RIPARIAN ZONE / RIPARIAN VEGETATION DEFINITION: PRINCIPLES AND RECOMMENDATIONS

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Abstract

Riparian vegetation corresponds to all vegetation units along river networks, regardless of their physiognomy or origin, and is functionally related to other components of fluvial systems and the surrounding area. It belongs to the riparian zone, which is a landscape unit that is open (to fluxes to and from river systems and uplands) and co-constructed (i.e. driven by natural and social processes). The land alongside fluvial systems influences, and is influenced by, the river and associated processes. The structure and ecological functioning of biotic communities in this zone are variables along the four dimensions of the fluvial system (longitudinal, lateral, vertical and temporal). This variability is driven mainly by bioclimatic, geomorphological and land-use conditions, which change over time under the influence of natural and human drivers. This variability influences the ways in which riparian vegetation is identified, named, delineated and studied. From a functional perspective, the delineation needs to be adapted to the functions targeted. Thus, inadequate or overly narrow delineation can cause some functions associated with riparian vegetation to be excluded. Conversely, keeping delineation wide would help to consider and manage the riparian zone using a real integrated process able to combine most of the issues related to riparian vegetation and its associated stakeholders.

Main recommendations:

1. Recognize riparian zones as co-constructed socio-ecological systems driven by natural AND human processes that follow complex trajectories over time
2. Consider riparian vegetation as an open system (i) related to the channel, the surrounding area, the upstream watershed, the atmosphere and the substrate and (ii) connected to these components through bidirectional fluxes
3. Promote the use of a definition/delineation that integrates and maximizes all functions within the socio-ecological system (i.e. supporting, provisioning, regulating and cultural ecosystem services)
4. Develop examples and tools to promote good practices in the application of riparian zone delineation
5. Clarify knowledge that is site-specific and knowledge that is transferable (e.g. minimum riparian zone width necessary for a given function, effectiveness of given topographic index in delineating the riparian zone)

Authors: Simon Dufour[1] and Patricia María Rodríguez-González[2]

[1]Université Rennes 2, CNRS UMR LETG

[2]Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa

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1. Introduction – Riparian vegetation: a crucial component of fluvial systems

Riparian vegetation is a crucial component of fluvial systems and serves multiple socio-ecological functions (Malanson, 1993; National Research Council, 2002; Naiman et al., 2005) (Fig. 1). Physically, riparian vegetation in rivers alters flow conditions and therefore sedimentary processes by protecting banks, colonizing deposits, supplying large woody debris, etc. (Gurnell and Gregory, 1995; Piégay and Gurnell, 1997; Tabacchi et al., 1998; Gurnell and Petts, 2006; Corenblit et al., 2007; Gurnell, 2014). From a morphological perspective, this influence can be strong enough to induce river metamorphosis (Tal et al., 2004). Chemically, riparian vegetation supports biogeochemical cycles of river systems. For example, its buffering effect improves water quality in agricultural watersheds that are affected by non-point-source pollution (Sabater et al., 2003; Mander et al., 2005). Biologically, riparian vegetation is species-rich and increases regional biodiversity (e.g. Tabacchi, 1992; Naiman et al., 1993; Pautou et al., 1997; Jobin et al., 2004; Sabo et al., 2005; Schnitzler-Lenoble, 2007). This biological role is also related to habitat and corridor functions (e.g. Décamps et al., 1987; Rosenberg et al., 1997; Seymour and Simmons, 2008; Schnitzler-Lenoble, 2007; Roshan et al., 2017, de la Fuente et al., 2018) and the influence of riparian vegetation on temperature, organic matter inputs, etc. of aquatic ecosystems (e.g. Beschta et al., 1987; Maridet, 1994; Hill et al., 2001; Ferreira et al., 2016; Miura and Urabe, 2015; Astudillo et al., 2016; Wawrzyniak et al., 2017; Dugdale et al., 2018). Some of these functions have been identified as critical for moderating local effects of global changes, such as thermal conditions of streams (Kristensen et al., 2015; Trimmel et al., 2018). Socially, riparian vegetation contributes to the identity of the landscape it belongs to; thus, it contributes to cultural services (e.g. recreation, spirituality, inspiration).

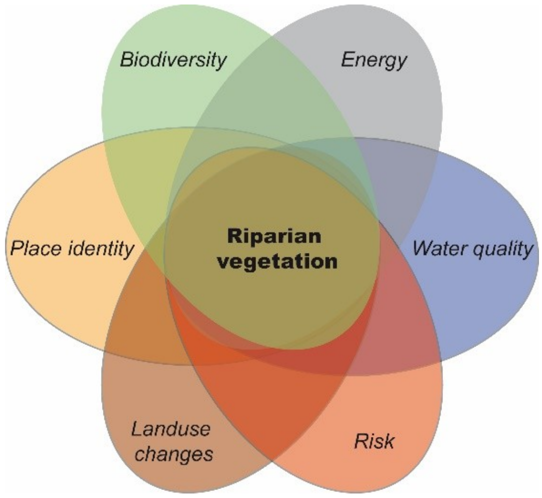


Figure 1. Riparian vegetation as a crucial component of many socio-ecological issues

Many of these functions are considered positive because they improve human well-being by providing many ecosystem services, such as recreation areas, raw materials (e.g. wood, energy) and water quality improvement (Gren et al., 1995; Kenwick et al., 2009; Recchia et al., 2010; Flores-Díaz et al., 2014). However, riparian vegetation is also associated with several limitations (disservices) and thus can generate a more negative perception, related mainly to extreme hydrological events. During low flow, riparian vegetation shades the channel, which decreases evaporation; however, it also consumes water (Pivec, 2002; Lamontagne et al., 2005; Salemi et al., 2012; Irmak et al., 2013; Flanagan et al., 2017), even if water consumption depends on vegetation type; for example, native vegetation can consume less water than exotic species (Ehrenfeld, 2003), which can compete with societal needs. During floods, riparian vegetation can have contradictory influences on flood risks. Locally, via roughness, it buffers flooding from the channel to the floodplain (i.e. reduces water velocity, erosion and damage to human infrastructure) but can also increase the water level for a given discharge. Downstream, riparian vegetation produces woody debris that can increase flood impacts but can also decrease flood peaks by storing water upstream. One potentially negative perception by riverine inhabitants is associated with woodland development that results from land use changes (i.e. abandoning grazing or agriculture) and modifies the cultural landscape and thus place identity (Schnitzler and Génot, 2012).

