVATE / BOTH or OTHER, according to specific features**	
If **PUBLIC**, are you aware of the maintenance works done by the public administration, and their main purpose? Please, indicate approximately the frequency of these works If **PRIVATE**, are you aware of the mandatory rules (e.g. restrictions of use) for the owners to maintain the riparian zones in proper conditions? If **BOTH, or OTHE**R, please could you describe the specific features to differentiate public vs. private domain or other?	

3. Are you aware if in your country do exist specific management plans or legislations directly addressed to the riparian zones? **YES / NO**

If **YES**, can you provide any information on them, and where this information applies?

Protection / Conservation of habitat (e.g. Natura 2000)

Protection / Conservation of buffer functions in agricultural land

Flood control measures

Specific constraints in urban areas

Others:

III. INFORMATION ON RIPARIAN VEGETATION CHARACTERIZATION AND ASSESSMENT IN YOUR COUNTRY

4. Are you aware of available data sets on riparian vegetation in your country?
YES / NO

If YES, can you provide relevant information about the existing data sets?

SCALE: National / Regional / Local / Other

DATA SOURCE: Air photographs / Field work / Both / Others

VEGETATION TYPE: Woody species (Trees, shrubs) / Herbaceous / Macrophytes

CONTENT: Vegetation structure / Presence of species / Abundance of species / Age of plants

ADDITIONAL INFORMATION: Habitat information Flow regime conditions Channel conditions

ECOLOGICAL STATUS; assessment of degradation / conservation status

OTHER ISSUES:

5. Are you aware of how riparian vegetation is characterized and assessed, as a component of hydromorphological conditions according to the Water Framework Directive? YES / NO

If YES, Can you provide information on the protocol or method, including their scientific reference, grey literature, field protocol, etc.?

Protocol name ……………………………
Reference where it is described …………………………………..
Data acquisition: Air photographs / Field work / Both / Others

6. **What type of RIPARIAN VEGETATION indicators are described in the referred protocol used in your country?**
Please, indicate the way of their measuring, if qualitative by classes, or quantitative by measured numbers. Select "No considered" if the indicator is not included in the protocol:

	Qualitative appraisal	Quantitative appraisal	Not considered

Longitudinal continuity (Fragmentation)			
Vegetation structure: spatial arrangement (isolated trees, patches …)			
Vegetation coverage:			
Species composition: Select “qualitative for Presence of species, “quantitative” for Abundance of species			
Lateral connectivity:			
Age classes:			
Pioneer recruitment:			
Dead wood: presence, abundance, others			
Other attributes:			

7. Does the protocol include assessment of the riparian vegetation status? YES / NO

Please, describe the additional information you consider relevant in the protocol, and duplicate this section as many times as official protocols you know from your country

IV. RIVER TYPOLOGIES AND REFERENCE CONDITIONS TO DEFINE ECOLOGICAL STATUS

8. Are you aware of river typologies in your country to establish reference conditions and thresholds of ecological status? YES / NO

If YES, could you include the reference, web page or other information where they are described?

9. Are you aware of the existence of reference conditions of riparian vegetation status according to river typologies in your country?
   YES / NO

If **YES**, please, can you indicate the scientific reference, grey literature, official administrative documents, etc where the official assessment is described?.

V. PRESSURES AND IMPACTS OF RIPARIAN VEGETATION. ADDITIONAL INFORMATION

10. Are you aware of any report or research from your country informing the main pressures and impacts of rivers at national /regional scale? YES / NO

If YES, could you give the reference, page web or source of information?

- From your point of view, could you Rank the following human activities from 1 (most important) to 7 (less important) affecting riparian vegetation?

Agriculture / Urbanization / Mining / Navigation / Recreation / Grazing / Others

- Could you rank the following impacts on riparian vegetation in the same way:

Land Cover changes / Water pollution / Flow regulation by dams and reservoirs / Groundwater depletion /

Channelization / Invasive species / Others

- From your point of view, and in general terms, riparian zones and their vegetation are in your country during the last decades:

Improving their status / Degrading their status / No significant changes

- Could you briefly state your answer?

11. Please, could you add any relevant information, or references dealing with riparian vegetation characterization and status assessment from your country?

Please send the filled questionnaire to marta.gtanago@upm.es before 31 May 2019 if possible

THANK YOU VERY MUCH FOR YOUR CONTRIBUTION!

ANEX II. Table 2.- Synthesis of the answers to the questionnaires.

