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Fluvial Meanders as Generators of Riparian Sylvan Areas

The Case of the Brenta and Bacchiglione in the Anthropized Padova Province

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ABSTRACT

The riparian sylvan areas of the Brenta and Bacchiglione rivers in the upper Padova province are privileged elements in the Veneto landscape. In a highly anthropized context, sylvan areas develop spontaneously from the rivers' banks, providing both the local populations and the riverine environment with numerous ecosystem services. Attempting to demonstrate the spatial correlation of riparian sylvan areas in the analyzed context, the present research investigates the relationship between these elements and the rivers' meanders, to prove the hypothesis for which meanders are naturally generators of spontaneous vegetation in the riparian environments of the Brenta and Bacchiglione rivers. Secondly, the analysis investigates and assesses the consequences of the anthropogenic pressure on the analyzed riparian environments in the upper Padova province. Based on the geo-historical analysis of the study area, the research is concretely implemented through GIS procedure. The creation of a dataset that quantitatively defines the object of study, namely the riparian sylvan areas, is the preliminary step to the investigation of the research hypotheses. Having placed the data in its geospatial context, the accuracy of the initial questions is tested, and the influence that different territorial actors exert on the definition of the riparian sylvan areas' spatial distribution is assessed. The meanders and their vegetated areas are finally investigated from a qualitative perspective. Through the analysis of certain peculiar environments, the 'sylvan' reveals its unspoiled and wild nature. This research investigates further, on the one hand, the experiential and cultural value of the riparian sylvan areas, and on the other hand, brings under a new light an element of the Veneto rural landscape that, so far, has not been the object of many studies.

Keywords: riparian sylvan areas, meanders, GIS, rural development, spatial correlation

ABSTRACT IN ITALIANO

Le selve ripariali del fiume Brenta e Bacchiglione nell'alto padovano rappresentano un elemento privilegiato nel paesaggio veneto. In un contesto fortemente antropizzato, la loro diffusione negli ambienti rivieraschi è associata a numerosi servizi ecosistemici, i cui destinatari sono sia le popolazioni locali sia lo spazio fluviale. Muovendo dalla constatazione che la loro distribuzione spaziale non sia casuale, la presente ricerca indaga la relazione tra le selve ripariali e i meandri fluviali, nel tentativo di dimostrare l'ipotesi per cui i meandri rappresentino elementi che favoriscono lo sviluppo di vegetazione spontanea nell'area d'interesse. Un secondo obiettivo dell'analisi proposta è quello di approfondire e valutare le conseguenze della pressione antropica sulle selve ripariali del Brenta e del Bacchiglione nell'alto padovano. Basata su un'analisi teorica del contesto ripariale e su un approfondimento geografico-storico dell'area studiata, la ricerca è concretamente svolta attraverso procedura GIS. La creazione di un dataset, che definisce quantitativamente l'oggetto di studio, ovvero le selve ripariali, rappresenta il momento preliminare dell'analisi. Attraverso la contestualizzazione e l'interpretazione dei risultati, è possibile testare la veridicità delle ipotesi iniziali della ricerca, e valutare l'influenza che diversi attori territoriali esercitano nel definire lo spazio d'espansione delle aree silvane nell'ambiente ripariale. Mantenendo il contesto fluviale meandriforme quale quadro di riferimento della ricerca, le selve ripariali sono infine indagate da un punto di vista qualitativo. Questo approfondimento sottolinea il carattere incontaminato ed intimo delle selve, le quali da un lato assumono valore esperienziale e culturale, dall'altro si elevano ad elementi del paesaggio rurale veneto il cui studio è solamente in una fase iniziale.

Parole chiave: selve ripariali, meandri, GIS, sviluppo rurale, correlazione spaziale

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1 INTRODUCTION

1.1 Objectives

«Everything is related to everything else, but near things are more related than distant things» (Tobler 1969, as cited in Poorthuis 2023). Known as Tobler's first law of geography, this notion underscores the significance of spatial information. Real life's observations reveal that entities tend to form clusters. For instance, individuals typically exhibit greater similarity with neighbors than with people residing thousands of kilometers away. A population from the same geographical area is more likely to frequent a nearby market. Flowers in a field may bloom in specific clusters, suggesting that such distributions are not random but rather influenced by underlying factors. In other words, these examples prove the existence of the fundamental theoretical notion of spatial correlation (Poorthuis 2023).

The primary objective of this thesis is 1) to analyze the spatial correlation in the context of the riparian vegetated landscape of the upper Padova province, focusing on the meandering stretches of the Brenta and Bacchiglione rivers. This study is inspired by the observations of Professor Silvia E. Piovan, who started a project on evaluating, analyzing, and mapping green areas in specific contexts of the Padova region, such as fluvial meanders and Venetian villa areas. Specifically, this research considers the concentration of forests that develop in the proximity of meander bends. To ascertain whether these two elements - fluvial green areas and meander bends - are spatially correlated, the research aims to investigate the meanders of the Brenta and Bacchiglione rivers as potential generators of fluvial green areas.

Furthermore, this analysis seeks to provide a more comprehensive understanding of the dynamics that lead to the formation and development of riparian vegetated areas. Consequently, the anthropic element is incorporated into the research. As will be seen, the upper Padova province has experienced significant industrial development, agricultural expansion, and urbanization in recent decades. These human activities play a crucial role in shaping the aspect and distribution of riparian areas. Thus, a secondary objective of this study is 2) to assess the extent of the anthropic impact on the dynamics explored in the primary objective.

From a more technical perspective, the research provides a theory-based analysis of the formation of the riparian green areas in the studied context, founded on a methodological approach that analyzes this areas' development considering both geomorphological and anthropic factors. In particular, two research questions are tested in this analysis:

Within the context of the meandering stretches of the Brenta and Bacchiglione rivers in the medium-high plain of the Padova province …

1) … are fluvial meanders generators of sylvan areas, …

2) … and how much do human practices influence this dynamic?

The scarcity of data and the shortage of literature concerning green areas within this theoretical framework represent both an obstacle and a stimulus for the research. These paucities underpin the necessity to first define, identify, and classify such areas, taking into account their environmental context. To do so, the theoretical framework of this study is partially based on the findings of the national multidisciplinary project PRIN SYLVA 2017, and in particular of the local unit of the University of Padova (Piovan and Luchetta, in press). The object of this project was to investigate the notion of 'sylvan' (It. 'selva') as a new element that links nature and society. In particular, the present research refers to the publication of the book *Guida alla selva padovana* (ibidem), which gathers the findings discovered in the context of the universities' collaboration on the topic. The work proposes an original definition for the concept of a 'sylvan' area. The latter is adapted to the riparian context of the study and represents the starting point to answer the research questions.

1.2 State of the Art

The review of the state of the art examines on one hand the international literature to analyze the geomorphological features related to fluvial meanders and riparian vegetation. On the other hand, the local literature is investigated both to outline the geographical context of the study and to define the methodological framework of the analysis. By integrating these sources, the study aims to provide a comprehensive understanding of the dynamic interactions between meander bends and riparian vegetation formation, with a specific focus on the Brenta and Bacchiglione rivers. This approach will facilitate a nuanced exploration of both broad theoretical insights and specific local information, establishing a strong basis for the analysis.

The relationship between fluvial meanders and riparian vegetation has been the object of analysis by different academic authors at the international level. Specifically, the linkage between meander migration and riparian vegetation evolution has been particularly explored. The major publications on the topic generally specialize in three study directions. The first branch emphasizes the role of meander migration in influencing the vegetated area's shape and extension. A milestone in this field is represented by the work of Perucca, et al. (2006), who provided a model to predict the evolution of riparian vegetation in a meandering context, highlighting different patterns in the long run (vegetation's constant extension) and in the short term (higher pressure from the external environment, specifically human intervention).

A second flourishing field of publications investigates the impact of riparian vegetation on meandering river dynamics, focusing on the influence of plants in stabilizing streams and directing migratory movement. Within this branch, the stabilizing function of riparian vegetation in meander dynamics is acknowledged by different publications, such as Ielpi et al. (2022), Perucca et al. (2007), and Yu et al. (2020). In particular, Ielpi et al. (2022) outline a correlation between riparian vegetation evolution and meander stabilization; however, it states that ambiguity is not solved, as the degree of the impact of vegetation is still to be demonstrated. Perucca et al. (2007) look at the relationship between fluvial meanders and riparian forests with a twofold perspective: on the one hand, meanders condition vegetation growth, while on the other hand, forests' development influences meanders both stabilizing and orienting their movements. Regarding the latter phenomenon, other publications, such as Finotello et al. (2024), highlight the role of vegetation in giving shape and directions to the meandering rivers' channels. Finally, other publications fail to see a correlation between the two elements of analysis: in a study on the Claro River, a tributary of the Araguaia River in Central Brazil, Castro, De-Campos, and Zancopé (2019) stress the minimum contribution of vegetation's mitigation activity against the erosion processes and lateral migration of meanders.

A third branch of publications recognizes riparian forests' role in providing ecosystem services. Within this context, an ambitious attempt to outline a general framework for riparian ecosystem services is delivered by Riis et al. (2020); their work maps all different types of services provided by various categories of riparian environments, resulting in a detailed guide available for local analyses. Another interesting study on the topic is the one by Grizzetti et al. (2019); this work looks at the relationship between the ecological status of the fluvial ecosystem and the effectiveness of the ecosystem services; the study highlights that when the ecological status of a river worsens, regulating and cultural ecosystem services become ineffective while provisioning services increase their efficacy.

At the local level, recent publications focusing on the riparian areas of the Brenta and Bacchiglione rivers are limited, especially for the latter. Due to the scarcity of information, the most effective approach is to consult general volumes and publications about these rivers and extract relevant data for their riparian environments. Two primary sources of this research are the manuals *Il Brenta* (Bondesan, 2003) and *Il Bacchiglione* (Selmin and Grandis 2008), both published by Cierre Edizioni. These books provide extensive descriptions of the geomorphological, historical, and managerial features of the rivers, indirectly offering significant insights into their riparian areas and associated forests.

Regarding academic articles, research addressing riparian vegetation of the Brenta and Bacchiglione rivers is sporadic. Moretto et al. (2013) examine the morphological evolution of riparian areas, considering the impact of anthropogenic interventions such as river regulation and mining activities over the last century. Similarly, Rigon et al. (2012) explore related themes. Additionally, Sitzia et al. (2023) investigate the qualitative variation of vegetation in these rivers, analyzing how plant community changes correlate with the degree of human disturbances in the riverine environment.

In this work, both international literature and local research are used to provide a comprehensive analysis. On the one hand, international literature is employed to outline the theoretical framework and to offer a geomorphological and naturalistic overview of the key elements under consideration, such as riparian green areas and fluvial meanders. On the other hand, local publications related to the riparian areas of the Brenta and Bacchiglione rivers contextualize the theoretical insights within the specific geographic and ecological characteristics of the study area. This dual approach ensures that the research is both theoretically founded and practically relevant, allowing for a nuanced understanding of the riparian zones in question.

Finally, the methodological approach adopted in this research draws heavily on the works of Arrò (2023) and Canfailla (2023) on the one hand, which focus on the vegetated areas of the Venetian villas in the upper and medium Padova province, and of Piovan and Mora (2022) on the other, within the context of the abandoned railway that connects Treviso and Ostiglia. These studies, promoted by Professor Piovan, feature methodological similarities to the present research, particularly in terms of outlining a methodology and implementing a digitalization process to identify and analyze green areas. Although the parameters of the current research have been modified to better fit its objectives, an element of continuity with these prior works is represented by the partial overlap in the study areas. This research aims to contribute to expanding the knowledge about the riparian areas of the Brenta and Bacchiglione rivers by implementing this approach.

1.3 Thesis Outline

The thesis is intended as an original contribution to research on the area of interest, i.e. the riparian context of the Brenta and Bacchiglione rivers in the upper Padua region. The work makes use of a theoretical framework to provide a solid structure to the analysis. For this reason, the thesis is structured in such a way that the practical part, related to the evaluation of the accuracy of the research questions, is amply and clearly supported by an in-depth theoretical, geographical-historical, administrative, and botanical contextualization.

The work initially outlines a theoretical framework that investigates the geomorphological and botanical context of the research, namely the riparian environment in the context of the meandering river (Chapter 2). Especially, a first section (2.1) analyzes spontaneous riparian vegetation as a contextualizing element, outlining its typical visible and structural traits. An important focus is provided on the one hand by the analysis of the forces that exert pressure on this element of the river ecosystem, and on the other hand the influence that riparian vegetation wields on the surrounding environment, with particular reference to its ecosystem services. In the second part of the chapter (2.2), the meander is analyzed as a geomorphological element of primary research interest. Ultimately, an overview of the literature outlines those elements and dynamics that make it theoretically possible to consider the river meander as a particularly favorable environment for the development of spontaneous riparian forests.

An analysis of the geographical and historical context is subsequently proposed (Chapter 3). The Brenta River (3.1) and the Bacchiglione River (3.2) are respectively investigated from different perspectives. The ultimate goal of this context analysis is to narrate the characteristics peculiar to the riparian contexts of interest and to highlight the dynamics in the riverine context that exert influence on the appearance and structure of riparian forests. The analysis first describes the geographical and geomorphological characteristics of the rivers, with special attention to the sections of interest. A brief historical excursus starting from the dawn of human civilization is proposed, to return a picture of the riparian landscape in different periods of civilization on the banks of the two rivers. Finally, the vegetation of the Brenta and Bacchiglione rivers is described (3.3), to provide a botanical contextualization to the object of study and specify the peculiarities of the environments described.

The thesis proceeds by outlining recent and current local management practices of the riparian areas of the two rivers of interest in the analyzed sections (Chapter 4). The Brenta and Bacchiglione are initially investigated according to the various human activities carried out on their banks, which significantly influence their appearance (4.1). A quantitative analysis of riparian land use precedes an excursus on the various experiential and tourism offerings that are provided by riparian forests, with theoretical reference to the cultural ecosystem services that are identified for the studied area. In the second part of the chapter, a new alliance between riparian green areas and society is hypothesized (4.1), building on theoretical insights related to the concepts of rural development and participatory governance, and exploring some examples of innovative practices and projects that are implemented in the area under study.