Considering all the socio-ecological roles it plays in fluvial systems, riparian vegetation is considered a scientific and applied object studied in a large body of management and research literature. However, many names are given to the vegetation that colonize river edges: "alluvial swamp forests", "gallery forests", "floodplain forests", etc. in English, "ripisylve", "forêt alluviale", "boisement riverain", etc. in French and "bosque de ribera", "bosque ribereño", "Soto", "bosque en galería", etc. in Spanish. In English, Fischer et al. (2001) listed more than 30 terms for vegetation located near aquatic systems. In addition to this diversity, there is also some confusion because the same object can have different names, and the same name can identify different objects (Clerici et al., 2011). This diversity and confusion of terms can generate misunderstanding and tension among actors.

2. Goal of the report

This report aims to provide elements to clarify identification of the riparian zone and the riparian vegetation of fluvial systems. By "identification", we mean both definition and delineation of this complex object, which are two different processes. Delineation implies the ability to draw a map that clearly indicates what is inside and what is outside the riparian zone, which can have legal implications. To achieve this goal, we first present common characteristics of the riparian vegetation/zone and then sources of variability in defining it.

Some relevant elements of review can be found in National Research Council (2002), Verry et al. (2004), Naiman et al. (2005), Clerici et al. (2011) and Dufour et al. (2019) for definitions and in Clerici et al. (2013) and de Sosa et al. (2017) for delineation.

3. Common characteristics of riparian zone/vegetation

Despite the diversity of terms used for the vegetation that colonizes river edges, they have some similarities.

1. The **land along the fluvial system influences the vegetation and is influenced by it** through physical, biological, chemical, etc. relations (Fig. 2).
    - The vector of interactions is mainly water, through lateral runoff, floods and groundwater dynamics.
    - This land hosts specific vegetation notably because of disturbance by floods (Fig. 3a), stress generated by anoxic conditions due to inundation (Fig. 3b) and/or more water resources than uplands due to a higher groundwater table.

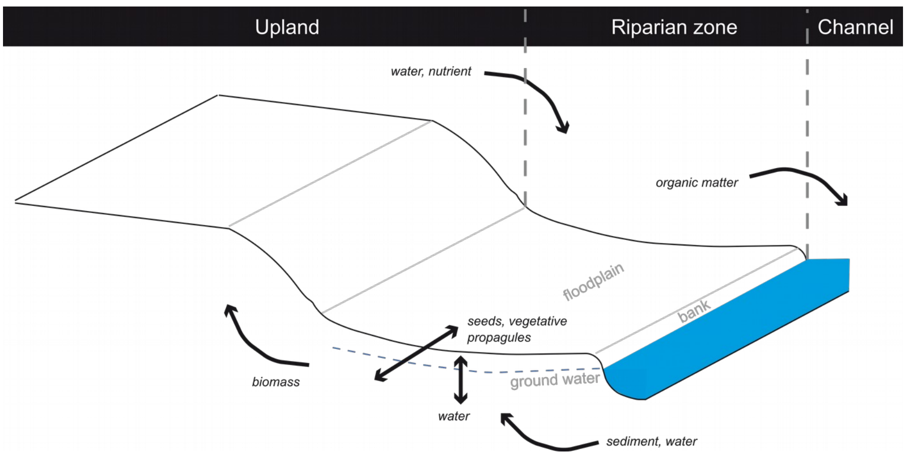


Figure 2. Cross section of a theoretical riparian zone. Arrows indicate fluxes of matter, energy, water, information. (examples are not exhaustive)

Figure 3. Specific vegetation related to (left) disturbance regime on a gravel bar colonized by *Salix* sp. (Ain River, France) and (right) anoxic conditions on the lower part of the bank (*Alnus* sp., Doulon River, France).

2. Riparian vegetation is the **complex of plant communities present in the riparian zone**.
    - It belongs to riparian zones, which were defined as “transitional between terrestrial and aquatic ecosystems and…distinguished by gradients in biophysical conditions, ecological processes and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence)” (National Research Council, 2002). The term “zone” is sometimes replaced by “area”, “ecotone”, “system” or “land” (Table 1), due to the fact that “zone” can be associated with a broad climatic zone rather than the dominant local character of a riparian area.
    - It forms a mosaic of vegetated patches that can have different physiognomy, structure and composition because of local variability in physical conditions (e.g. flow velocity during floods, elevation above the water level, substrate), landform age and land use (e.g. grazing, forestry) (Fig. 4).

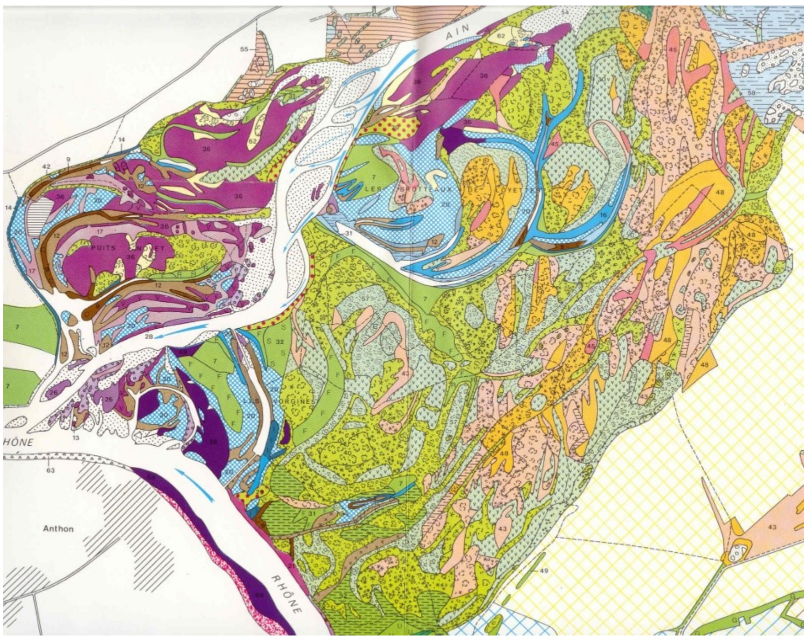


Figure 4. Map of vegetation units at the confluence of the Ain River and the Rhone River (Source: Girel, 1986). Each color represents a different plant community.

- It contains plant communities significantly different from those in upland habitats, so riparian vegetation increases regional richness across the globe (Sabo et al., 2005).
- It can be simplified using a discrete approach that groups plant communities based on the dominant fluvial dynamic processes. For diverse bioclimatic contexts across Europe, Gurnell et al. (2016) distinguish four zones in the riparian zone respectively named, from the channel to uplands, “fluvial disturbance dominated (coarse sediment erosion and deposition)”, “fluvial disturbance dominated (fine sediment deposition)”, “inundation dominated” and “soil moisture regime dominated” (Fig. 5).