			COUNTRY (Name of reporter)	FRA (S. Dufour)	PRT (P. Rodríguez)	PRT (F. Aguiar)	PRT (T. Ferreira)
Riparian zone: LEGAL DEFINITION				Absolute value: 5 m	10 -30 (non navigable –navigable rivers)	10 -30 (non navigable – navigable rivers)	10-30-50 m, according to river width and navigation
Riparian OWNERSHIP				Mixed: Public if floatable and navigation possible/private for others	Mixed: Public if urban, private if land limiting rivers is private, public rest of cases.	Mixed: Public if urban, private if land limiting rivers is private, public rest of cases.	Mixed: Public if urban, private if land limiting rivers is private, public rest of cases.
Riparian MANAGEMENT PLANS			Conservation/Biodiversity (E.g., Natura 2000)	YES???	YES	YES	YES
			Protection / Conservation of buffer functions in agricultural land	YES	NO	NO	YES
			Flood control	-	YES	YES	YES
			Specific constraints in urban areas	-	NO	YES	YES
			Other (specify)		-River Basin Manag. Plans. -Restoration after fires		
Riparian Vegetation (RV) DATA SOURCE	RV inventories		National scale	YES	YES	YES	-
			Regional /Local scale	-	-	-	-
			RV indirect monitoring (included in HYMO monitoring within the WFD implementation)	YES	YES	YES	YES
	Data acquisition		FW: field work AP: air photos	Both	FW	Both	-
Riparian Vegetation CHARACTERIZATION	Phytosociological / Autoecological approach	Species composition	Presence	Native vs. non native	NO	YES	YES
			Abundance	NO	NO		YES
		Habitat features	Flow conditions	-	YES	YES	-
			Channel conditions	YES	YES	YES	NO
	Spatial features		Longitudinal continuity	Semiquantitative	Semiquantitative	Qualitative	Qualitative/Quantitative
			Vegetation cover	Quantitative	Semiquantitative	NO	Qualitative/Quantitative
			Size / Shape vegetation patches	Semiquantitative	Semiquantitative	Qualitative	Qualitative/Quantitative
			Other structural features	NO	Lateral Connectivity	Lateral Connectivity	Lateral Connectivity
	Functional approach		Age diversity	NO	NO	NO	NO
			Pioneer recruitment	NO	NO	NO	YES
			Functional traits	NO	NO	NO	NO
			Dead Wood	YES	Qualitative classes	Qualitative	Qualitative

		Other	-		Trees rooted in riverbed	
		(continuation)	**FRA (S. Dufour)**	**PRT (P. Rodríguez)**	**PRT (F. Aguiar)**	**PRT (T. Ferreira)**
Riparian Vegetation Assessment	**Name of protocol /index**		SYRAH; CARHYCE	QBR, RHS and Riparian Vegetation Index	Macrophyte protocol	RHS
	Related to WFD HYMO assessment		YES	YES	YES	YES
	Referred to river typologies		YES	YES	YES	YES
	Referred to reference conditions		YES	YES	NO	YES
	Existence of RV reference types		NO	YES	NO	YES
Riparian Vegetation PRESSURES AND IMPACTS (Rank of human activities from 1, most important, to 7, less important)		**Agriculture**	1	1	1	1
		Urbanization	4	5	2	2
		Mining	7	4	6	4
		Navigation	5	7	-	6
		Recreation	6	6	-	3
		Grazing	3	3	5	5
		Others	2 Maintenance	2 River Manag.	3 Forestry	7
Riparian Vegetation PRESSURES AND IMPACTS (Rank of impacts from 1, most important, to 7, less important)		**Land cover changes**	1	1	1	1
		Water pollution	7	5	6	4
		Flow regulation by dams and reservoirs	5	2	3	2
		Groundwater depletion	3	4	4	3
		Channelization	2	2	6	5
		Invasive species	6	3	2	6
		Others	4 Plantation		5 Fire	7
Riparian zones and their vegetation are in your country during the last decades:			Improving their status	Degrading their status	Degrading their status	No significant changes
Reason			Large part of network is less pressured due to agricultural changes	Intensification of agriculture, increase effort in hydroelectric engineering, increase in the number and incidence of invasive species	Agricultural activities, forest plantations, urbanization, flow regulation and interruption of longitudinal connectivity.	On a local level, many changes and a greater awareness, but globally, riparian zones are ecotones with constant pressure from human activities and water scarcity