The methodological approach provides contextualization and an interpretative key to the analysis (Chapter 5). The first need is to provide qualitative and quantitative parameters for defining the object of study of the research (5.1), which is identified as a 'riparian sylvan area'. The delineation of the features of the geospatial analysis is then proposed (5.2), with emphasis on the GIS theoretical framework, the used software, and the available data sources. Finally, the implemented procedure to answer the research questions is defined (5.3). Especially, the chapter outlines the rules for the digitalization of polygons representing riparian sylvan areas, identification of meandering river sections, and population of the dataset with the variables chosen for the analysis.

The results are then presented (Chapter 6). The quantitative analysis used to test the hypotheses outlined is described (6.1) through the display of graphics and maps, and an objective comment of the latter. Through this procedure, the two research questions are respectively investigated. In the second part of the chapter (6.2), a qualitative analysis aims to show the vast number of forest types that can be found in the riparian areas of the Brenta and Bacchiglione rivers. Using diverse visualization tools, a brief excursus is proposed, documenting the presence of unique landscapes hidden in the meanders of the two rivers.

The discussion is the last step of the research (Chapter 7). During this stage, an interpretive commentary is initially provided (7.1), concerning the findings of the previous chapter and to give an answer to the first research question. The findings related to the second research question are then discussed and interpreted (7.2), with particular attention to the significance of the procedures related to the creation of a new variable and its theoretical consequences. Finally, the discussion proposes a general reflection on the results (7.3). At this last stage, the limitations of the research and the development possibilities are described; in addition, a final account provides the main legacies of the thesis.

2 THEORETICAL FRAMEWORK

Although a definition of 'riparian sylvan area' is provided at later stages in this work (Chapter 5), this chapter outlines a theoretical framework for the context of study describing the aspect and structure of this typology of environment. Moreover, it analyses the features of the geomorphological entity influencing such areas, i.e. the fluvial meander.

In the first section, the characteristics of riparian areas are investigated (2.1). A structural framework for riparian vegetation is then outlined, identifying its types and progressive disposition. Subsequently, the analysis describes the factors influencing riparian area formation and evolution, with a focus on river sedimentation processes and on anthropogenic pressure. Finally, the ecosystem services of riparian vegetation are outlined, through an overview of the literature that emphasizes the importance of these environments from an ecological point of view.

In the second part of the chapter, the analysis looks at the relationship between riparian vegetation and meandering rivers (2.2). For this reason, the characteristics of the meanders are initially described with a focus on those processes - sedimentation and lateral-oriented meander migration - that most influence the formation and evolution of riparian vegetation. A literature overview is then proposed, regarding the role of meanders as generators of riparian forests.

2.1 What is Riparian Vegetation?

Riparian vegetation defines a riverine environment characterized by a high degree of heterogeneity (Bennett and Simon 2004). Riparian areas are inhabited by various plants that can be rigid or flexible, emergent or submerged, dead or alive. Despite the context variability, this vegetation shows certain specificities that contribute to its definition. The analysis of these elements represents the content of the first part of the chapter.

2.1.1 A Definition for Riparian Vegetation

The riparian vegetation is a transitional feature in the fluvial geosystem. Intermediate between the river and the upland, it exerts reciprocal influence with the adjacent realities. Numerous dynamics are grafted within these areas, involving the exchange of energy and matter between environments and actors. Moreover, when the riparian vegetation flourishes and expands in the river banks without interruptions, it forms buffer strips, serving as an ecological corridor with important ecosystem functions (Bennett and Simon 2004; Charlton 2008; National Research Council (U.S.) 2002).

Referring to the river framework, the riparian environment is defined by the type of vegetation that populates it, the soil composition of the area, and the reference hydrological characterization. These characteristics differentiate it from other riverine environments, such as the wetlands, even though flexibility is required when analyzing them. For example, concerning wetlands, the 'riparian zone' has a more expansive meaning on the one hand – since wetlands can be part of riparian environments – and a less expansive interpretation on the other hand – because riparian vegetation is related to specific geomorphic settings (National Research Council (U.S.) 2002).

In light of the stated characteristics, the riparian vegetation could thus be defined as the «plant life along a river network» (Riis et al. 2020), which is the result of the relationship between the river system and the upland (Bennett and Simon 2004) and which is characterized by a high rate of diversity (Gilvear et al. 2016).

2.1.2 Riparian Structure and Aspect

Literature has analyzed riparian forests within fluvial ecosystems, focusing on their transitional and transient elements to provide a structural explanation of their characteristics. The extreme variability of these environments represents an obstacle to its categorization. Nevertheless, the presence of constants in its appearance and disposition makes it possible to delineate a structural framework (Bennett and Simon 2004).

Riparian Vegetation Aspect

The riparian vegetation's type, disposition, and aspect are strictly related to the influence of the river, which plays a fundamental role in shaping its structure. Despite numerous context variations, certain characteristics are frequently found in such environments – at least in the mid-European and Mediterranean areas (Marchi 2009; Sitzia et al. 2023).

The framework described in this section refers to a specific monographic publication, the *Quaderni Habitat*, promoted by the Italian Ministry for the Environment, Land and See. This publication describes natural environments on Italian soil at high risk of degradation or with peculiar ecological characteristics[1]. The *Quaderno Habitat 21* ('*Fiumi e boschi ripari. Calme vie d'acqua e loro margini ombrosi*'), in particular, refers to river and riparian forests. Starting from the contents of this publication, the paragraph provides a quick overview of the different vegetation types in the riparian areas. Some ecological and botanical elements are provided, to underline the peculiar role of these environments.

[1] General information about the *Quaderni Habitat* content, objectives and methodologies are declared in the Italian Ministry of Environment and Energy Security website: https://www.mase.gov.it/pagina/i-quaderni-habitat-collana

Hydrophytic vegetation

Hydrophytic plants represent the first type of vegetation in the river environment. They develop on the riverbed and in the floodplain, especially when this is characterized by wetlands or, more generally, stagnant water. Hydrophytic vegetation usually roots in water and rarely comes to the surface – if not through the floral apparatus. These helophytes play an important role in the fluvial system decelerating the water flow and incentivizing sediment deposition in the areas where they are concentrated. At the same time, they receive the necessary oxygen supply from the water flow, and they can develop to form plant islands. In the riparian environment, various plant *genera* are found, such as the *Ranunculus* (*subgenus Batrachium*): *Ranunculus trychophyllus*, *R. penicillatus*, and *R. fluitans* are some of the members of this *genus* that populate the river environment (Argano 2012).

Halophytic riparian vegetation

Species such as *Nasturtium officinale*, *Apium graveolens*, *Veronica anagallis-aquatica*, or *Veronica beccabunga*, which generally develop from the edges of the banks, represent the main elements - for the area of interest - of riparian halophytic vegetation, i.e. that type of vegetation that, although rooted in the water, emerges with its body outside of it. A particular example of halophytic vegetation is represented by the reedbeds, usually located not far from the riverbanks. Reedbed (e.g. *Phragmites australi*, *Glyceria maxima*, *Typha latifolia*) is a typical riparian element in the mid-European context (Argano 2012).

Woody riparian vegetation

Gradually moving away from the watercourse, trees of variable height appear in the floodplain. Woody riparian forests owe their characteristics and structure mainly to the influence of the river, rather than to climate or geographical position (Argano 2012). Nowadays, the appearance of riparian forests is also heavily influenced by anthropogenic intervention: the expropriation of riparian vegetation is a human-led process that gradually releases the forest from its relationship with the river. As a result, it is complex to classify the types and progressive disposition of woody riparian vegetation. Literature has proposed different categorizations. An interesting classification model divides forest zones according to their features (Argano 2012). In particular, the model includes a tripartition:

- **Softwood floodplain forest**: a forest that includes tree species of low specific weight, normally affected by river flooding, such as poplars (*Populus*) and willows (*Salix*).
- **Hardwood floodplain forest**: a forest that develops above the normal high-water level and that is occasionally flooded. It includes species such as elm (*Ulmus*), English oak (*Quercus robur*), and ash (*Fraxinus excelsior*).

- **Lowland floodplain forest**: a forest that is free from the river influence and develops as a complex woodland populated by various species.

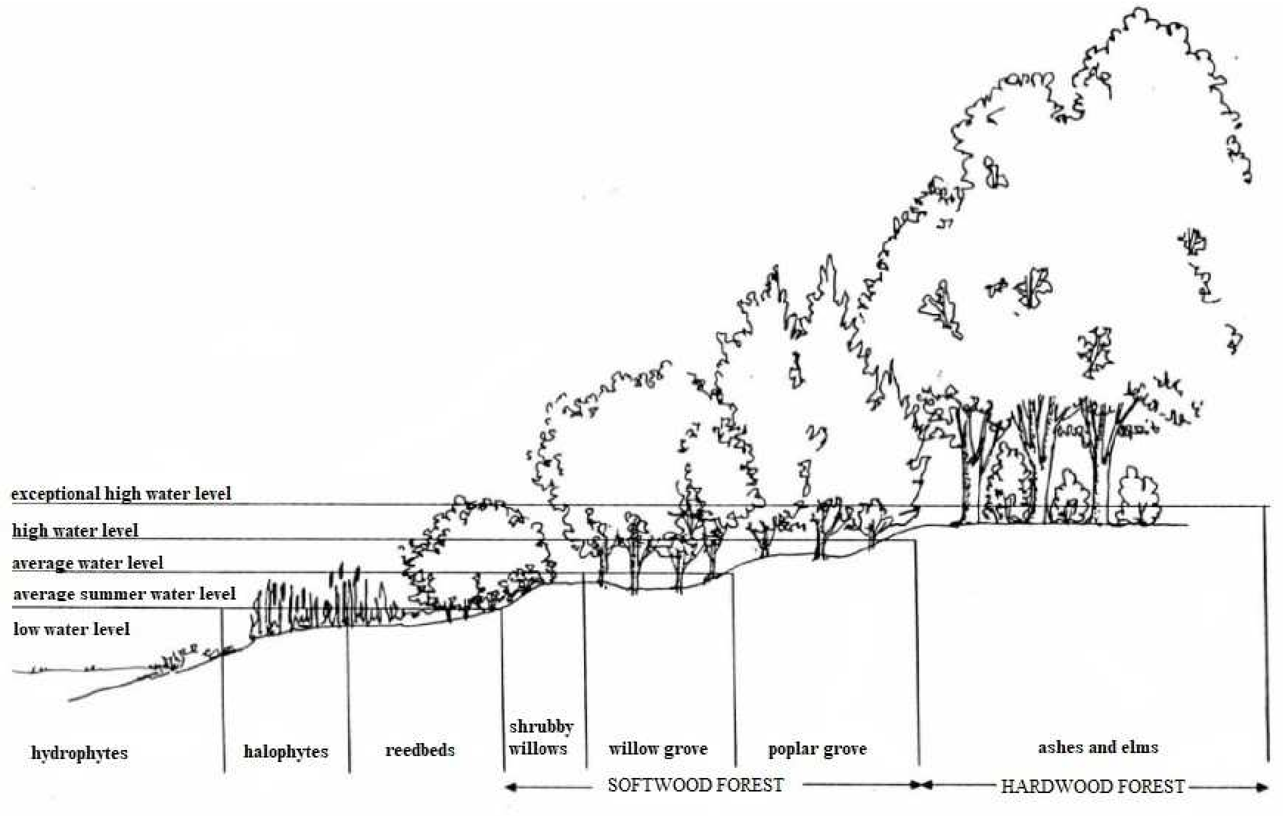

Figure 1. An example of the progressive disposition of riparian vegetation. Source: Paiero 1996, as cited in Marchi 2009. Modified by the author.

As summarized in Figure 1, different vegetation typologies populate the riparian areas. The characteristics of the specific riparian environments vary greatly depending on the geographical context. Therefore, models and frameworks are quite flexible, when used to guide the analysis of local environments. At the same time, certain elements represent a constant in such contexts: this is the case, for example, of the willow tree (*Salix*). Willow trees are a «typical riparian formation in the temperate mid-European area, with a preference for loamy-sandy soils with a shallow groundwater table» (Marchi 2009). The peculiarity of this plant is its adaptability to the variable water balance. On one hand, the *Salix* is endowed with a peculiar transpiring apparatus in its leaves and roots, that help the tree to compensate for the lack of water during low-flow phases. On the other hand, if a flood takes place and the willow's body is submerged in water, the *Salix* uses lenticels in its stem or other types of alternative metabolic pathways to overcome the oxygen deficiency and to eliminate the catabolites (Argano 2012; Marchi 2009).

The willow grove represents a distinctive element of the riparian system, thanks to its ability to cope with changes (even sudden ones) in the river channel. Several species of *Salix* can be found in this environment, relating to the type of soil on which they grow. In stony and gravelly riverbeds, shrubby willows spread (such as *Salix eleagnos*, *S. purpurea*, *S. triandra*). Large trees develop when the soils are richer in minerals and organic substances (*S. cinerea*, *Frangula alnus*, *Alnus glutinosa*). Finally, a prominent role is played by a peculiar species, the white willow (*Salix Alba*). This tree, once a constant feature of the Italian agricultural and rural landscape, is characterized by a pioneer and unstable feature that helps the tree to cope with river changes. The white willow quickly develops into a plant community, forming a willow grove that houses a rich and diverse undergrowth. The latter includes various vine species (e.g. *Humulus lupulus*, *Bryonia*, *Solanum dulcamara*, *Hedera*) and balsamic invasive species (*Impatiens*: *I. balfourii*, *I. parviflora*). If human- or natural-driven geomorphological modifications occur - reshaping the course of the river and reducing flooding phenomena – willow groves go into senescence, and the tree cover becomes rarefied (Argano 2012; Bondesan 2003; Marchi 2009).

2.1.3 Influence on Riparian Vegetation

The intermediate and transitional position of the riparian vegetation determines its exposure to various factors that shape its appearance and heavily condition its structure and evolution. From the point of view of hydrography, for example, the river's flow constantly influences the riparian area through bank erosion, sediment deposition, and changes in the soil moisture (Perucca, Camporeale, and Ridolfi 2006). The riparian environment copes not only with the river's influence, but also with the increasing effects of climate change on the one hand, and anthropogenic action on the other. All these processes significantly impact its diversity, density level, and colonization rates (Bennett and Simon 2004).