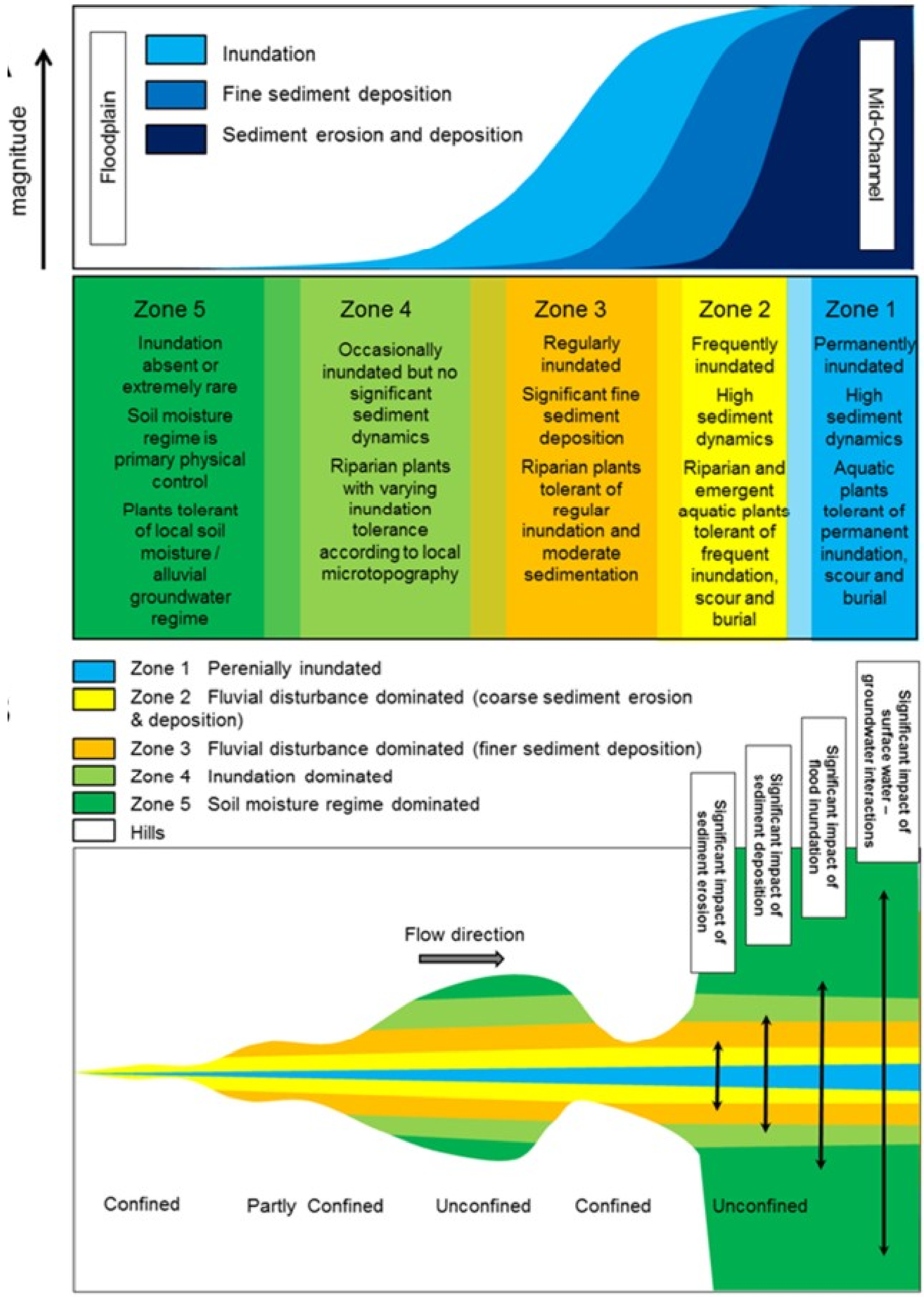


Figure 5. Lateral zonation of the riparian zone along the river network; zones are dominated by different hydrogeomorphological processes (Source: Gurnell et al., 2016)

3. Most definitions of the riparian zone and riparian vegetation use a functional approach and highlight **bidirectional influences between aquatic and terrestrial systems** of hydrological, morphological, chemical and biological processes (Table 1).

Table 1. Selected list of definitions of the riparian zone and related vegetation units. Type of definition: (F = Functional and S = structural); Main focus of the definition: (Flu = fluvial processes, Geo = topographic/geographical delineation, Soi = Soil characteristics, Bio = biological communities)

Expression	Definitions	Type	Main focus	Sources
Riparian zone (or area or ecotone or land or systems)				
Riparian zone	Zone of direct interaction between terrestrial and aquatic environments Vegetation, hydrology, and topography all determine the type, magnitude, and direction of functional relationships. The direction of riparian interactions refers to the notion that the terrestrial system may affect the aquatic or vice versa.	F	Flu	Swanson *et al.*, 1982
	Three dimensional zone of direct interaction between terrestrial and aquatic ecosystems. Boundaries of riparian zone extend outward to the limit of flooding and upward into the canopy of streamside vegetation	F	Flu	Gregory *et al.*, 1991
	Area in close proximity to a stream or river, the environment of which is distinctly influenced by that proximity	F/S	Flu/Geo	Bren, 1993
	Encompasses the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high-water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water. [...] Vegetation outside from the zone that is not influenced by hydrologic conditions but that contributes organic matter to the floodplain or channel, or that influences the physical regime of the floodplain or channel by shading, may be considered part of the riparian zone.	F	Flu	Naiman and Décamps, 1997
	Transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands	F	Flu	National Research Council, 2002
	Ecological term referring to that part of the fluvial landscape inundated or saturated by flood flows; it consists of all surfaces of active fluvial landforms up through the flood plain including channel, bars, shelves, and related riverine features such as oxbow lakes, oxbow depressions, and natural levees. Particularly in arid and semiarid (water-deficient) environments, the riparian zone may support plants and other biota not present on adjacent, drier uplands.	F	Flu	Osterkamp, 2008
	Semi-terrestrial areas lying at the interface of the terrestrial and aquatic environment. They are often influenced by overbank flooding events and connect upland and aquatic environments through surface and subsurface hydrologic flow paths.	F	Flu	Vidon *et al.*, 2010
	Area between the edge of the stream and the characteristic transition between organic and mineral soils. […] This definition based on soil characteristics also has topographical and biological dimensions. The aforementioned soil transition is usually accompanied by an increasing terrain slope and by vegetation changes	S	Soi	Ledesma *et al.*, 2018
	The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding in a riparian zone is generally much shorter, and	S	Flu	http://medwet.org/aboutwetlands/wetland-terminology/