				ESP (I. Biurrum)	GRC (E. Papastergiadou)	DEU (S. Lorenz)	CZE (J. Jakubinski)
	COUNTRY (Name of reporter)			ESP (I. Biurrum)	GRC (E. Papastergiadou)	DEU (S. Lorenz)	CZE (J. Jakubinski)
Riparian zone: LEGAL DEFINITION				-	-	Fixed width (not said)	-
Riparian OWNERSHIP				PUBLIC	PUBLIC	PUBLIC	PUBLIC
Riparian MANAGEMENT PLANS	**Conservation/Biodiversity (E.g., Natura 2000)**			YES	YES	YES	YES
	Protection / Conservation of buffer functions in agricultural land				YES		-
	Flood control			-	-	YES	YES*
	Specific constraints in urban areas						
	Other (specify)			-	-	-	-
Riparian Vegetation (RV) DATA SOURCE	**RV inventories**	**National scale**		YES (SIVIM)	YES	-	NO* (starting now)
		Regional /Local scale		YES (BIOVEG)		-	NO
	RV indirect monitoring (included in HYMO monitoring within the WFD implementation)			YES	-	-	NO
	Data acquisition	**FW: field work AP: air photos**		FW	FW	-	FW
Riparian Vegetation CHARACTERIZATION	**Phytosociological / Autoecological approach**	**Species composition**	**Presence**	YES	YES	YES	YES
			Abundance	YES	-	NO	-
		Habitat features	**Flow conditions**	-		-	-
			Channel conditions	NO	-	-	-
	Spatial features	**Longitudinal continuity**		-	Qualitative	Quantitative	Qualitative
		Vegetation cover		-	Qualitative	Quantitative	Qualitative
		Size / Shape vegetation patches		-	Qualitative	Qualitative	Qualitative
		Other structural features		-	-	-	-
	Functional approach	**Age diversity**		-	-	NO	Qualitative
		Pioneer recruitment		-	-	NO	Qualitative
		Functional traits		-	-	NO	-

		Dead Wood			Qualitative	-
		Other	-	-	NO	Water regime characteristics
		(continuation)	**ESP (I. Biurrum)**	**GRC (E. Papastergiadou)**	**DEU (S. Lorenz)**	**CZE (J. Jakubinski)**
Riparian Vegetation Assessment	**Name of protocol /index**		-	MEDGIG	Gewässerstrukturgütekartierung	No official prot. (Evaluation of current state of bank vegetation)
		Related to WFD HYMO assessment	-	YES	YES	NO
		Referred to river typologies	-	YES	YES	NO
		Referred to reference conditions	-	YES	YES	NO
		Existence of RV reference types	-	YES	NO	NO
Riparian Vegetation PRESSURES AND IMPACTS (Rank of human activities from 1, most important, to 7, less important)		**Agriculture**		1	2	1
		Urbanization		3	1	2
		Mining		-	5	3
		Navigation		-	3	4
		Recreation		4	4	5
		Grazing		2	6	6
		Others		-		7
Riparian Vegetation PRESSURES AND IMPACTS (Rank of impacts from 1, most important, to 7, less important)		**Land cover changes**		1	2	1
		Water pollution		4	3	2
		Flow regulation by dams and reservoirs		2	4	3
		Groundwater depletion		5	5	4
		Channelization		3	1	5
		Invasive species		6	6	6
		Others		-		7
Riparian zones and their vegetation are in your country during the last decades:			Degrading their status	Degrading their status	Degrading their status	Improving their status
Reason			water depletion, flow regulation, eutrophication, channelization, spread of invasive species…		consistent conflicts on land use (agriculture, urbanization, nature conservation, recreation) riparian zones are threatened by diffuse inputs or area shrinkage.	More restoration actions, but actions are mostly aimed primarily at restoring the watercourse itself or

				creating natural flood protection measures

				COUNTRY (Name of reporter)	SVK (A. Kidová)	SVK (M. Slezák & M. Šibíková)	BIH (R. Nurković)	SVN (G. Urbanič)
Riparian zone: LEGAL DEFINITION					Absolute value: 20 m	Not defined	NOT SAID	1st order stream 40 m, 2nd order stream 5 m
Riparian OWNERSHIP					PUBLIC	MIXED	MIXED	MIXED
Riparian MANAGEMENT PLANS	Conservation/Biodiversity (E.g., Natura 2000)				YES	-	YES	YES
	Protection / Conservation of buffer functions in agricultural land				NO	-	YES	-
	Flood control				YES	-		YES
	Specific constraints in urban areas				NO	-		-
	Other (specify)					-	-	Management plans according to WFD
Riparian Vegetation (RV) DATA SOURCE	RV inventories	National scale			YES	YES	YES	YES
		Regional /Local scale			-	-	YES	-
	RV indirect monitoring (included in HYMO monitoring within the WFD implementation)				YES	-	-	-
	Data acquisition	FW: field work AP: air photos			FW	FW	-	Both
Riparian Vegetation CHARACTERIZATION	Phytosociological / Autoecological approach	Species composition	Presence		-	YES	YES	NO
			Abundance		-	YES	YES	NO
		Habitat features	Flow conditions		-	-	YES	NO
			Channel conditions		-	-	YES	YES
	Spatial features	Longitudinal continuity			Qualitative	-	-	
		Vegetation cover			-	-	-	Qualitative
		Size / Shape vegetation patches			Qualitative	-	-	Qualitative
		Other structural features			-	-	-	NO
	Functional approach	Age diversity			-	-	-	NO
		Pioneer recruitment			-	-	-	Invasive species
		Functional traits			-	-		-
		Dead Wood						YES