River Influence on Riparian Vegetation: Erosion and Sediment Deposition

The riparian vegetation's formation and evolution are strictly connected to the river system's processes, particularly the erosion and transport dynamics, and sediment deposition processes (Charlton 2008).

The sediment cycle is a fundamental process in the river system, continuously shaping the morphology of the territory. When the river crosses wide valleys with little slope and low channel gradient, the sediments are typically composed of fine elements, of sandy-silty or organic type. In such contexts, erosion increases the exportation of fine debris and dissolved materials such as salt and organic matter (Argano 2012; National Research Council (U.S.) 2002).

The sediment deposition process actively influences the riparian vegetation formation and evolution in the floodplain for two main reasons. Firstly, the river flow - through the sediment erosion-deposition activities - shapes the floodplain providing direction and space for the development of riparian vegetation. Secondly, it increases the unevenness of the soil in the floodplain. Riparian zones are typically very fertile and rich in nutrients and organic matter, as they are distinguished by heterogeneous soil type and depth. This represents a favorable element for the formation of spontaneous vegetation, but also for agricultural practices (Argano 2012; National Research Council (U.S.) 2002).

Anthropogenic Pressure on Riparian Vegetation

Human pressure represents a challenge for the riverine environment. Riparian vegetation often grows in the vicinity of agricultural areas, or on the banks of rivers that flow through cities and towns. Thus, it comes into contact with population centers and industrial districts. Anthropogenic action in most cases takes the form of hydro-geomorphologic alteration and regulation of the watercourses. These interventions harm the hydrologic footprint of the river, the level of conservation of the different riparian habitats, and the balance between different ecosystems (Bondesan 2003; National Research Council (U.S.) 2002).

Many reasons drive anthropogenic pressure on the riparian environment. Industrial activities have led human societies to consider the river a «mine» (Bondesan 2003), supplying economically relevant raw materials such as water and fish. Recently, mining – especially gravel quarrying – has resulted in the strong physical alteration of the riverine soil. The creation of quarries profoundly and drastically impacts the riparian landscape reducing its density and interrupting ecological corridors. A similar discourse can be held for hydroelectric power plants. Moreover, industrial and urban waste is typically poured over river water in the lowland context; chemicals and pollutants negatively affect the soils on which the vegetation grows (Bondesan 2003; Charlton 2008; Selmin and Grandis 2008).

In addition to industrial activities, agriculture significantly impacts riparian areas. Agricultural companies tend to expand cultivated land on the one hand and to ensure easy and direct access to river water on the other. As a consequence, spontaneous riparian areas are systematically restricted and replaced with more functional environments, such as row crops, livestock, or forestry. The interventions often lead to soil impoverishment and the increased instability of the river banks, which are no longer supported by riparian trees' roots (Charlton 2008; National Research Council (U.S.) 2002).

2.1.4 Riparian Ecosystem Services

The functions of riparian vegetation are all those biological, physical, and hydraulic services the riparian environment provides to the territories bordering it (Bennett and Simon 2004).

The riparian vegetation provides a series of services, properly called 'ecosystem services', to the river system and the upland. The concept of 'ecosystem service' is fundamentally economic, referring to the production of a certain type of value (Gambarotto 2022). This value carries a dual, intrinsic and instrumental, nature (Gilvear et al. 2016). On the one hand, something has intrinsic value when it refers to an ethical or ecological perspective, detached from any form of economic value based on people's willingness to pay (Gambarotto 2022; Riis et al. 2020). On the other hand, instrumental value specifically concerns the ecosystem's utility for humans (Gilvear et al. 2016).

Bearers of both these values, ecosystem services are defined as the concrete and tangible benefits that humans derive from the ecosystem and the natural processes (Gambarotto 2022; Riis et al. 2020). These services can be described as 'final services' when they directly benefit people, or as 'support services' if they concern the maintenance of the ecosystem's equilibrium (Riis et al. 2020).

Riparian vegetation performs numerous ecosystem services, affecting and influencing different environments and actors. The analysis and comparison of the literature led to the definition of a framework for these functions. Specifically, the global overview of riparian vegetation's ecosystem services proposed by Riis et al. (2020) and shown in Table 1 identifies 3 categories: provisioning services, regulating/maintenance services, and cultural services[2].

[2] The division of categories by Riis et al. (2020) follows the classification proposed by: Maes J, et al. 2016. *An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020*. Ecosystem Services 17: 14–23.
The list of ecosystem services is identified from the CICES framework: https://cices.eu (v. 5.1).

ES SECTION	**ES**	***BENEFITS AND GOODS***
Provisioning	Biomass production	*Fuel for heating* *Green biogas*
	Genetic material	*Food* *Extract genes for breeding*
Regulation and maintenance	Filtration of pollutants	*Filtration of sediments and toxic elements in streams*
	Carbon sequestration	*Reduction of carbon dioxide*
	Erosion control	*Protection and strengthening of banks* *Erosion resistance from roots*
	Flow alteration	*Deceleration, modulating effect*
	Pollination and seed dispersal	*Increased productivity for cultivated fields* *Increase biodiversity*
	Maintenance of nursery population and habitats	*Sustain population*
	Pest control	*Reduced in pest damage to agriculture*
	Microclimate regulation	*Temperature control*
Cultural	Direct interaction	*Recreation, tourism, etc.* *Local identity* *Knowledge about the environment*
	Indirect interaction	*Mental well-being, social cohesion, etc.*

Table 1. Riparian Vegetation Ecosystem Services Overview. Source: Riis et al. (2020). Modified by the author.

Riparian areas have various aspects: herbs, grasses, dry and wet forests, or wetlands. The type of riparian environment determines the intensity with which the ecosystem services enrich the land and provide tangible benefits to humans (Riis et al. 2020). Many of these functions are only hinted at in the proposed framework and are below analyzed more in depth.

For example, riparian vegetation provides a water purification function, through a twofold filtering action. On the one hand, hydrophytic vegetation acts as a mechanical filter, decreasing the flow speed and thus lightening the solid load; on the other, it represents a biological filter decreasing the phosphorous and nitrogen load in the water (Bondesan 2003; Marchi 2009; Naiman and Décamps 1997).

Microclimate regulation is another fundamental riparian service. Woody riparian trees – especially willows and poplars – can reach considerable sizes and provide shade for the surrounding environment. The benefits of shading are represented by the lowering of the water temperature - with oxygen dissipation - and by the reduction of the growth rate of aquatic plants, thus increasing the habitat space for fish (Argano 2012; Bondesan 2003). Similar discussions could be held for other services provided by riparian areas, such as the photosynthetic activity of aquatic plants - concerning phytoplankton, the first component of the food chain - or the role of riparian forests as nesting sites for birds and mammals (Bonato and Farronato 2012; Bondesan 2003).

Overall, it is possible to state that a large number of ecosystem services are provided by the riparian sylvan environment. These functions - which can be provisional, regulating/maintaining, or cultural - produce tangible benefits for humans through direct relationships or as a consequence of human non-use. For this reason, the management of riparian areas needs to be effective, considering both their intrinsic-ecological and instrumental-economic values.

2.2 Riparian Vegetation and Fluvial Meanders

Having assessed the main features of riparian vegetation, the analysis now looks at the dynamics of the formation and evolution of riparian vegetation in the meandering river context. Firstly, the investigation concerns the fundamental characteristics of meanders and the processes that are linked to them. This overview highlight the phenomena that positively or negatively influence the vegetation that grows in the floodplain of meandering rivers.

2.2.1 Meandering Rivers: Geomorphologic Elements

Fluvial morphology is briefly defined as «the study and interpretation of those landforms that originate from the river» (Marchetti 2000). In other words, river morphology is that discipline that investigates the processes involved in the production, transport, and deposition of sediment in the catchment area and the riverbed and the resulting territorial modifications. The dimensions and evolutions of all the elements that are part of the river systems lead to the creation of the riverine landscape as we see it (Bottazzo 2013).

In river geomorphology, the term 'meander' applies to a watercourse whose planimetric layout shows curvilinear loops that follow one another in a more or less repetitive and uniform manner. Generally located in low-slope areas, meandering rivers show moderate stream power and dense sediment activity, concerning the movement of fine debris such as sands, silts, and clay (Bottazzo 2013; Marchetti 2000)[3].

[3] This represents an opposite situation to what generally occurs in mountain river courses, where the slope is more pronounced and the erosion process more powerful, generally resulting in the transport of coarse sediments (Bottazzo 2013; Charlton 2008).

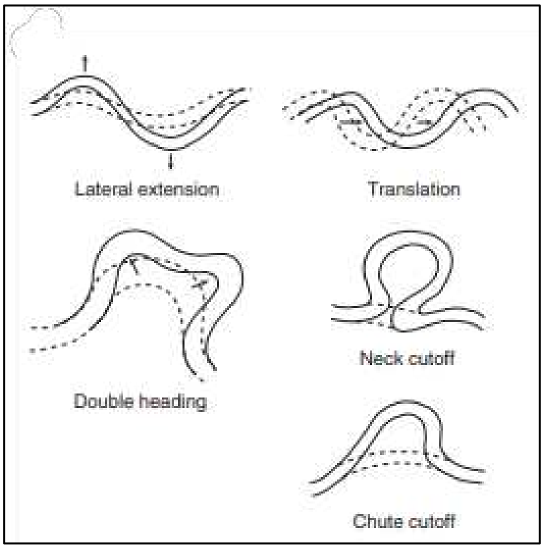

Figure 2. Types of meander migration and cut-off formation. Source: Charlton (2008). Modified by the author.

Generally scaled to the size of the channel, meandering rivers feature the typical meander bar in the inner part of the bend, where the finer sediments settle. The meander bar is not a stable element and is affected by intense mobility. On long time scales, or during exceptional floods, the meander makes lateral and longitudinal movements that heavily alter its shape. Channel movements can result in the transformation of the meandering river into a braided or straight river, and in the cut-off of the meander itself, as seen in Figure 2 (Bottazzo 2013).

Meandering rivers' channels are highly sinuous. Literature tends to consider channels with a sinuosity *ratio* greater than 1.5 as meanders (Bridge 2007; Bottazzo 2013), although flexibility is required (Charlton 2008). Meanders' sinuosity is not determined by the channel's width or depth, nor by the percentage of fine sediments in the water. Instead, it is mainly related to the channel slope (Bridge 2007).

Meanders sinuosity and appearance are also related to the migration phenomenon that interests the meandering channel. The evolution of meandering rivers is mostly led by the erosion and sediment deposition processes that are characteristics of these river morphologies. The tendency of the water flow to concentrate on the outer bank of the meander's bend has two main consequences. On the one hand, the erosion of the outer bank of the meander takes place: the flow digs into the floodplain causing lateral migration of the channel. On the other hand, the concentration of water in the outer part of the meander's bend leads to the increase of the channel depth of this section. This phenomenon creates a «pressure gradient across the channel» (Charlton 2008) that results in the generation of a compensatory flow that moves from the outer bank (high pressure) toward the inside of the bend (low pressure). This flow is weaker than the main one but is significant for the sediment transport to the inner part of the curve. Here, point bar deposits are created, with thick sediments sinking in the lower part of the bar and fine debris settling on the surface. This process allows the meander to maintain its width as it moves laterally. Over time, these phenomena lead to a considerable shift of the meander, and to the formation of cut-offs – i.e. former meander sections that are buried in the land and that are visible as slight slopes in the ground (Bennett and Simon 2004; Bottazzo 2013; Castro, De-Campos, and Zancopé 2019; Perucca, Camporeale, and Ridolfi 2006).

Many approaches have been used to quantify the features of meander rivers. Meander wavelength (λ) for example is represented by the mean of the distance between each meander bend and the successive one. Meander wavelength is strictly linked to the width of the channel usually being ten to fourteen times wider than the bankfull width (Figure 3). Moreover, it is influenced by the channel's substratum: gravel increases the wavelength, while finer debris - such as silt and clay - decreases it (Bridge 2007; Charlton 2008).

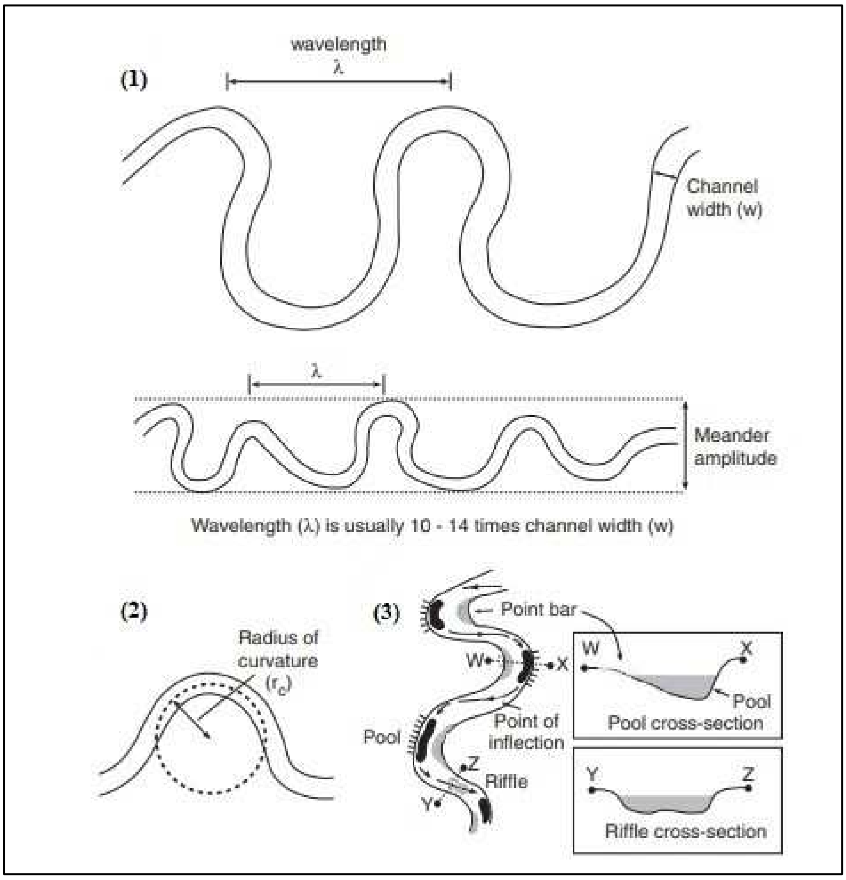

Figure 3. Aspects of meander geometry: 1) M. wavelength; 2) Radius of curvature; 3) Channel cross-sections at pools (X to W) and riffles (Y to Z). Source: Charlton (2008). Modified by the author.