	the timing less predictable than in a river floodplain.			
Riparian area	Three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems, that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.	F	Flu	Ilhardt *et al*., 2000
Riparian ecotone	Three-dimensional space of interaction that includes terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.	F/S	Flu	Verry *et al*., 2004
Riparian systems	Transitional semi-terrestrial areas regularly influenced by fresh water, usually extending from the edges of water bodies to the edges of upland communities	F	Flu/Bio	Naiman and Décamps, 2005
Riparian land	Any land which adjoins, directly influences, or is influenced by a body of water	F	Geo	Lovett and Price, 1999
Riparian formations*				
Alluvial meadow*	Grassland that grows on sediments deposited by river The meadows are characterised by regular flooding and the impact of mowing	S	Bio	Eriksson, 2008
Riparian forest*	Floodplain vegetation or vegetation directly adjacent to rivers and streams. The riparian forest extends laterally from the active channel to include the active floodplain and terraces	S	Bio	Naiman *et al*., 1998
Riparian thicket*	Shrubland that grows along rivers	S	Bio	Davies et al., 2004
(Semi)-aquatic community	Abandoned channels with aquatic and/or hydrophytic herbaceous vegetation	S	Bio	Marston et al., 1995
Others				
Alluvial forest	Forested ecosystems linked to groundwater, regularly or rarely flooded	S	Bio/Flu	Pautou, 1984
Riparian corridor	Stream channel and that portion of the terrestrial landscape from the high-water mark towards the uplands where vegetation may be influenced by elevated water tables or flooding, and by the ability of soils to hold water. *Note: the influence of vegetation of the river is explicitly mentioned*	F	Flu	Naiman *et al*., 1993
Riparian vegetation	Hydrophytic vegetation growing in the immediate vicinity of a […] river close enough so that its annual evapotranspiration represents a factor in the […] river regime	S	Bio	http://medwet.org/ aboutwetlands/wetland-terminology/
Riparian ecosystems	Complex assemblage of organisms and their environment existing adjacent to and near flowing water Without definite boundaries, it may include streambanks, floodplains, and wetlands as well as sub-irrigated sites forming a transitional zone between upland and aquatic. Mainly linear in shape and extent, they are characterized by laterally flowing water that rises and falls at least once within a growing season	S	Bio	Lowrance *et al*., 1985
Gallery forest*	Narrow strip of forest associated with creeks and rivers, in an otherwise unforested landscape	S	Bio	Veneklaas *et al*., 2005
Floodplain forest	Forested ecosystems that colonize the floodplain. The floodplain may be defined in hydrological terms as the surface that is flooded […] or in geomorphological terms as the alluvial surface constructed by the river under current environmental conditions	S	Bio/Flu	Bendix et Hupp, 2000

** terms used in the list of the European Union Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora*

4. The land alongside fluvial systems influences, and is influenced by, the river and its associated processes but it is also **open to surrounding areas** (e.g. hillslope, plateau) through fluxes driven by physical (e.g. runoff), biological (e.g. species mobility) and human (e.g. biomass removal through cultivation) processes.

5. Riparian zones are **hybrid systems because they result from co-construction driven by human and natural processes**. This means that human activities such as land use and river management are major drivers that shape riparian vegetation greatly (e.g. Piégay et al., 2003; Kondolf et al., 2007; Dufour et al., 2015; Brown et al., 2018). It implies incorporating into the definition of the riparian zone how human populations use(d) and value(d) the area, factors not currently considered in the literature (Table 1).

4. Sources of variability in identifying the riparian zone and vegetation

Beyond the common characteristics of the riparian zone and vegetation of fluvial systems, the scientific and applied literature can be confusing due to the variety of terms used. This variety is notably related to the inherent variability in the object. For example, riparian vegetation can refer either to a narrow strip of trees in a grassland or field matrix (Fig. 6A), to a large floodplain forest (Fig. 6B) or to a forest colonizing steep colluvial deposits (Fig. 6C). But this variety is also related to variability in how scientists and managers represent it.