	Other	erosion destruction, permanent grassland, planting, artificial construction, cultivated arable land	-	-	Invasive species
	(continuation)	**SVK (A. Kidová)**	**SVK (M. Slezák & M. Šibíková)**	**BIH (R. Nurković)**	**SVN (G. Urbanič)**
Riparian Vegetation Assessment	**Name of protocol /index**	Hydromorphological monitoring for ecological status assessment (GES, GEP)	-	NOT SAID THE NAME	SIHM method
	Related to WFD HYMO assessment	YES	NO	YES	YES
	Referred to river typologies	YES	YES	-	YES
	Referred to reference conditions	YES	NO	YES	YES
	Existence of RV reference types	YES	NO	NO	YES
Riparian Vegetation PRESSURES AND IMPACTS (Rank of human activities from 1, most important, to 7, less important)	**Agriculture**	1	3	RELEVANT	1
	Urbanization	2	2	RELEVANT	2
	Mining	3	1		5
	Navigation	5	4	RELEVANT	6
	Recreation	4	5		4
	Grazing	6	6		3
	Others	7	7		7
Riparian Vegetation PRESSURES AND IMPACTS (Rank of impacts from 1, most important, to 7, less important)	**Land cover changes**	1	2		1
	Water pollution	4	4	RELEVANT	4
	Flow regulation by dams and reservoirs	3	1		3
	Groundwater depletion	6	6		6
	Channelization	2	5	RELEVANT	2
	Invasive species	5	3		5
	Others	7	0		7
Riparian zones and their vegetation are in your country during the last decades:		Improving their status	Degrading their status	Degrading their status	Degrading their status
Reason		Due to actual trend of the river channels incision, the riparian zone is less affected by flood			Especially increased pressures from the agriculture, river

	discharges, i.e. increased riparian zone area.			damming and urbanization.

	COUNTRY (Name of reporter)			LTU (L. Baležentienė)	HUN (T. Kiss)	ITA (N. La Porta)
Riparian zone: LEGAL DEFINITION				No exist	2 year flood return period in free floodplains; In confined FP: area between embanked levees	Not said (Rinaldi et al 2011)
Riparian OWNERSHIP				Mixed. All people have the right to access water bodies. Land owners have a duty not to impede them to do so.	Mixed. Different rules according to ownerships: public, towns, forestry companies…	Both. Maintenance works mainly done by public administration. Removal of wood and vegetation for safety
Riparian MANAGEMENT PLANS	**Conservation/Biodiversity (E.g., Natura 2000)**			-	YES	YES
	Protection / Conservation of buffer functions in agricultural land			YES	YES	YES
	Flood control			YES (some restrictions)	YES	YES
	Specific constraints in urban areas				YES	YES
	Other (specify)			-		
Riparian Vegetation (RV) DATA SOURCE	**RV inventories**	**National scale**		-	-	-
		Regional /Local scale		YES	YES	-
	RV indirect monitoring (included in HYMO monitoring within the WFD implementation)			-	-	-
	Data acquisition	**FW: field work AP: air photos**		FW	FW	Both
Riparian Vegetation CHARACTERIZATION	**Phytosociological / Autoecological approach**	**Species composition**	**Presence**	YES	YES	YES
			Abundance	NO	-	YES
		Habitat features	**Flow conditions**	-	-	-
			Channel conditions	-	-	-
	Spatial features	**Longitudinal continuity**				Qualitative/Quantitative
		Vegetation cover		-	Qualitative/Quantitative	Quantitative
		Size / Shape vegetation patches		Qualitative	Qualitative/Quantitative	Qualitative
		Other structural features		-	-	-
	Functional approach	**Age diversity**		-	-	-
		Pioneer recruitment		-	-	QUANTITATIVE/ QUALITATIVE
		Functional traits		-	-	-