Characterized by large curvilinear and constant loops, the meander represents a typical feature of fluvial geomorphology. Distinguished by a high sinuosity *ratio*, it is affected by the erosion process and sediment deposition that determine its evolution. In long timeframes, these phenomena lead to the movement of the meander and the re-shape of the floodplain, with important consequences for the aspect of the riparian landscape.

2.2.2 River Meanders as Generators of Riparian Vegetation

As previously seen, the riparian vegetation is strictly connected to the river system. This relationship consists of a reciprocal influence between the two environments. On the one hand, the river has a 'provisioning' role for riparian zones, continuously shaping the floodplain and enriching it with water, nutrient sediments, seeds, and organic materials that favor the growth of vegetation (Perucca, Camporeale, and Ridolfi 2007). On the other hand, riparian vegetation influences the river's flow, morphology, and water quality (as noted in section 2.1.4).

Nevertheless, the literature has provided scarce material on the relationship between riparian vegetation and meandering rivers, particularly regarding the possibility that meanders generate environmental conditions that favor the vegetation's expansion in the floodplain. As highlighted in the introductive chapter, the majority of the studies (Castro, De-Campos, and Zancopé 2019; Finotello et al. 2024; Ielpi et al. 2022; Perucca, Camporeale, and Ridolfi 2006, 2007; Yu et al. 2020; Zhu et al. 2022) look at the relationship between meanders and riparian vegetation in the context of channel migration. These studies are mainly directed towards two domains: on the one hand, the impact that meander evolution has on riparian vegetation; on the other, the influence that vegetation exerts in orientating meander movement.

Concerning the first field, meanders are considered favorable environments for the formation of important and diversified ecosystems. Hosting various habitats and significant carbon reservoirs, meanders offer resistance against the stress caused by anthropogenic action and the effects of climate change (Ielpi et al. 2022). The meander migration across the floodplain directly affects the riparian vegetation growing in it: the movement of a meander influences the evolution of the floodplain area through bank erosion, sediment deposition, and the creation of new spaces for vegetation establishment (Perucca, Camporeale, and Ridolfi 2006).

Concerning the second dynamic, the literature observes that riparian vegetation represents a key element in the development of meanders, given the importance of roots for bank stability (Yu et al. 2020); in general, vegetation is a potential stabilizer of meander channels and an enhancer of mud retention (Ielpi et al. 2022).

Meandering rivers and the vegetation growing in their floodplain exert a reciprocal influence in the context of channel evolution and migration. This relationship shapes the appearance, history, and evolution of these environments. In most of the analyzed research, the meander emerges as a decisive factor that positively conditions the growth and evolution of riparian vegetation. The literature's overview highlights at least three reasons to support this theory:

- The meander's mobility influences the size and shape of the floodplain, defining the spatial conditions for the formation of riparian vegetation (Bennett and Simon 2004; Castro, De-Campos, and Zancopé 2019; Charlton 2008; Finotello et al. 2024; Perucca, Camporeale, and Ridolfi 2006).
- The intense activity of sediment deposition - often including organic material - along the meander's banks increases the fertility of the riparian soil (Argano 2012; Bridge 2007; Gilvear et al. 2016; National Research Council (U.S.) 2002; Perucca, Camporeale, and Ridolfi 2006, 2007).
- The meander sinuosity determines an increased water availability in the riparian area, triggering dense exchanges of energy and materials - seeds, nutrients, dark organic matter - between environments (Bottazzo 2013; Bridge 2007; Ielpi et al. 2022; National Research Council (U.S.) 2002; Perucca, Camporeale, and Ridolfi 2007).

3 THE CASE STUDY

Having defined a theoretical framework on the characteristics and structure of the riparian green areas, as well as the role of meandering rivers in incentivizing the formation of such environments, the following pages are dedicated to the geographical and historical outline of the case study.

In particular, the object of this research is represented by the fluvial sylvan areas lying in the meandering stretches of the Brenta and Bacchiglione rivers, in the area north-west of Padova, Italy. As seen above, the riparian vegetation is closely connected with the river system in which it develops. For this reason, a focus on the Brenta (3.1) and Bacchiglione (3.2) rivers is provided in the first part of the chapter, through the outline of a geographical and morphological profile on the one hand, and a brief historical digression of the fluvial landscape on the other. In the last part of the chapter, the floristic peculiarities of these territories are explored (3.3).

3.1 The Brenta River

The Brenta is one of the largest rivers in northern Italy, with a total length of 174 km. It initially flows in the mountainous area south of Trento, then extends into the Veneto Po Valley, passing through Padova and flowing into the Adriatic Sea at Chioggia. The Brenta is a significantly anthropized river, that features a considerable variety of habitats, resources, and raw materials (Bottazzo 2013).

The stretch of the river Brenta that is the subject of the research is that of the territory north of Padova, especially in the area between Carturo and Vigodarzere. In this area, the river takes a typical meandering conformation associated with a flourishing growth of riparian vegetation.

3.1.1 Geomorphological References of the Brenta River

The Brenta River originates from Lake Caldonazzo, 450 meters above sea level. The river crosses the Valsugana valley in its mountain section, receiving the waters of several tributaries such as the Centa and Lake Levico. Characterized by a pronounced sinuosity, the river merges with the Ceggio and Maso to form the ‘Canal di Brenta’ - located in the valley that flows between Tesino and the Asiago Plateau on one side and the Grappa massif on the other. At Cismon del Grappa, the river’s capacity is increased by a second confluence with the Vanoi, the Senaiga, and the Cismon (the largest tributary). The river then flows between Cismon del Grappa and Bassano del Grappa through steep slopes and vertical walls. Finally, it reaches Bassano del Grappa, concluding its mountainous course after 70 km and opening up to the Po Valley (Bondesan 2003; Mihaila and Vallerani 2014).

The present research is mostly interested in the stretch of the river Brenta that flows in the high and medium plains of the Po Valley until the river reaches the city of Padova. The connection with the low plain occurs in Nove, in the province of Vicenza. Here the steep and craggy banks that characterize the riverine landscape before Bassano make way for low banks and pebbly beaches. This favors the development of the riverbed, which reaches an extension of over one kilometer in the stretch between Cartigliano and Friola. In the first part of the lowland section, the Brenta is configured as a braided river; it is characterized by large stretches of gravel on which the main branches of the river develop. The main branch is generally always active, while secondary channels' flow varies depending on the time of year: they are active during the flooding periods of the river. Riparian vegetation appears with increasing density and variety in inactive secondary channels (Bondesan 2003; Bottazzo 2013).

After crossing the Fontaniva bridge, the Brenta decreases its width and number of channels. Finally, at Carturo, the Brenta becomes a straight river with one channel. At Piazzola sul Brenta, the meandering course begins. The meanders continue sinuously until Limena, on the outskirts of Padova. In this stretch, the nature of sediments changes: they are typically of silty clayey and sandy type, while in the high plain stretch, gravel was the predominant type of sediment (Bondesan 2003; Bottazzo 2013).

The Brenta does not receive the contribution of major tributaries in its upper and middle plain sections. The Muson dei Sassi represents the only considerably large tributary of the area, converging with the Brenta in Vigodarzere. The Brenta River in this stretch is mostly affected by the influence of underground aquifers. The connection between surface and underground water bodies represents the starting point of the water cycle in the eastern Po Valley - especially in the Padova-Vicenza area[4]. In the upper and middle plains, the water cycle of the Brenta River takes different connotations based on the position. On the one hand, the Brenta karst spring area (It. 'Fascia delle risorgive del Brenta') is located in its piedmont section. In this territory, the channel floodplain is mainly composed of gravel which increases the permeability of the soil. This favors water absorption, increasing the risk of summer drought. Humans have historically overcome this risk by implementing an irrigation system for agricultural activities. An opposite situation occurs in the middle plain, up to the river's entrance in Padova: the presence of finer sediments (silt, clay, sand) in the water leads to lower soil permeability and to an increase in the risk of water stagnation. For this reason, humans intervene in

[4] This cycle is environmentally very important, as it determines the flow of chemicals and pollutants transported in water. For more information see: Bondesan 2003.

this territory by building drainage works (ditches) to contain the river flow (Bondesan 2003; Surian et al. 2005).

The considerable variety of riverbed types of the Brenta up to its arrival in Padova represents a peculiarity of this river. In the mountain section in fact, the Brenta is generally a single-channel river; in the high plain section, it is braided and characterized by gravel; finally, in the medium plain section, it takes on a meandering conformation. The considerable typological diversity of the riverbed can be explained by looking at the relationship between the river's flow speed and its transport capacity - i.e. the ability of a watercourse to move sediment (Bondesan 2003; Sun et al. 2023). In particular, the higher the flow speed, the greater the river's transport capacity. For this reason, the slope plays a fundamental role: in the foothills, for example, where the river has a slope of 4%, the flow moves gravelly debris. Downstream, where the slope is <1%, it is mainly sandy and silty debris that is transported. Therefore, the slope variation between the different sections of the Brenta River determines the riverbed variety. This conformation is also typical of other rivers, such as the Piave and Tagliamento (Bondesan 2003; Bottazzo 2013; Surian et al. 2005).

3.1.2 Anthropogenic Pressure on the Brenta

The scientific interest in the Brenta area increased significantly between the 19th century and the 1980s. The considerable amount of sources relating to this period makes it possible to outline a recent history of the variations undergone by the riverbed in the section of the upper and middle plains (Bondesan 2003).

The meandering stretch between Friola and Carturo on the one hand, and Limena on the other, was subject to modifications in the last century. In Limena, in particular, flood events led to the cut-off of meanders. In Campo San Martino, the erosion and sediment deposition activities caused the meander bars to migrate southwards in the 1950s (Bondesan 2003).

In the second half of the 20th century, human intervention in the Brenta River became more insistent, and several gravel quarries were created along its high plain course. Gravel extraction has led to an increase in the width of the meanders, eventually creating small artificial lakes. In addition, quarries' activities have led to the river incision, increasing its depth by 7-8 meters and spreading the risk of bridge scour. This is what happened when the Fontaniva bridge collapsed on 14 October 1976. Since the 1970s, careful regulations have been imposed on mining activities (Bottazzo 2013).

Gravel extraction is not the only reason why human population has dealt with the Brenta River throughout its recent history. The Brenta is a river with a modest flow rate and a general low-water condition – even though sudden floods can occur, especially in heavy rainfall periods (Mihaila and Vallerani 2014).

The Brenta's waters have been used for various functions, such as timber flow and energy supply for mills. More recently, other functions have been identified, as outlined above. In general, it is possible to divide the typologies of use of the river and its environments into three fields: hydroelectric, civil, and agricultural. In particular, the latter greatly influences the floodplain and riparian zone of the river, through the diversion of the river channel, and the creation of irrigation systems and drainage facilities (Bondesan 2003).

Humans have also dealt with the Brenta River during the sporadic but disastrous flooding episodes that have characterized its recent history. The local authorities have frequently devised defense systems against these phenomena, although the floods have not always been contained - for example during the catastrophic episodes of 1882 and 1966 (Bondesan 2003; Mel et al. 2020).

3.1.3 History of the Brenta and its Riparian Areas

The outline of a history of the Brenta River in its upper Padova section is necessary to highlight the historical context of the area of interest and to analyze the evolution of the territory and landscape over the centuries. A concise description is proposed providing the reader with an 'image' of what the Brenta's riparian green areas looked like at different historical moments. The temporal division reflects the one that has been proposed by Bondesan (2003), despite some modifications.

Prehistory and Protohistory of the Brenta River

The oldest human evidence in the upper and middle Brenta plains is in Cittadella, in the province of Padova. In the late Bronze Age, a village was built near the river at the height of Motte di Sotto di San Martino di Lupari. The proximity to the river had to represent an advantage for proto-agricultural (cereal) practices and for the goat, cattle, and sheep breeding that were developing at that time. Later on, at the turn of the Bronze and Iron Ages, the area north of Padova became a settlement and peopling attraction for the people inhabiting the upper Veneto plain. The improvement of agricultural and breeding practices is closely linked to the proximity to the river and its waters. Despite this development, the area of interest was still dominated by forests and few settlements were present; the societies that inhabited it were scattered, uncoordinated, and mainly tribal - with the preponderance of a few individuals, or Big Men (Bondesan 2003; Fabietti 2015; Zago and Guarnieri 2022).

In the Iron Age (8th century), true hegemonic centers emerged in the area, with important political and economic functions. The rise of centers of power is related to the development of the society of the Veneti, a population with a complex social organization who had settled in the area. The main centers of this civilization were Este, south of the Colli Euganei, and Padova. The latter was founded on the eastern counter-anchor of the Brenta (or *Meduacus*, as it was called by the Latins). The new centers of power, with the institution of markets between indigenous populations and external civilizations, led to an increased circulation of objects of various kinds. Artifacts of Etruscan and Villanovan origin have been found in this area, demonstrating the dense network of exchanges that existed at the time (Matteazzi 2017).

The Brenta Landscape under the Romans

From the 2^{nd} century, the area of interest fell under the complex Roman management system. Indeed, the territory, located along the banks of the Brenta *up* to the north of the city of Padova, became an important transit area, especially during the seasonal transhumance of sheep from the mountain down to the plains. It was during this period that two transhumance routes were consolidated along the Brenta: the so-called ‘Arzeron della Regina’, located on the right of the river and reaching Marostica, and a second route located left of the river and going as far up to Trento. They both were important in defining the breeding and economic activities of the territory and intersected with the Via Postumia, an important Roman trade route (Bondesan 2003; Matteazzi 2017).

The riparian area of the Brenta north of Padova has been affected since the 1st century B.C. by the massive process of ‘centuriation’ by the Romans. The centuriation resulted in the disruption of the riparian landscape, as well as an increase in agricultural and livestock production. In general, it can be said that the centuriation process stabilized the area of interest, at least in its portion to the left of the Brenta. As for the western part, the territory was not subjected to land reclamation and cultivation; this seems to be due to the difficult hydraulic regulation of this area. As a consequence, while the eastern side of the Brenta was made suitable for agriculture and human settlement, the part to the right of the river remained uncultivated, inhabited by forest, and used by humans only for hunting, fishing, timber production, and grazing (Bondesan 2003; Favaro and Previato 2023).