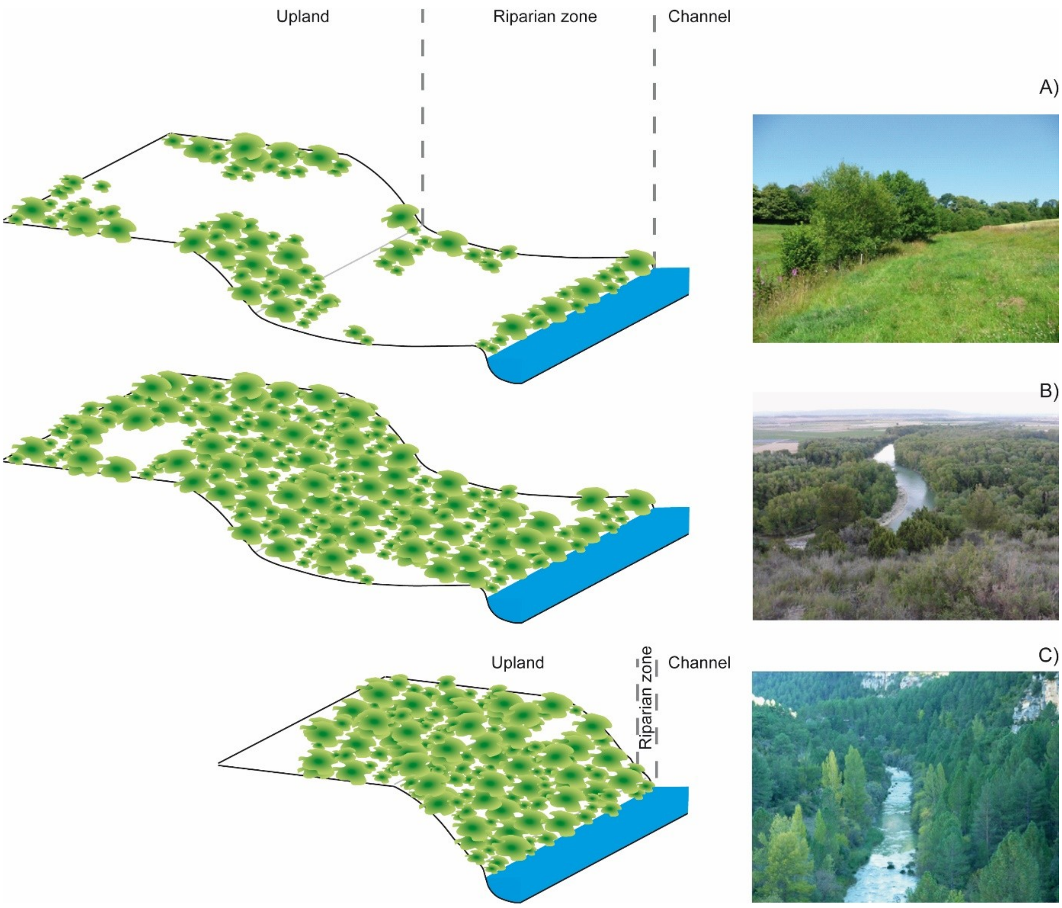


Figure 6. Illustration of variability in the riparian zone and vegetation; A: small rural stream with a riparian zone dominated by grasslands, with a narrow strip of trees along the stream (Normandy, France); B: a large forested floodplain (Aragón River, Ebro basin, Spain); C: narrow upstream riparian zone with forested banks and slopes (upper reach of the Tagus River, Spain).

4.1. VARIABILITY IN THE OBJECT

The first source of variability used to identify the riparian zone and vegetation is their inherent variability. Indeed, their structure and ecological functioning vary from one geographical context to another (Figs. 7 and 8). Globally, the main drivers that underlie the variation in structure and functioning are the following:

- **bioclimatic regime**, which drives, for example, the amount and the timing of water availability, disturbance by floods and post-disturbance relaxation times (Bendix and Stella, 2013)
- **morphological pattern**, which creates a 3D physical template for vegetation colonization and growth and drives stress and disturbance regimes (Corenblit et al., 2015)
- **land use context,** through direct (e.g. clearing) and indirect (e.g. water abstraction, river regulation) influences on vegetation

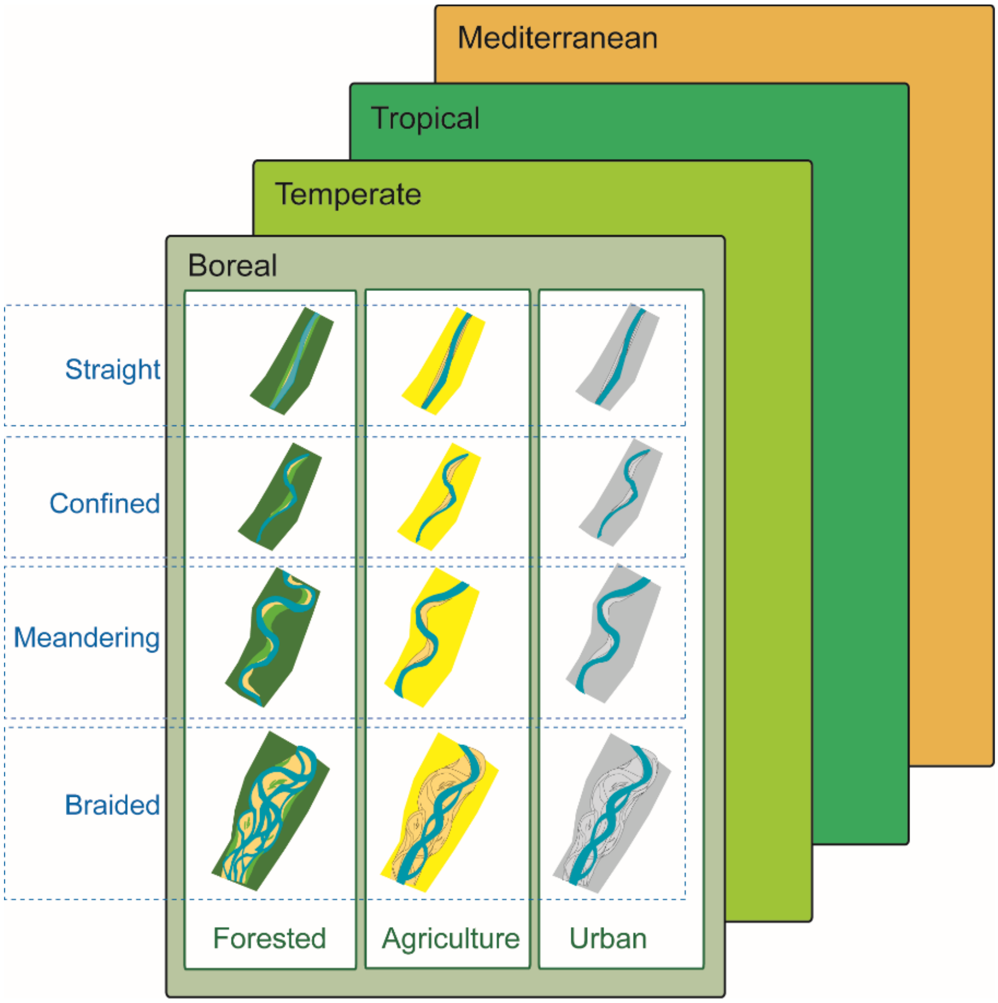


Figure 7. Sources of variability in riparian vegetation structure and functioning, showing examples of bioclimatic regions, each potentially harboring different fluvial biogeomorphological types and land-use matrices (e.g. forested, agricultural, urban). Note that not all situations are listed (e.g. arid climate) and not all combinations are necessarily possible. Time is not represented, but each reach follows a trajectory and can pass from one state to another over time. Moreover, each situation can refer to various sub-situations corresponding to different conservation statuses (e.g. spontaneous or planted, for a forested landscape).

In most ecoregions, late-successional phases should be dominated by trees, so the terms often refer to forested units: bottomland forest, riparian forest, alluvial forest (Table 1). In harsher ecoregions (i.e. colder and drier ones), however, thicket, shrub and grassland physiognomy should dominate.

Variability in contexts also influences the priority of applied issues and how riparian vegetation is studied. For example, from a hydrological perspective, upland water supply tends to dominate fluxes in upstream and narrow valley contexts, while channel water supply tends to dominate fluxes in downstream wider valley settings. Thus, studies of large systems may use the term “floodplain forest” and emphasize the roles of floods and groundwater (e.g. Pautou, 1984), while studies on upstream portions of a watershed focus more on the role of vegetation in the channel (e.g. Swanson et al., 1982).

Bioclimate, morphology and land use are all modified by human activities in a wide range of magnitudes depending on the sociological, cultural and economic contexts. Thus, the riparian zone and vegetation are co-constructed socio-ecological systems that follow complex trajectories and, for both biophysical (e.g. fluvial dynamics) and anthropogenic (e.g. grazing, planting) reasons, riparian zones are often a complex mosaic of a variety of land cover types and ecosystems (e.g. grassland, forests) (Fig. 7 and 8G, H and I). This mosaic can form a corridor at the landscape scale (Malanson, 1993). For example, in a drier context, riparian ecosystems can be particularly visible in the landscape as a strip of greener vegetation; in this case, the term “forest gallery” is sometimes used.