	Dead Wood		NO	QUANTITATIVE
	Other	Invasive herbaceous species	Floodplain width	
	(continuation)	**LTU (L. Baležentienė)**	**HUN (T. Kiss)**	**ITA (N. La Porta)**
Riparian Vegetation Assessment	**Name of protocol /index**	The total plant species composition and cover (%)	IMMI EQR	NAME IS NOT PROVIDED
	Related to WFD HYMO assessment	NO	YES	YES
	Referred to river typologies	YES	YES	YES
	Referred to reference conditions	YES	YES (1860-70)	YES
	Existence of RV reference types	YES	NO	YES
Riparian Vegetation PRESSURES AND IMPACTS (Rank of human activities from 1, most important, to 7, less important)	**Agriculture**	-	1	1
	Urbanization	-	5	2
	Mining	-	7	4
	Navigation	-	6	6
	Recreation	-	5	5
	Grazing	-	0 Positive	3
	Others	-	Forestry (1)	
Riparian Vegetation PRESSURES AND IMPACTS (Rank of impacts from 1, most important, to 7, less important)	**Land cover changes**	-	1	2
	Water pollution	-	4	5
	Flow regulation by dams and reservoirs	-	6	6
	Groundwater depletion	-	3	3
	Channelization	-	5	1
	Invasive species	-	2	4
	Others	-	-	-
Riparian zones and their vegetation are in your country during the last decades:		-	Degrading their status	Degrading their status
Reason			Intensive forest plantations since 80's, problems with invasive species, incision problems	The above human activities are increasing. Also invasive species.

				ITA (A. Andreoli)	SRB (J. Milovanović)
	COUNTRY (Name of reporter)			**ITA (A. Andreoli)**	**SRB (J. Milovanović)**
Riparian zone: LEGAL DEFINITION				-	Areas unprotected from floods: 10 m; Areas protected from floods: 50
Riparian OWNERSHIP				PUBLIC	PUBLIC
Riparian MANAGEMENT PLANS	**Conservation/Biodiversity (E.g., Natura 2000)**			-	YES
	Protection / Conservation of buffer functions in agricultural land			-	-
	Flood control			-	-
	Specific constraints in urban areas			-	-
	Other (specify)			-	Special laws relating with national parks and monuments
Riparian Vegetation (RV) DATA SOURCE	**RV inventories**	**National scale**		-	-
		Regional /Local scale		YES	YES
	RV indirect monitoring (included in HYMO monitoring within the WFD implementation)			-	-
	Data acquisition	**FW: field work AP: air photos**		Both	FW
Riparian Vegetation CHARACTERIZATION	**Phytosociological / Autoecological approach**	**Species composition**	**Presence**	-	YES
			Abundance	-	NO
		Habitat features	**Flow conditions**	-	YES
			Channel conditions	-	YES
	Spatial features	**Longitudinal continuity**		Quantitative	Qualitative
		Vegetation cover		-	Quantitative
		Size / Shape vegetation patches		-	NO

		Other structural features	Lateral connectivity	Lateral connectivity
	Functional approach	**Age diversity**	-	QUANTITATIVE/QUALITATIVE
		Pioneer recruitment	-	NO
		Functional traits	-	NO
		Dead Wood	QUANTITATIVE	QUALITATIVE
		Other		
		(continuation)	**ITA (A. Andreoli)**	**SRB (J. Milovanović)**
Riparian Vegetation Assessment	**Name of protocol /index**		IDRAIM/SUM/MQI	Stream Visual Assessment Protocol 2 (SVAP 2) and Proper Functioning Condition (PFC)
	Related to WFD HYMO assessment		YES	YES
	Referred to river typologies		NO	YES
	Referred to reference conditions		NO	YES
	Existence of RV reference types		NO	NO
Riparian Vegetation PRESSURES AND IMPACTS (Rank of human activities from 1, most important, to 7, less important)		**Agriculture**	2	3
		Urbanization	4	1
		Mining	3	2
		Navigation	-	4
		Recreation	-	5
		Grazing	-	6
		Others	1.River cleaning	
Riparian Vegetation PRESSURES AND IMPACTS (Rank of impacts from 1, most important, to 7, less important)		**Land cover changes**	3	4
		Water pollution	5	3
		Flow regulation by dams and reservoirs	2	2
		Groundwater depletion	6	6
		Channelization	1	1
		Invasive species	4	5
		Others	-	0
Riparian zones and their vegetation are in your country during the last decades:			Improving their status	Degrading their status
Reason			Conscience about the importance of riparian vegetation is slowly growing,	Dam construction, drought, erosion

	together with river restoration actions promoted by WFD	