The organization of the riparian area north of Padova, in the upper and middle plains, remained unchanged during the Roman imperial age, between the 1st and 4th centuries AD. Only in the second part of this period, when the empire was hit by a severe economic recession, did the countryside enter a crisis. In addition, increasingly frequent invasions by barbarian tribes upset the social, legal and economic structure of the territory, and further disrupted the countryside, which lost part of the stability and order it had gained in previous centuries (Bondesan 2003; Favaro and Previato 2023).

Territorial Modifications during the Middle Age

In the Middle Ages, the name 'Brenta' began to appear to designate the river. In particular, it was Bishop Venanzio Fortunato, a native of Valdobbiadene, who between the 6th and 7th centuries mentioned the name *'Brinta'* to indicate the river in his *Vita Sancti Martini* (IV, 677) (Matteazzi 2019). The name likely derives from a revival of a traditional term generally used to identify watercourses in the Veneto region. It is no coincidence that many rivers in the area - even the Bacchiglione - are sometimes called by the same name in written sources (Bondesan 2003; Matteazzi 2019).

The history of the riparian area bordering the Brenta in the upper and middle plains is quite tumultuous in the medieval period. In particular, the river was in close contact with the *'contado'*, i.e. the countryside under the influence of a city. The *contado* north of Padova experienced a politically agitated situation in the medieval period, which directly influenced the appearance of the river and its riparian area (Bondesan 2003).

Before the year 1000, documentation concerning the Brenta was scarce, and the only sources we have to reconstruct the relations between humans and the river environment are represented by a few documents concerning prevention measures or claims of sovereignty by the public power. During the early Middle Ages, the river Brenta was generally considered a prerogative of the sovereign, who could grant the waters and riparian areas to the population. It is only after the 11th century that the sources become more consistent. In particular, the war that Padova and Vicenza fought to secure control of the countryside area between the two cities assumes primary importance. Between the 11th and 12th centuries, a series of fortified centers rose on the riparian areas of the Brenta, controlled by various feudal houses. The presence of strongholds in the Middle Ages, which would later become strategic bases for rural lords in the Ottonian Age, is documented in several towns, such as Fontaniva, Tavo, Carmignano, Canfriolo, Piazzola, Curtarolo, Limena, Busiago di Saletto, Carturo, Vigodarzere, and Torre. During this period, we also witnessed the rise of several noble families, such as the Sicheri from Fontaniva or the Counts Maltraversi from Carturo, who carried out important land management operations in the Brenta's areas (Bondesan 2003).

Parallel to the political-military activity, between 1050 and 1200 a massive clearing of the forest area west of the Brenta took place. This dense vegetation included extensive forests of oaks, hornbeams, ash trees, alders, willows, and poplars. The area was used by humans mainly for timber provision and hunting since Roman times. In the 12th century, the deforestation process was followed by the foundation of numerous new centers. These villages maintained until today a micro-toponymy that recalls their 'sylvan' origin: Fratta, Boschetto, Boschiera, and Saletto are some of the examples. The action of deforestation did not, however, lead to the total disappearance of the woods, and the presence of several forests - renamed at the time *nemus Busillaci*, *n. Altacarisice*, *silva Coaza*, *silva de Brenta*, and *silva Porpora* - is attested along the margins of the Brenta (Bondesan 2003; Brogiolo 2015).

Starting from the 12th century, the dispute between Padova and Vicenza over the banks of the Brenta became more bitter, culminating in the war of 1147. Following the peace of (Di Bernardo 2014) Fontaniva in that same year and some incursions northwards, Padova gained control of the Brenta from Valsugana to its mouth. The consolidation of Padova's presence in the area was entrusted to the ecclesiastics: an example is provided by the foundation of the monastery of San Bernardo, which established chiefs and tithes in Campo San Martino, Curtarolo, Vaccarino, Vigodarzere, Cadoneghe, etc. In the meantime, the Padovan public authority carried out a series of hydraulic interventions, aimed at increasing the stability of the river. In this way, Padova would be able to consolidate its dominant position in the river territory, further developing agriculture and building a navigation infrastructure (Bondesan 2003; Cabianca 2022).

In the 14th century, the river was influenced by further human interventions - especially when Padova was under the control of the Carrara seigniory. These interventions were aimed at improving the defensive system of Padova, but also at the construction of mills and factories on the riverbanks. In addition, modifications to the river geomorphology would improve the 'wood route', through which tree trunks were transported from the mountainous environments to the city of Padova, where they could be processed (Bondesan 2003).

The river's anthropization level increased again in the 15th century. In addition to the phenomena described above, Padova's authorities attempted to modify the river morphology of the Brenta at the height of the meanders south of Carturo. This was because the frequent flooding of the Brenta and the modifications of the riverbed undermined the stability and safety of the riparian environments and the villages. Moreover, the construction of the Brentella Canal in Limena represented an important hydraulic intervention in that period. The artificial canal would connect the Brenta and Bacchiglione, increasing the latter's water capacity (Mel et al. 2020; Padova Municipality 2004).

New Challenges under the Venetian Republic

In modern times, the Venetian influence gradually interested the entire area. The Brenta River and its riparian territories were in a transitional position, particularly privileged from a political and economic point of view. Also, for this reason, Venetian and Italian scholars started a wide-ranging hydraulic-scientific debate concerning the management of the Brenta and the need to regulate its course. This led, in particular for the area south of Padova, to an intensive river regulation, which heavily modified the appearance of the riverine environment (Bondesan 2003).

In general, it can be said that in the Venetian era, the area of interest represented a challenge for the local administration. Indeed, the latter had to constantly look for a balance between the different activities - especially agricultural ones - that were carried out in the area. The Venetian authority looked at the Venetian countryside with a twofold purpose: on the one hand, it supplied the capital with agricultural and food products, and on the other, it represented the 'garden' of the city itself, with which certain aesthetic obligations were associated (Bondesan 2003; Occhi 2004).

3.2 The Bacchiglione River

The riparian area of the Bacchiglione River in the upper part of the Padova province represents the second subject of investigation in this research. The Bacchiglione River is smaller in size than the Brenta, with a length of 118 kilometers. It originates in the Veneto region, specifically in the piedmont area above Vicenza. The river crosses the Po Valley south of the Brenta and flows into the Adriatic Sea at Chioggia, in proximity to the mouth of the Brenta (Selmin and Grandis 2008).

The stretch of the river that interests this study is the one between Cervarese Santa Croce and the southern gates of Padova. The river flows through the entire upper Padova area along a sinuous meandering path. The sylvan vegetation that develops on its floodplain features specific characteristics, linked to the geomorphological elements of the river, as well as to its history and relationship with man.

3.2.1 Geomorphological References of the Bacchiglione River

The Bacchiglione River features an intricate hydrographic system, that is even more complex than that of the Brenta. The complexity is clear from the river's origin, which is twofold: it originates from the confluence of the outflows of several pre-alpine streams on the one hand, and the groundwater located in the plain above Vicenza on the other. The Bacchiglione karst spring (It. 'Fascia delle risorgive del Bacchiglione') represents an element of primary importance for the territory of the upper Veneto plain. It supplies the aqueducts of several cities, such as Vicenza, Padova, and Treviso. This belt originates in the transition zone between the gravelly soils of the high plain and the silty-sandy soils of the low plain. The low permeability of the latter soils determines the outcropping of water and the formation of the so-called 'Risorgive' of Vicenza (Di Bernardo 2014; Picci 2015; Selmin and Grandis 2008).

The course of the Bacchiglione River originates in Novoledo, at about 60 m above sea level. Here, water from several springs forms the Bacchiglioncello, which represents the initial trunk of the river. Later, the channel merges with the Timonchio and takes on the new nomenclature of 'Bacchiglione'. In the karst spring area, the Bacchiglione benefits from the inflow of several resurgences at Muzzana, Menegatta, Maddalene, and Feriana. In Vicenza, the river joins the Astichello and Retrone canals, significantly increasing its flow rate. From the southern gates of Vicenza, the river takes on a meandering course (Selmin and Grandis 2008).

When it reaches the Berici Hills, at Logare, the Bacchiglione converges with the Astico-Tesina, a river that accounts for about half of the Bacchiglione basin (700 km^2). After being fed by other resurgences (at San Pietro in Gu and Grantorto), the river continues its meandering course as far as the gates of Padova. In the upper Padova section, the river is wide, muddy, and subject to sudden floods. Just before entering Padova, the Bacchiglione obtains a new water supply from the Brentella, an artificial canal that originates from the Brenta. Once it enters the city, the Bacchiglione divides into three artificially created branches. In particular, the main canal - the Tronco Maestro - goes in the direction of the Naviglio. It is complemented by two other branches: the Battaglia, built between 1189 and 1201, and the Scaricatore, built in 1863 (Di Bernardo 2014; Selmin and Grandis 2008).

The Bacchiglione is a river that in its upper and middle reaches is characterized by a complex hydrographic system, due to its peculiar dual origin and its relationship with the underground waters. In the mountain and foothill area, it flows through a considerable variety of environments, such as the alpine and pre-alpine contexts. In the plain area instead, starting from the area south of Vicenza and continuing in the Padova area, it is characterized by a peculiar meandering course. The meanders of the Bacchiglione are particularly favorable to the development of aquatic vegetation, which strongly characterizes the riparian landscape (Selmin and Grandis 2008).

3.2.2 The Bacchiglione and Human Intervention

Over the centuries, the Bacchiglione River has represented a challenge for the population and the authorities in charge of the river management. This is due, first of all, to the complexity of the river itself which, as we have seen, has peculiar characteristics. Moreover, the significant anthropization of the river has led to major modifications to the riverine environment, compromising some of its functions. Finally, the management of the Bacchiglione is complicated by the link of the river with the Brenta and the influence exerted by the latter (Selmin and Grandis 2008).

Similar to the Brenta, the Bacchiglione is subject to sudden and frequent floods. In addition to the two great floods of 1882 and 1966, which affected the entire upper Padova area, many other flooding phenomena have characterized the riparian area of the Bacchiglione. One of the main problems concerns the Brentella artificial canal, which has occasionally excessive flow rates at the point where it joins the Bacchiglione (Mel et al. 2020).

In recent years, the local authorities have tried to manage the river's flood risk. In particular, the assessment of the hydraulic risk represents a primary necessity for the authorities in charge of the fluvial system management. Hydraulic risk is given by the relationship between the probability of a flood and the impact that this flood may have on the territory. Its assessment requires an integrated approach, that recognizes the role and space of the river. In general, the management of hydraulic risk in a territory represents a sustainability indicator of a territorial development model. Regarding the Bacchiglione River, the situation is not yet resolved: the river still represents a major management challenge, both from the point of view of flood containment and water quality prevention against pollutants (Selmin and Grandis 2008).

3.2.3 History of the Bacchiglione and its Riparian Areas

The history of the Bacchiglione River in the upper Padova area is outlined in this subchapter, in an attempt to provide the reader with a general indication of the appearance of the riparian areas of interest. The narrative follows the same thematic structure previously used for the historical description of the Brenta, starting from prehistory and arriving at the time of the Venetian Republic. As already partly observed, the Bacchiglione features variable and complex elements, which have strongly influenced its relationship with man, both from a settlement perspective and from the point of view of resource use and river channel regulation.

Protohistoric Evidence of Human Presence in the Bacchiglione's Banks

The Bacchiglione River Museum, in Cervarese Santa Croce, is today the main institution to manage the history of the Bacchiglione River, starting from the dawn of human civilization. The Bacchiglione has represented a settlement attraction for local populations since the Neolithic period (6,000-3,500). In this era, the river hosted several villages on its banks. The local protohistoric population probably sought the proximity to the river system as an advantage for agriculture practices (Selmin and Grandis 2008).

The settlement process along the banks of the Bacchiglione continued until the Bronze Age. The discovery of many artifacts testifies the presence of an organized human civilization, dedicated to sheep farming and agriculture. The nature of these populations' practices may explain the location of the villages, which arose on the riparian areas of the river. Moreover, up to the 1st millennium B.C., these centers were involved in a network of communication and exchanges with external civilizations, confirming that trade was present and developed as early as the protohistoric period (Leonardi and Tiné 2015).

The Bacchiglione during the Roman Age

From the 2nd century B.C. onwards, the Veneti culture – the civilizations that resided in the area of interest - started numerous and friendly relations with Rome. The stretch of the Bacchiglione between

Vicenza and Padova is crossed by the Via Postumia and the Via Annia, i.e. some of the main trade networks in the area. This shows that the economic framework of the territory was highly complex, representing a transit area for trade between different civilizations (Selmin and Grandis 2008).

The Roman victory against the Cimbri (2^{nd} century B.C.) provided an opportunity for Rome to redesign the territorial layout of the upper Padova area and the riparian zones of the Bacchiglione. Centuriation - land reclamation, partitioning, and cultivation of the territory – was implemented, while the authorities attempted to regulate the water flow of the river, to provide water for agriculture, and contain the floods. Under Roman authority, the Via Gallica was also established, as a link between the Via Postumia and the Via Annia. The riparian area of the Bacchiglione, due to its strategic position, became an important trade route (Marca Aperta 2016).

At the dawn of the imperial era, the territory surrounding the Bacchiglione in the upper and middle plains represented an area characterized by economic vitality. In the Julio-Claudian period, the area of interest was under the influence of two poles, those of Vicetia and Patavium (i.e. Vicenza and Padova), which aimed at grabbing the resources of the river's environment. In particular, the area south of Vicenza was particularly suitable for grazing and was interested by the transhumance seasonal movements. The area north of Padova, on the other hand, was mainly used for agricultural practices, which were widespread throughout the territory. Another important resource linked to the Bacchiglione River was marble: stone marble quarries were present in Longare and Costozza (Selmin and Grandis 2008).

Contado Modifications in the Middle Age

The term 'Bacchiglione' appears in medieval historiographic sources only from 1200 onwards. It replaces a variegated series of names – 'Retrone', 'Edrone', 'Rotrone', 'Rodolone '– that were used by previous sources. After a period in which the new nomenclature complements the older ones, from 1300 onwards, the term 'Bacchiglione' is the only one used to indicate the course of the river (Di Bernardo 2014).