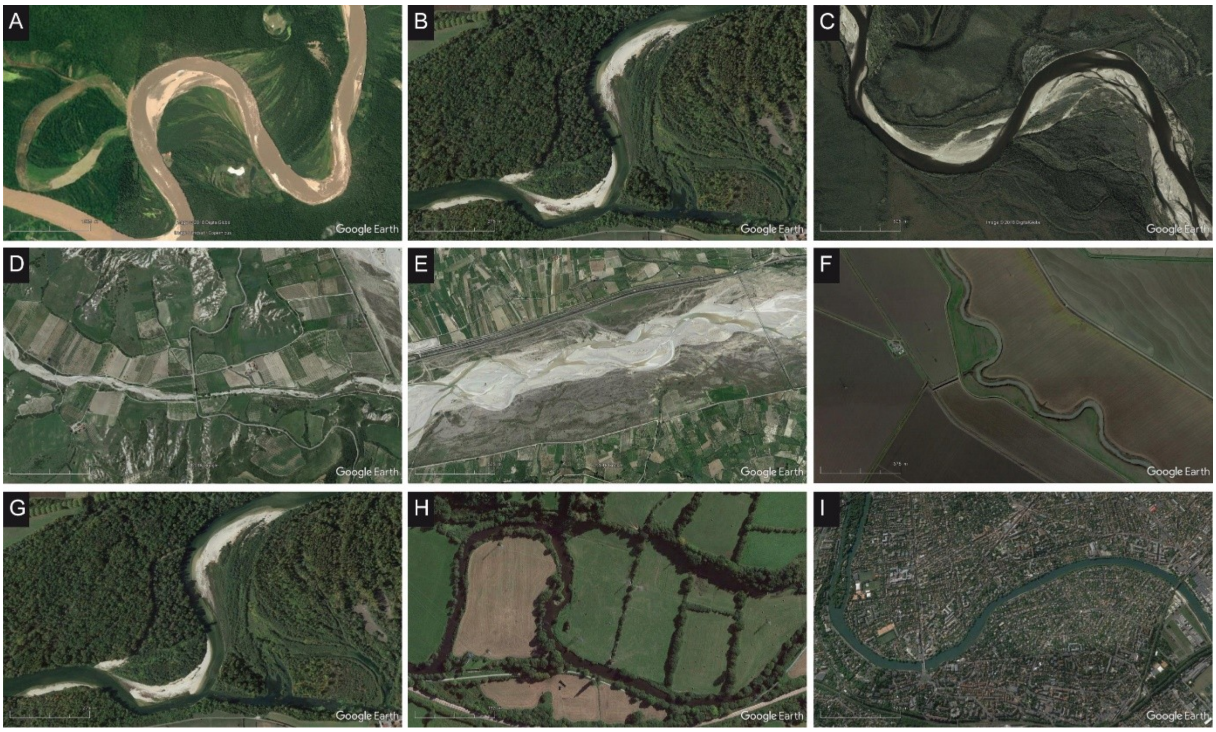


Figure 8. Examples of river reaches across bioclimatic regions, fluvial biogeomorphological types and land use matrices as illustrated in Fig. 1. A, B and C are meandering forested reaches in different climates. A: tropical context in the Amazon basin (Brazil), B: temperate context in the Rhone basin (France), C: boreal context in Alaska (USA), D, E and F are Mediterranean agricultural reaches in different morphological contexts. D: confined reach in the Duero basin (Spain), E: braided reach in the Duero basin (Spain), F: meandering reach in the Sacramento basin (USA), G, H and I are temperate meandering reaches with different land uses. G: forested in the Rhone basin (France), H: agricultural in the Seine basin (France), I: urban in the Seine basin (France). Images taken from Google Earth.

4.2. Variability in the representation

The second source of variability in identifying the riparian zone and vegetation is related to the variability in how scientists and managers perceive and represent them. For example, confusion can start with the adjective "riparian". In English, "riparian" appeared only in 1873, after the adjectives "riparious", "riparial" and "ripicolous" in 1656, 1846 and 1859, respectively (The Oxford English Dictionary, www.oed.com). It means “of, relating to, or situated on, the banks of a river”, but the definition of “banks” may include only the slope or also the top of the slope, which can extend to most of the floodplain.

This variability in representation can come from the goal of the study, the riparian function analyzed, the scientific background of the authors, etc. For example, the riparian zone has been defined as all of the following:

- the “area between the edge of the stream and the characteristic transition between organic and mineral soils” (pedological perspective of Ledesma et al., 2018)
- “part of the fluvial landscape inundated or saturated by flood flows [which] consists of all surfaces of active fluvial landforms up through the floodplain including channel, bars, shelves, and related riverine features” (hydromorphological perspective of Osterkamp (2008))
- “...where vegetation may be influenced by elevated water tables…and by the ability of the soils to hold water [and the] vegetation…that contributes organic matter to the floodplain or channel, or that influences the physical regime of the floodplain or channel by shading“ (more biologically oriented approach of Naiman and Décamps (1997))

5. Delineation of the riparian zone

The transitional nature of the riparian zone makes it difficult to provide an easy and universal approach to delineating it (Clerici et al., 2013; de Sosa et al., 2017). Two main approaches exist to solve this problem.

First, one can set a distance from the channel, possibly weighted by the size of the river. The advantage of this approach is a simple implementation of legal rules for banks (e.g. authorization to cut vegetation). Thus, it is used in several countries to preserve the riparian zone (e.g. USA, Brazil, Slovenia). In this approach, the distance should be based on literature that identifies a minimum requirement to ensure the production of one (or more) service(s) (e.g. bank stabilization, nitrogen removal). For example, in a review, Castelle et al. (1994) found that a buffer of at least 15 m is necessary to protect wetlands and streams under most conditions. Since the appropriate distance depends on the target service (or bundle of services; see de Sosa et al., 2017), this approach can yield a variety of values: Castelle et al. (1994) indicate a range of 3-200 m of buffer. When this fixed distance has a legal dimension, it results necessarily from a political compromise among several issues and actors. So, in many cases, the distance is based on a decision with little or no scientific evidence behind it, and the compromise often produces a relatively short distance that cannot capture all functions. Moreover, a fixed distance does not consider specific site characteristics such as fluvial landform configuration or processes, which are crucial for understanding riparian functioning and thus for adequately managing the riparian zone. A fixed distance can be considered a minimum requirement, but, from a sustainability perspective, it is far from being the most relevant approach because it is not based on socio-ecological functioning of a riparian zone.