In the early Middle Ages, the riparian area of the Bacchiglione River in the upper Padova region was affected by the same political-economic dynamics that characterized the Brenta area. In particular, the privileged economic position of this area led to the clash between its two main neighboring cities, Padova and Vicenza. Despite lively political-military activity, the Bacchiglione's riparian environment developed considerably in this period: numerous villages, monastic courts, parish churches, and even several castles were founded along the river banks (Cabianca 2022; Selmin and Grandis 2008).

As previously seen, in the early Middle Ages, the control of the river and its products was the prerogative of the public authority, which frequently provided concessions of use to the local power. In this dynamic, the bishops emerged as pivotal figures in the management of the river: by their intermediary role between sovereign and local interest, they were often designated as managers of the river and its riparian area. The full authority of the bishop in the river area is testified by the sources of the period: for example, two diplomas of Henry IV - dated 1079 and 1090 respectively - grant the bishop of Padova the authority to manage the waters of the Bacchiglione[5].

Until the beginning of the 12th century, the upper Padovan area crossed by the Bacchiglione was interested by political-economic and military tensions between the two poles of Padova and Vicenza. These cities, which alternated in the management of the area, carried out various interventions in this period that would strongly condition the appearance of the river and its riparian area. In particular, between 1200 and 1300, a series of embankment, excavation, reclamation, and deforestation operations were carried out (Bondesan 2003; Cabianca 2022).

From the 12th century onwards, the land crossed by the Bacchiglione River from the Berici hills became an integral part of the Padovan *contado*. During the remaining centuries of the mediaeval age, Padova's authorities regularly sought to find a balance between the urban demands and the efficient management of the countryside. This led to a series of regulation interventions on the river system, with harmful consequences for the river and its riparian areas. An example is represented by the construction of the Brentella Canal in 1314. This artificial canal connected the river Brenta and the Bacchiglione, with a defensive-military function but also to ensure water access to the city[6]. The Brentella, however, which connected the two rivers between Limena to the north and Brusegana to the south, led to an important water imbalance in the territory, sparking local grievances (Mel et al. 2020; Selmin and Grandis 2008).

Between the 13th and 14th centuries, the riparian area of the Bacchiglione River in the upper Padova region underwent a peculiar process of urbanization. This populating phenomenon was strongly encouraged by various religious orders - Benedictines, Franciscans, and Dominicans - in an attempt to secure new landfalls for the city. As a consequence, the anthropization of the riverine environment increased significantly: numerous mills and factories were located on the banks of the Bacchiglione, to exploit its water flow. Other productive activities developed in the riparian areas, which represented a privileged place for naval trade with the city. Boats could easily and quickly

[5] Historical documentation reference: CDP, I,259 p.183,304,329; Diplomata Heinrici IV, 414 p.551. Source: Selmin and Grandis 2008.

[6] The war and tensions between Padova and Vicenza led the latter to divert the course of the Bacchiglione at Longare in 1142, through the construction of the Bisatto canal. Vicenza would then deprive the rival city of access to the Bacchiglione river water (Selmin and Grandis 2008).

transport raw materials and manufactured products to the city and its squares. At the gate of the Padova, numerous stonecutters and stonemasons set up their workshops by the river: the transport of raw materials such as marble and granite is facilitated by the proximity of the river (Selmin and Grandis 2008).

The riparian landscape of the river Bacchiglione in the Middle Ages features peculiar elements. It was dominated by large forests of oak and elm; wetlands and humid lands were also widespread. The area between Vicenza and Padova was populated by two large forests: the ‘Selva Maggiore’ - whose use was the prerogative of the sovereign - and the ‘Selva Minore’ - whose services were enjoyed by the community. The deforestation that had affected the area west of the Brenta until the 12th century was carried out on the banks of the Bacchiglione, too. The destruction of considerable parts of the forest was here due to the colonial advancement of the local populations (Bondesan 2003; Selmin and Grandis 2008).

In the late Middle Ages, the territory witnessed the progressive appearance of numerous castles and centers of power located on the banks of the Bacchiglione. The presence of these strongholds significantly influenced the riparian landscape. In the area of Cervarese, for example, many castles were founded, at least according to the notarial documentation of the period. In addition, castles were built in San Martino di Vaneza (later transformed into a trading center), in Trambacche, Selvazzano, and Tencarola. Parallel to the multiplication of castles, the Benedictine courts also spread: historical sources outline 35 courts in the area of the *contado* of Padova. Even today, various archaeological sites reveal the presence of courts in Cervarese, Saccolongo, and Selvazzano (Canzian 2013; Selmin and Grandis 2008).

The Venetian Republic: New Priorities for the Bacchiglione

In the Modern Age, the Bacchiglione River became part of the Venetian Republic system, similar to the Brenta. Due to its economically privileged position, the Venetian administration repeatedly tried to stabilize its channel. Between the 17th and 18th centuries, several attempts were made to manage and contain the increasingly frequent flooding events of the river. In this period, the *Consorzi di Bonifica* were established, i.e. self-management associations with flood-prevention roles. Despite the attempts at containment, the numerous interventions on the river system led to an increase in the number and severity of natural disasters in the area (Scodro 2020; Selmin and Grandis 2008).

Parallel to the river regulation operations, the riparian territory of the Bacchiglione was influenced, during the Venetian period, by numerous interventions aimed at increasing the aesthetic value of the landscape. In particular, the Bacchiglione River features a high variety of environments along its course in the middle plain, mainly due to the geomorphological differentiation of this territory. The Venetian authority led a series of operations of hydrographic adjustment, reclamation, and construction of irrigation canals, to increase both the functional and aesthetic value of the areas adjacent to the river. In this period, the Venetian villa emerged as an important identifying element of the rural and riparian landscape of the area. These villas had lost their defensive function by the 15th century, becoming control centers for agricultural production. Over the centuries, however, new functions were associated with these places, which became true seats of prestige for the local agricultural nobility. The Bacchiglione played a primary role in defining the space of the Venetian villas. These mansions - being often arranged linearly on the banks of the Bacchiglione – were characterized by a series of elements that progressively developed from the river: on its banks was the landing, which - through steps - led to a grassy space in front of the villa. From here, an elaborate garden developed and, only later, was the agricultural countryside (Arrò 2023; Canfailla 2023).

3.3 Vegetation of Brenta and Bacchiglione Riparian Areas

The riparian vegetation of the Brenta and Bacchiglione rivers' meandering stretches show, on the one hand, comparable characteristics, and display on the other hand, considerable differences. These environments feature a high degree of floristic variety and density, too often affected and limited by anthropogenic pressure. In general, it can be stated that the riparian areas of the Brenta and Bacchiglione rivers in the upper Padova province show a layout that is fairly consistent with that traditionally indicated and explored in the previous chapter. Starting from the meandering and embanked channel, the floodplain of these rivers is characterized by the presence of the willow and poplar grove, as well as shrubs (also of exotic and infesting origin) and nitrophilous herbs. Where, on the other hand, the water quality conditions are worse, only hydrophytic and halophytic species grow. Nowadays, the flora of these riparian zones is very fragmented (Argano 2012; Selmin and Grandis 2008; Sitzia et al. 2023).

3.3.1 Botanical References

The significant anthropogenic operations in the riparian area of these meandering rivers - in particular those concerning the regulation of the river system and the mining works - have heavily influenced the vegetation of this territory. As a consequence, in the area north of Padova, the Brenta and Bacchiglione riparian area appears today as a territory partly inhabited by the typical riparian vegetation and partly by other vegetation types. Among the latter, invasive synanthropic plants, ruderal species, meadow vegetation, and de-alpinized species stand out for their importance and diffusion. The presence of non-native vegetation represents an important asset in assessing the ecological value of these areas, which host a variety of environments with a high degree of biodiversity (Bondesan 2003; Sitzia et al. 2023).

Origin	**Typology**	***Species***
Native riparian vegetation	Discontinuous *xerophilus* aggregations	*Sanguisorba minor* *Scrophularia canina* *Reseda lutea* *Epilobium dodonaei* *Saponaria officinalis* *Centaurium erythraea*
	Shrubs formations	*Cornus sanguinea* *Frangula alnus* *Salix purpurea* *S. triandra* *S. alba* *S. eleagnos*
	Ephemeral formations of riparian synanthropic plants	*Urtica dioica* *Artemisia vulgaris* *Bidens tripartita*
	Submergent and marsh *consortia*	*Myriophyllum spicatum* *Potamogeton sp. pl.* *Ranunculus tricophyllus* *Callitriche stagnalis* *Typha latifolia* *Phragmites australis*

Table 2. Some examples of native species that populate the riparian area of the Brenta and Bacchiglione rivers. Source: Bondesan (2003), Argano (2012). Modified by the author.

Origin	**Typology**	*Species*
Non-native vegetation	Riparian meadow vegetation	*Achillea millefolium* *Leucanthemum vulgare* *Taraxacum officinale* *Plantago lanceolata*
	Foothill species	*Sedum sp. pl.* *Tragopogon pratensis* *Echium vulgare* *Dactylis glomerata* *Lotus corniculatus* *Euphorbia cyparissias* *Hypericum perforatum*
	Invasive species	*Bromus arvenis* *B. secalinus*
	Herbaceous invasive synanthropic species	*Senecio inequidens* *Melilotus altissima* *M. alba* *Erigeron annuus* *Conyza canadensis* *Helianthus tuberosus*
	Shrubby invasive synanthropic plants	*Buddleja davidii* *Solanum dulcamara* *Amorpha fruticosa*
	Specie alpine	*Festuca altissima* *Bartsia alpina*

Table 3. Some examples of non-native species that populate the riparian area of the Brenta and Bacchiglione rivers. Source: Bondesan (2003), Argano (2012). Modified by the author.

As mentioned above, humans have exerted excessive pressure in the areas of interest. This has led to the fragmentation and decrease in diversity of the plant species that populate the riverbanks in the upper Padova section. Many species listed in both Table 2 and Table 3 are now at risk of disappearance in these areas, and local management must take into account the need for preservation, so that humans can continue to enjoy the benefits provided by the ecosystem services of these areas. The presence of non-native species represents - or represented, - an important element of richness in the riparian vegetation of these rivers. These formations join the willows and poplars - typical trees of the area - to define the riparian landscape in an original way (Argano 2012; Marchi 2009).

3.3.2 Riparian Specificities of the Upper Padova Province

The riparian areas of the Brenta and Bacchiglione rivers are united by the presence of another specific element: the stable meadow (It. 'prato stabile'). The stable meadows represent a peculiar exception of the upper Padova area: it is a field on which forage plants grow without the need to implement irrigation systems. These meadows, which maintain a green hue throughout the year, represent an agronomic and landscape anomaly. Their distinctiveness is due to the water-richness of the karst spring in this area, as well as the soil's strong permeability and tenacity. Until a few decades ago, stable meadows were an important resource for producing hay and foraging pastures. Dairy products derived from the animals grazing on these fields represented traditional excellence. However, in recent years, these stable meadows have experienced a significant reduction as a consequence of the pressure of the industrialized agricultural programs – which aim at turning these areas into cereal production fields (Selmin and Grandis 2008).

As pointed out above, the Brenta and Bacchiglione rivers feature different and distinctive elements, too. These differences are partly due to the geomorphological peculiarities of the two rivers, and partly to the different types of anthropogenic intervention that have conditioned the current structure of the river systems. In particular, on the one hand, the Bacchiglione hosts an extraordinarily diversified aquatic ecosystem[7]. On the other hand, the meandering stretch of the Brenta has ecological and environmental relevance: the *Natura 2000* network identifies the floodplain and wetlands of the Brenta as a site of particular importance in terms of natural habitat preservation. Starting from the end of the Valsugana and reaching as far as the municipality of Padova, the riparian area of the Brenta River has been affected over the years by processes of shrinkage and disappearance, as a consequence of the human impact. In concrete terms, the main causes are represented by the mining activity - now almost concluded - and the fragmentation of the forests. The latter process gives rise to the creation of ruderal areas, which favor the establishment of invasive species. Nevertheless, despite nefarious phenomena and human pressure, the upper Padovan agricultural landscape associated with the riparian zone of the Brenta still features peculiar characteristics. The cultivated fields are populated by various elements of high naturalistic value, such as woods, wetlands, hedges, and ditches. For this reason, the *Natura 2000* network has identified a total area of 3848 acres, covering 11 municipalities in the Padova area, as Special Areas of Conservation (SAC) and Special Protection Area (SPA) (Bondesan 2003; Buffa and Lasen 2010).

[7] The karst spring area of the Bacchiglione does not interest this research and therefore the description of its specificities is not included. For further information: Selmin and Grandis (2008).

4 TERRITORIAL MANAGEMENT FROM THEORY TO PRACTICE

The Brenta and Bacchiglione rivers' sylvan areas are sometimes locally managed service-equipped parks, sometimes wild environments where abandonment by humans is followed by natural reconquest of the territory. This landscape variety derives not only from specific geomorphological features but is directly influenced by the local and rural development practices in the territory. For this reason, when discussing the sylvan areas generated by the meanders of the Brenta and Bacchiglione rivers, it is necessary to address the issue of their management by local authorities and organizations.

To better understand such dynamics, the recent stages of Brenta and Bacchiglione rivers management history are investigated, highlighting those processes that have conditioned the fluvial green areas' aspect and structure (4.1). Moreover, the main cultural, tourist and artistic assets of the area are identified to map the territorial capacity for implementing an effective and sustainable development practice in the riparian environment. Finally, innovative governance practices are outlined, based on community participation and on a new vision of the relationship between humans and the river environment in the territory (4.2).

4.1 River and Land Management in the Brenta and Bacchiglione

4.1.1 Local Management and Territorial Configuration

As highlighted by Bottazzo (2013), the Brenta is one of the most anthropized rivers in Italy. Since the second half of the twentieth century, gravel quarries can be found in the middle course of the river, between Bassano del Grappa and Padova, and specifically in Prè (VI), Santa Croce Bigolina (PD), Carmignano di Brenta (PD), San Giorgio in Brenta (PD), Grantorto (PD), and Piazzola sul Brenta (PD)[8]. During their activity period, quarries have significantly conditioned the riparian vegetation development. After many quarries were shut down, nature generally reclaimed the land: today, in the sites where there were quarries now ceased, peculiar environments have been created. This is the case, for example, of the meander north of Piazzola sul Brenta, where a considerably big

[8] Gravels' specific location is deducted from literature (Bottazzo 2013; Bondesan 2003) and from the analysis of the data available in the Geoportale Veneto.

lake has formed – the so-called ‘Busa de Bastianeo’. Mining is not the only activity that has influenced the territorial landscape on the banks of the Brenta: industrial clusters in the medium-high Paduan plain – especially in the area east of Vigodarzere – strongly limit the expansion of spontaneous vegetation. Similarly, riparian sylvan areas’ growth space is significantly limited by agricultural practices and urban development. Finally, as seen in the previous chapter, regulation interventions lead to the banalization of the river and the loss of biodiversity in the riverine environment (Bottazzo 2013; Mozzi et al. 2006).

A similar discourse can be held for the Bacchiglione River’s green areas in the stretch between Cervarese Santa Croce and Padova. The Bacchiglione River has always been challenging to manage for local populations due to various factors. Firstly, as seen in the previous chapter (3.2.1), the Bacchiglione is a river with peculiarities, which define both its appeal and its unpredictability. The river is subject to frequent flood events that represent a problem not just for the agricultural and industrial activities of the area, but also for the population and urban infrastructure. The big floods of 1966 and 2010 are not isolated cases: recently, the river has been affected by periodically flooding, creating inconveniences for society. Because of its untamed nature, the river has been recently the object of regulation, which had as its main consequence the loss of biodiversity and green areas. Moreover, as for the Brenta green areas, the Bacchiglione ones are significantly influenced by the urban, agricultural, and industrial expansion, especially in the proximity of Padova. This stretch of the Bacchiglione River is not included in the *Natura 2000* network, therefore not benefiting from the status of Special Protection Area (SPA) (Selmin and Grandis 2008; Velo 2020).

4.1.2 A Glimpse at the Riparian Landscape

Decades of relations and reciprocal influence between society and nature have shaped the territory and the fluvial landscape of the Brenta and Bacchiglione rivers in the upper Padova province. As for today, the area surrounding the two rivers is strongly conditioned by the pressure of the agricultural economy. The analysis of the soil use typologies in the areas in proximity of Brenta and Bacchiglione allows for the outline of this trend and the disclosure of further information. The tables (Table 4 and 5) and associated figures (Figure 4 and 5) show the soil use qualitative and quantitative differentiation in the territory surrounding the Brenta and Bacchiglione rivers, at a maximum distance of 150 meters from the channel of the rivers. Such areas are predominantly classified as ‘arable land’, i.e. land used for intensive culture. This predominance is particularly strong for the Bacchiglione riparian environment, where the arable lands in ‘non-irrigated areas’ represent 38.2% of the territory. This is matched by what is declared by Charlton (2008) who highlights agriculture-originated anthropic intervention as the most significant form of pressure for riparian green areas (Badrzadeh et al. 2022; Charlton 2008).

Legenda	Total area (ha)	% area
Arable land in irrigated areas	246.75	23.2
Rivers and streams	200.44	18.9
Willow grove and other riparian formations	120.69	11.4
Permanent spontaneous grassland, commonly untilled	94.17	8.9
Arable land in non-irrigated areas	83.26	7.8
Dense discontinuous urban fabric with mixed use (Art. Sup. 50%-80%)	55.36	5.2
Broadleaf forests	53.06	4.9
Medium discontinuous urban fabric, mainly residential (Art. sup. 30%-50%)	31.30	2.9
Industrial areas and annexed spaces	29.30	2.7
Sparse discontinuous urban fabric, mainly residential (Art. Sup. 10%-30%)	28.58	2.7
Herbaceous areas: non-rotational grasses	24.26	2.3
Isolated residential facilities (disconnected from urban territorial context)	21.31	2.0
Secondary road network with associated territories (regional, provincial, municipal roads, etc.)	14.11	1.3
Other permanent cultures	10.92	1.0
Other	48.44	4.8

Table 4. Land use absolute and percentage area in the territory surrounding the Brenta River (300 m range) between Piazzola sul Brenta and Padova. Own elaboration. Credits: Geoportale Veneto[9].

Legenda	Total area (ha)	% area
Arable land in non-irrigated areas	273.77	38.2
Rivers and streams	102.17	14.2
Permanent spontaneous grassland, commonly untilled	83.45	11.6
Arable land in irrigated areas	61.64	8.6
Dense discontinuous urban fabric with mixed use (Art. Sup. 50%-80%)	32.88	4.6
Medium discontinuous urban fabric, mainly residential (Art. sup. 30%-50%)	30.99	4.3
Broadleaf forests	26.41	3.7
Herbaceous areas: non-rotational grasses	15.75	2.2
Isolated residential facilities (disconnected from urban territorial context)	15.23	2.1
Secondary road network with associated territories (regional, provincial, municipal roads, etc.)	10.53	1.5
Sports areas (Football, athletics, tennis, etc.)	9.94	1.4
Sparse discontinuous urban fabric, mainly residential (Art. Sup. 10%-30%)	8.11	1.1
Others	44.41	6.5

Table 5. Land use absolute and percentage area in the territory surrounding the Bacchiglione River (range 300m) between Cervarese Santa Croce and Padova. Own elaboration. Credits: Geoportale Veneto[10].

[9] All translations from the original Italian nomenclature are provided by the author.
[10] Ibidem.

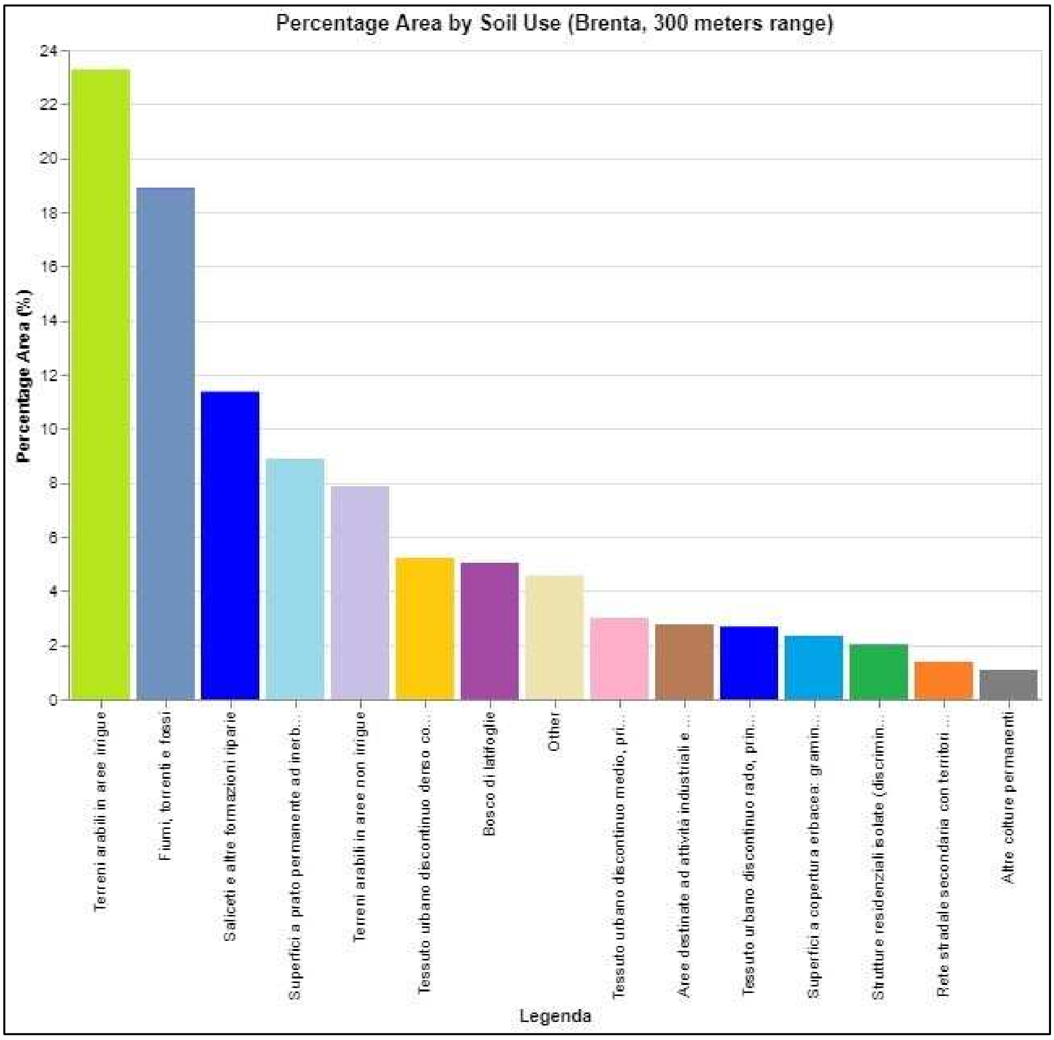

Figure 4. Land use percentage area in the territory surrounding the Brenta River (300 m range) between Piazzola sul Brenta and Padova. Own elaboration. Credits: Geoportale Veneto.

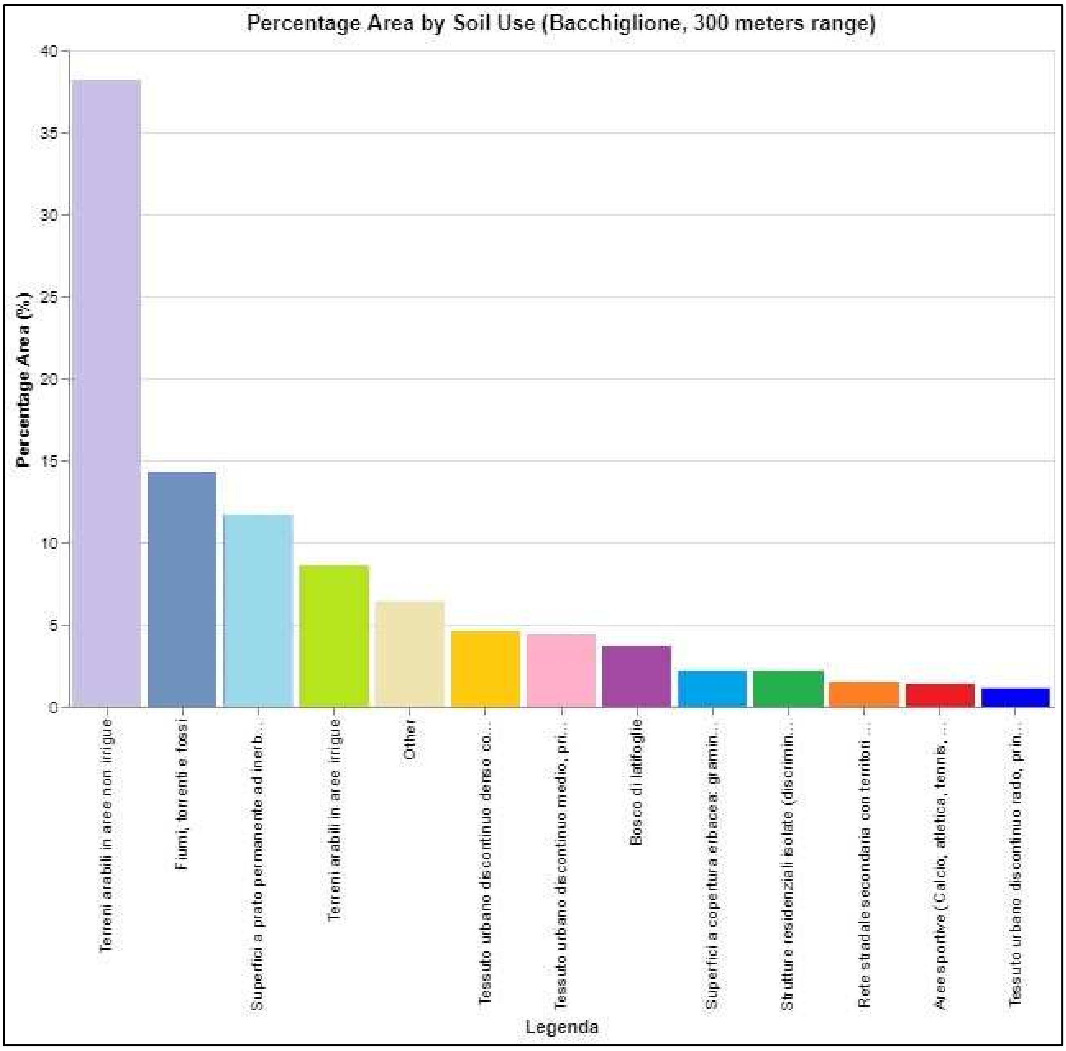

Figure 5. Land use percentage area in the territory surrounding the Bacchiglione River (range 300m) between Cervarese Santa Croce and Padova. Own elaboration. Credits: Geoportale Veneto

Figure 4 and Figure 5 show that the two rivers' lands differ in the presence and relative distribution of certain specific features, especially the variety of green areas in proximity to the rivers' channels. On the one hand, consistent green spaces inhabit the land surrounding the Brenta River, with riparian forests representing the most frequent element (11.4%). Other significant formations are spontaneous meadows (8.9%), temperate broadleaf forests (4.9%), and herbaceous surfaces (2.3%). The presence of these elements in the riparian environment of the Brenta suggests a wide variety of green areas in the proximity of the river.

A different discourse should be held for the land use distribution in the territory adjacent to the Bacchiglione River. In fact, green areas are here more rarefied and less variegated. Stable meadows, which have been discussed in the previous chapter (3.3), represent the most dominant typology (11.6%). Broadleaf forests have a limited extension (3.7%), as well as the herbaceous surfaces (2.2%). Finally, willow groves and riparian forests represent only 0.6% of the areas surrounding the

Bacchiglione River. Therefore, it is possible to conclude that – based on the analysis of the soil use type for the riverine environment of the two rivers – the Bacchiglione differs from the Brenta River by a lesser presence and a lower variety of green areas in its surroundings. This disclosure represents a starting point for a discussion about land use and management of the territory, with implications related to the analysis of the development practices operated by the different local authorities and economic actors.