Alternately, one can delineate the riparian zone using structural, functional or mixed approaches (for a comparison of approaches, see for example de Sosa et al. (2017) and Fig. 9). Indeed, formal delineation of riparian zones currently uses some structural parameters, mainly land cover and topographical characteristics. For example, Thomas et al. (1979) delineated the riparian zone by identifying the vegetation that requires free or unbound water or conditions that are wetter than average. Species composition can be used based on vegetation (Hagan et al., 2006) but also based on animals such as amphibians (Perkins and Hunter, 2006). Using different biological groups, however, can result in different delineations: Hagan et al. (2006) were not able to define the riparian zone of small headwater streams based on tree and shrub species, but they found a specific composition of herbaceous communities in the riparian zone that differed from those in surrounding areas. Moreover, they found a narrower width of the riparian zone than Perkins and Hunter (2006), who used amphibians. Additionally, this approach is difficult to apply at large scales.

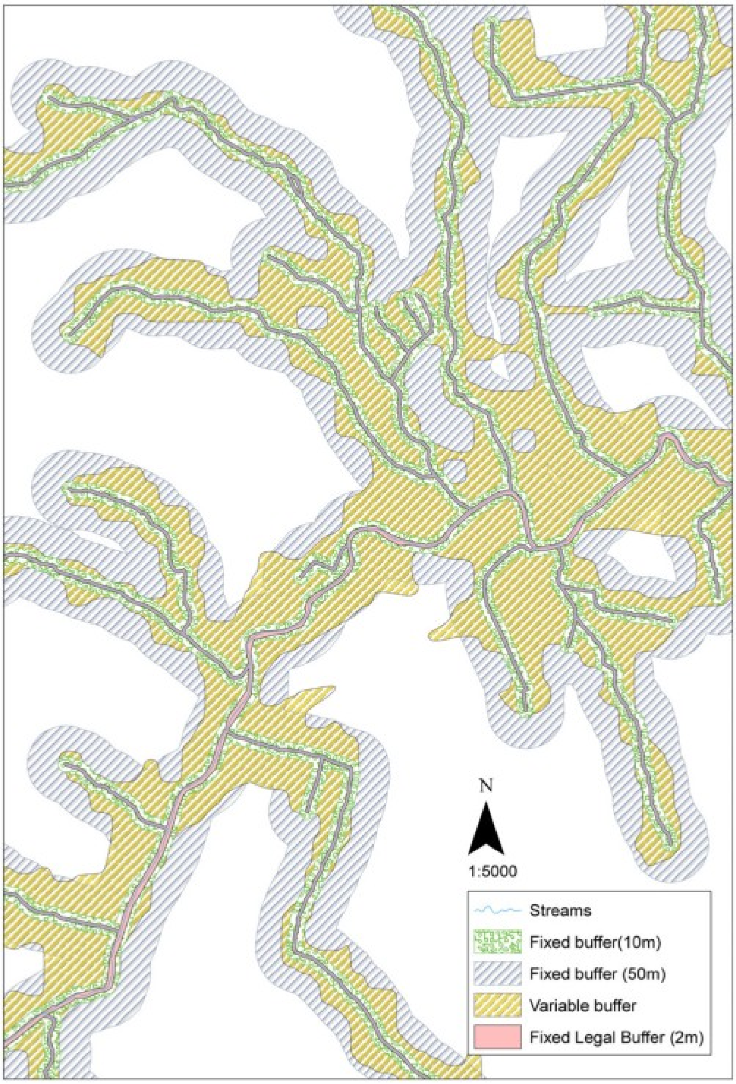
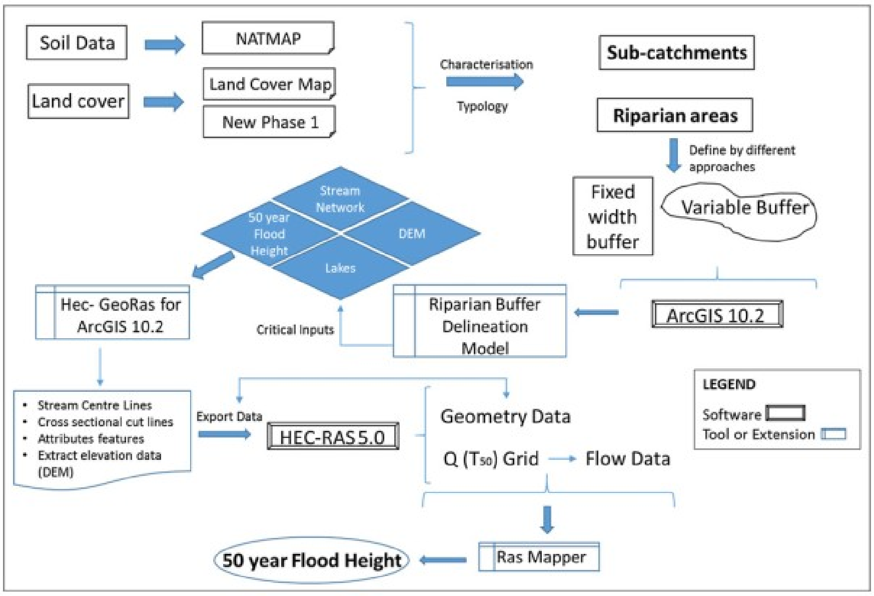


Figure 9. Example comparing approaches for delineating riparian buffers (Source: de Sosa et al., 2017).

At large scales, another structural approach is used, based mainly on topographical characteristics. For example, Ilhardt et al. (2000) and Verry (2004) developed approaches based on topographic characteristics and valley shape. This approach is particularly useful for large-scale identification, and the mapping process is regularly improved by continual development of remote sensing tools (especially for small streams). It has some limitations, however, notably for low-gradient streams with no valley floor.

Obviously, structural approaches struggle to capture the functional dimension of the riparian zone, and it is possible to develop more dynamic approaches, particularly by using a hydraulic criterion. For example, assuming that most riparian seeds need a flooding event to germinate and develop, the riparian zone could be delineated by the temporal requirements of a sustainable population of a target riparian species. If the target species are annual or perennial herbaceous plants, they will require a flood every 2-3 years, but if they are woody species (e.g. willows, poplars, alders), which have a longer life cycle, they may require a flood only every 10-20 years. Therefore, the riparian zone should be defined as the width that is flooded by the high flows with a return period of 10-20 years. This delineation corresponds approximately to Zone 4 of Gurnell et al. (2016) (Fig. 5), which is occasionally flooded but without sediment dynamics. This approach has three main limitations. First, it requires a flood elevation model. Second, it provides different widths of the riparian zone depending on the target species. Last, the driest zone in the Gurnell et al. (2016) conceptual model (i.e. flooding is absent or extremely rare, but soil moisture is permanent since phreatic water levels are high throughout the year) is difficult to model and, in most cases, needs field work to be identified.

Recent developments in available data and computing resources allow mixed approaches to be developed at large scales (de Sosa et al., 2017; Fig. 10). For example, at the European scale, an approach developed by the European Union (EU) Joint Research Centre combines a variety of information: a valley shape index calculated with a DEM, a flood elevation model (when available) and a fixed minimum buffer distance of 40 m from the stream based on scientific literature (Clerici et al., 2011; Clerici et al., 2013). Combining a fixed buffer distance and flood criteria (or topographic proxies) is a way to consider both the influence of the riparian zone on the river system and that of fluvial dynamics on the riparian zone; thus, it is the only way to provide coherent and relevant information for the main EU directives concerned by riparian zones (i.e. Habitats, Water and Nitrate directives). The EU system for monitoring, Copernicus, also provides three datasets dedicated to riparian zones (Land Cover/Land Use, Delineation of Riparian Zones and Green Linear Elements; see https://land.copernicus.eu/local/riparian-zones and Weissteiner et al., 2016).



A

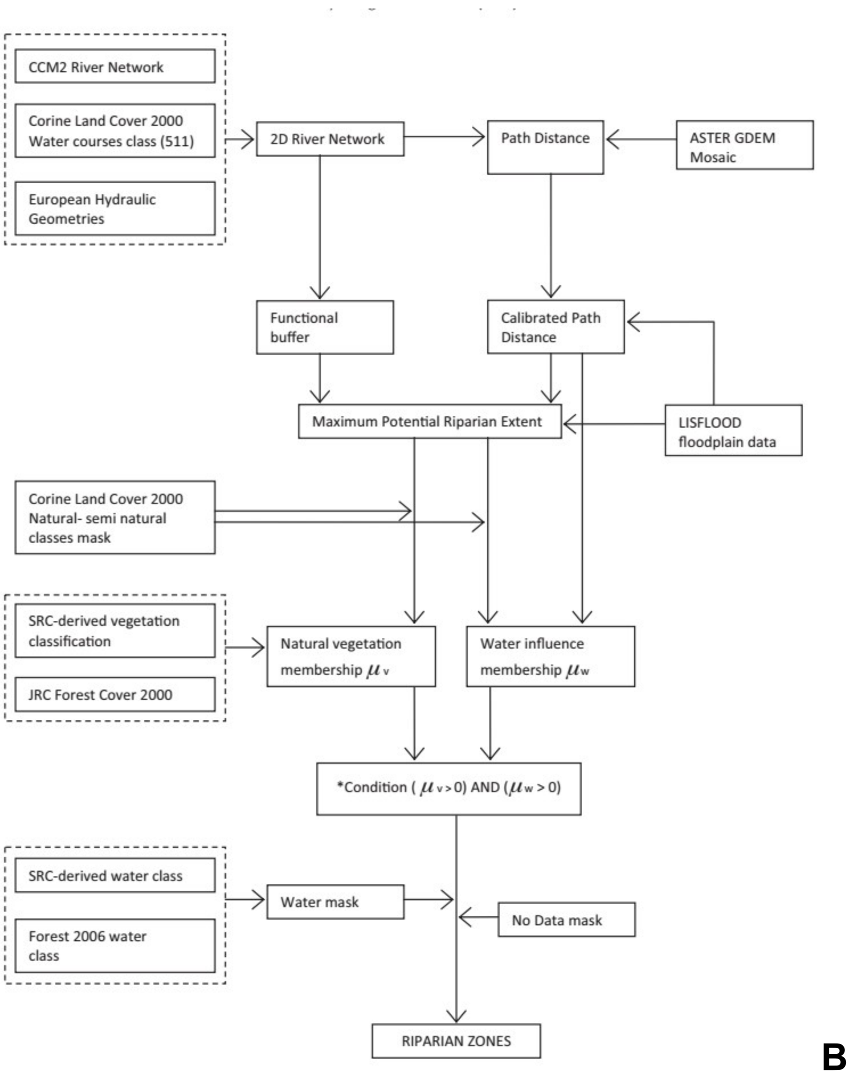


Figure 10. Examples of flowcharts for modeling riparian zone delineation (A) at the watershed scale in de Sosa et al. (2017) and (B) at the European scale in Clerici et al. (2013). The latter combines a fixed width ("functional buffer") with hydraulic ("LISFLOOD floodplain data", i.e. modeled 50-year frequency floodplain areas), topography ("ASTER GDEM Mosaic") and land cover data ("Corine Land Cover 2000").

CONCLUSION - RECOMMENDATION

To conclude, we consider riparian vegetation in fluvial systems as a co-constructed complex of vegetation units along the river network, regardless of physiognomy or origin, that is functionally related to the other components of the fluvial system and surrounding area. It belongs to the riparian zone, which is a hybrid and open landscape: hybrid because it results from co-construction driven by human and natural processes, and open because the land alongside fluvial systems influences, and is influenced by, the river and associated processes. Thus, the structure and ecological functioning of the biotic communities in this area vary along the four dimensions of the fluvial hydrosystem (including time). This variability is driven mainly by bioclimatic, geomorphological and land-use conditions, which change over time under the influence of natural and human drivers. This variability clearly influences how riparian vegetation is studied. Moreover, the fact that this variability is related to a particular context imposes some notable contingencies, creating difficulties for generalization and knowledge transfer.

To conclude, the main recommendations to improve integration of riparian vegetation in fluvial landscape management are the following:

1. Recognize riparian zones as co-constructed socio-ecological systems driven by natural AND human processes that follow complex trajectories over time
2. Consider riparian vegetation as an open system (i) related to the channel, the surrounding area, the upstream watershed, the atmosphere and the substrate and (ii) connected to these components through bidirectional fluxes
3. Promote the use of a definition/delineation that integrates and maximizes all functions within the socio-ecological system (i.e. supporting, provisioning, regulating and cultural ecosystem services)
4. Develop examples and tools to promote good practices in the application of riparian zone delineation
5. Clarify knowledge that is site-specific and knowledge that is transferable (e.g. minimum riparian zone width necessary for a given function, effectiveness of given topographic index in delineating the riparian zone)

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