4.1.3 Territorial Assets of the Brenta and Bacchiglione Rivers: The Cultural Value

In Chapter 2, the ecosystem services of riparian environments have been outlined, highlighting their provisioning and maintenance functions. However, green areas can carry another type of value, which is cultural in nature. Specifically, the cultural function of the green areas that form from the banks of the rivers is the product of the interaction between humans and nature, as stated by Yeakley et al. (2016). This cultural value can also arise from the opposite situation where a lack of interaction between humans and nature occurs. As a consequence, such environments can be the outcome of human planning activities on the one hand, and the unforeseen result of the human-nature interaction on the other. Providing the society with a cultural service, riparian ecosystems are a resource for the local development practices, tourism, and daily life of the community.

As highlighted by Riis et al. (2020), ecosystem cultural services are either direct or indirect, according to the modalities through which they benefit the human community. Initially considering direct cultural services, it is possible to outline a further classification to investigate the dynamics related to the green areas of the Brenta and the Bacchiglione rivers. Moreover, this analysis helps delineate the new local development and touristic dynamics present in these territories.

Experiential ecosystem services

Cultural ecosystem services are experiential, i.e. connected to the naturalistic profile of the green areas and to the human response to coming into contact with them. Riparian environments, especially in the Brenta River, feature a high degree of biodiversity and variety, allowing for the development of numerous nature-based recreational practices. The inclusion of the Brenta river's green areas in the Natura 2000 network allows for the implementation of bird-watching and carp fishing practices – especially in the area in the proximity of San Giorgio in Brenta (Bondesan 2003).

A dense network of cycle routes surrounds the Brenta and Bacchiglione rivers, crossing the fluvial green areas and riparian forests. Regarding the Brenta River, the 'Ciclovia del Brenta' connects the middle course of the river between Bassano del Grappa and Padova. It extends on the right of the river until Limena and, after crossing the river, it ends in Vigodarzere, at the gates of Padova. The 'Ciclovia del Brenta' is also connected and intertwined with other cycle routes of the province, such as the 'Ciclabile Treviso Ostiglia'. The intersection between the two paths is in Curtarolo, where the Treviso-Ostiglia lane crosses the Brenta River on the 'Ponte del Brenta – Ostiglia Ciclabile'. For what concerns the Bacchiglione, instead, the 'Ciclovia del Bacchiglione' is a route that connects Vicenza and Mestre, following the river's channel. In the stretch between Cervarese Santa Croce and the southern gates of Padova, the lane constantly runs alongside the river. The Ciclovia del Bacchiglione's path stretches on the rural landscape, crossing areas populated by many historical buildings such as villas, monasteries, and castles (Fogliato 2022; Piovan and Mora 2022).

The concentration of riparian green areas represents a place of relaxation, rest, and refreshment for the community. Spontaneous and unregulated vegetation development gives birth to wild and picturesque atmospheres, suitable for exploration, walks, and bathing. This is particularly spread in the area of the Parco del Brenta, in the medium stretch of the Brenta until Limena. Various beaches lie in Piazzola sul Brenta – such as 'Paradise Beach' – where the abandonment of an old gravel quarry gave birth to a lake formation, the Busa de Bastianeo. Moving further south, in Campo San Martino, the 'Bagni del Sole' represents a wild and lush naturalistic area, similar to the Area Verde Palazzina in Curtarolo. Finally, moving to the southern borders of the Parco del Brenta, the naturalistic area of Tavello and the Parco of Punta Speron are situated in Limena (Bondesan 2003; Piovan and Luchetta, in press).

Finally, the Brenta and Bacchiglione rivers' green areas represent a sporting and recreational resource for the local population. In the Brenta, for example, several riding schools are located in the riparian area of the river in Limena and Vigodarzere (Barca, McCann, and Rodrìguez-Pose 2012). Associations of rowers and canoeists are present in the courses of both rivers, in the areas near Padova (Selmin and Grandis 2008).

Touristic and artistic services

From a cultural and historical perspective, riparian areas of the Brenta and Bacchiglione rivers represent elements of unique relevance for the territory and an appealing one for both tourism and architectural contemplation. As seen in the previous chapter (3.1.3; 3.2.3), the upper Padova region has been subject since ancient times to intense political, economic, and administrative dynamics that have significantly influenced the rural landscape. Nowadays, the rivers' banks and their buildings reveal traces of the past: villas, castles, churches, and historical palaces inhabit the riparian landscape of the Brenta and Bacchiglione. Such buildings are strictly related to the green areas that surround them, shaping with them a peculiar landscape element. The high degree of cultural and historical significance of these areas makes them significantly attractive for tourist flows. It is also for this reason that local administration has often granted easy access to riparian green areas and to historical buildings that lie in such contexts, both by way of motor vehicles, bicycles, or by foot (Fogliato 2022).

Venetian villas represent an element of primary importance in the characterization of the riverine and agricultural landscape in the upper Padova province. Generally constructed in the modern era, many villas lie in the proximity of the rivers. They are associated with wide and lush parks, which nowadays merge with the spontaneous vegetation that grows from the river's banks. In the area surrounding the Brenta River, some villas stand out: for example, Villa Contarini and Villa Trieste-De Benedetti in Piazzola sul Brenta, Villa Breda in Campo San Martino, Villa Pacchierotti-De Benedetti and Barchesse di Villa Fini in Limena, Villa Marin-Zusto-Vendramin in Vigodarzere. On the other hand, the Bacchiglione River has been representing a place for artistic and architectural experimentation of the Venetian Republic since the modern age (3.2.3). This trend is still visible in different villas that lie in the proximity of the river. Villa Labia Tommasini (Santa Maria), Villa Trento (Cervarese Santa Croce), Barchessa Pisani (Creola-Vecchia), Villa Carretta and Villa de Besi (Saccolongo), Villa Emo Capodilista and Villa Melchiorre Cesarotti (Selvazzano Dentro), they all represent examples of Venetian villas in which tradition is mixed with experimentation and a peculiar taste for variation (Arrò 2023; Canfailla 2023).

Venetian villas are not the only significant architectonic elements in the territory. Many other historical buildings represent nowadays an attraction for tourists, such as the Castello di San Martino della Vaneza, in Cervarese Santa Croce. Reachable by bicycle and surrounded by a park, it hosts a museum on the history of the Bacchiglione since the dawn of human civilization. Moreover, along the banks of the two rivers, several sacred churches and monasteries have been constructed since the medieval period. Alongside the Brenta, for example, are the Certosa of Vidogarzere, the Franciscan Oratory of Curtarolo, and the Sanctuary of Beata Vergine of Tessara. The Bacchiglione riparian area hosts, at the height of Cervarese Santa Croce, the church of Santa Maria del Carmine (also called 'del Crivelli') and the Oratory of Santa Croce (Bondesan 2003; Selmin and Grandis 2008).

Directly connected to the artistic and architectural offer of these areas, numerous farmhouses, restaurants, and accommodation facilities lie on the banks of the Brenta and Bacchiglione. Their position is usually connected to existing touristic attractions in the proximities, even though this is not a prerogative. It is the case, for example, of the various urban agriculture practices (It. 'Fattorie didattiche') that are usually located in green oases inside the agricultural landscape and that benefit from a privileged position to access the riparian green area and its fruits[11].

In conclusion, the Brenta and Bacchiglione rivers' green areas represent a variegated resource for the local population. Their function can also be connected with the ecosystem's indirect cultural services – related to the symbolic value of the places, for example, or to their entertainment function. The cultural value of a place increases its appeal to the resident community and tourist flows. In general, it is possible to state that mapping and recognizing the significance of these services represent a fundamental process for the local community. The recognition of the territory's cultural value justifies the efforts to preserve it and defend it against the anthropic pressure. On a more general level, the cultural ecosystem services offered by such green areas represent a fundamental asset for the development of those touristic and non-touristic practices that are the basis for the valorization and the improvement of the territory.

4.2 A New Alliance Between Humans and the River's Green Areas

4.2.1 Rural Development and Territorial Necessities

As previously stated, this work analyses the Brenta and Bacchiglione fluvial meanders as environments that favor the generation of sylvan areas. However, in this chapter, we highlighted that human intervention and development dynamics influence territorial configuration. Therefore, the explanation of the characteristics of the territory of interest is not mono-causal, as it has to keep into account variegated factors of political, economic, and social nature. For this very reason, the most recent trends in river management and rural development have to be taken into account, as they represent the global framework within which local initiatives take place. The analysis of this framework allows for the comprehension of the direction of territorial dynamics, and the outline of possible future scenarios (Barca, McCann, and Rodrìguez-Pose 2012; Rivolin et al. 2013).

The concept of rural development traditionally refers to those practices – of agricultural or forestry nature – whose implementation brings a socio-economic improvement for «people living in sparsely-populated areas» (Wear 2024). Recently, the concept has become more flexible, incorporating a number of previously neglected dynamics. Rural development refers today to variegated practices,

[11] Information regarding the touristic offer of the Brenta River is provided by the Parco Fiume Brenta association on the webpage: https://www.parcofiumebrenta.it/esplora-il-fiume/. For specific detail about the Bacchiglione River on the topic, see Selmin and Grandis, 2008.

such as tourism, landscape studies, and sustainable rural economics. The differentiation of practices generally leads to an increased number and typology of stakeholders, that merge local processes and global trends in the management of the territory. In conclusion, rural development refers today to a series of activities related to agriculture and beyond it, that aim at the valorization of the territory through the action of the local governance and the influence of supra-territorial institutions (Wear 2024).

The new definition of rural development highlights a fundamental characteristic of the territory, determining the direction of the development practices. The territory is configured as the product of the action of all its 'actors', represented by stakeholders from different political, economic, societal, and environmental spheres. The analysis of the dynamics between these actors allows for the individuation of the fundamental territorial features, its assets, and the social and cultural capital. In local development discourse, the mapping of such factors - which Barca, et al. (2012) address as the territorial «endogenous forces» – represents the *sine qua non* condition for the success of territorial management practices (Barca, McCann, and Rodrìguez-Pose 2012; Davoudi et al. 2008).

New rural development vision, territorial management, and feature mapping are elements that need to be present in policies related to the protection and improvement of fluvial green spaces. In such a context, society and the river environment experience a continuous dialectic. Their relationship is a complex dynamic, that cannot be solved by looking only at the strategic function of the river. This predatory and conflictual vision produces significant externalities, undermining the chances of survival of riverine green spaces. On the contrary, territorial management policies need to look at the dense network of relations between the various human and non-human actors of the territory. The territory's peculiarities and necessities have to be taken into account: hydraulic safety cannot totally replace ecosystem protection, moreover considering the fundamental and numerous services that such ecosystems play for the neighboring populations.

4.2.2 An Innovative, Participative Governance

The institution of a new alliance between society and the fluvial ecosystem requires specific preconditions. Recently, different authors have highlighted the fundamental relationship between the fluvial environment and the community that lives in its proximity (*inter alia*, Bréthaut 2016; Mould, Fryirs, and Howitt 2020; Syahputra, Fajar, and Sudarno 2023). As seen above, the increase – both in number and typologies – of the stakeholders represents a necessary evolution within the framework of the implementation of local and rural projects. Participation of the community, landholders, and local entities, with the formation of a group of experts, represents the first step for the foundation of a new governance. The latter is the primary condition for the effective implementation of projects related to environmental issues. These projects' objectives are economic sustainability on the one hand, and the recognition of the importance of ecosystem services in the fluvial context on the other hand (Syahputra, Fajar, and Sudarno 2023).

The success of participatory projects in such contexts is related to the participation of agricultural landholders. As seen above, the majority of the territory surrounding the Brenta and Bacchiglione rivers' channels is occupied by agricultural land. Generally, the agrarian economy in the upper Padova province takes the form of sown fields and meadows. On the one hand, these environments represent important ecological corridors for the local fauna, characterizing the rural landscape. On the other hand, they are threatened by various factors such as frequent droughts and the disequilibrium between the agricultural economy and environmental necessities. Nowadays, different initiatives – mostly related to the territory adjacent to the Brenta River – seek to preserve and improve the relationship between agriculture and the riverine environment. In such a context, the formation of a network that embraces the territorial actors – firstly and foremost, agricultural landholders – is of fundamental importance. However, landholders' participation is not easily achieved: as highlighted by Mould, Fryirs, and Howitt (2020), their participation is hindered by a series of economic, administrative, and relational barriers. Regarding the area of the Brenta River, an interesting project aims to solve the landholders' participation problem, through innovative approaches: the Go Brenta 2030 is an initiative designed by the Parco Fiume Brenta association, that reaches farmers through the companies they work for, proposing educational events (workshops, formation webinars) on the topics of innovation and sustainability[12] (Mould, Fryirs, and Howitt 2020; Thomas and Mefalopulos 2009).

A wider perspective moves from the field of agriculture and agricultural economy and extends to society as a whole. International policies increasingly require community participation in river management (Mould, Fryirs, and Howitt 2020; Rivolin et al. 2013). Environmental education represents the first instrument to transform the community into the primary stakeholder of local initiatives. As stated, the object of analysis of the present work are those sylvan areas that take place in unexpected ways, from the relation between human practices and fluvial processes. Such green areas represent small oases, *loci amoeni* in which the community can find rest and relaxation. If environmental protection of these places is achieved through the implementation of participatory projects, it then becomes fundamental for environmental education to be effectively delivered to the population. The area of the Parco del Brenta represents an exemplary case, providing the community

[12] The Go Brenta 2030 project is accurately described by one of its main partners, Etifor, in: https://www.etifor.com/it/portfolio/gruppo-operativo-brenta-2030/.

with centered initiatives. In particular, different projects such as Etra Academy (promoted by the Etra organization) introduce the topics of biodiversity and ecosystem services in elementary schools. Similarly, the University of Padova provides the students with seminars and field trips to the Brenta Park. Moreover, municipality workers are educated and updated: the Parco Fiume Brenta association delivers formation courses for municipality technicians and for private companies' workers. Finally, awareness-rising initiatives, field trips, and waste collection events are organized by different environmental associations of the territory[13].

The adoption of a participatory approach is possible when local authorities and associations start a dialogue with the different territorial actors. The creation of new governance represents an advantage for the implementation of projects for different reasons. Agricultural actors' and community participation during all the phases of the project cycle determines the increase of all the actors' ownership sense. Moreover, the inclusion of the communities that live in the areas surrounding the rivers empowers the population itself, which becomes the project's primary stakeholder (Thomas and Mefalopulos 2009).

The Parco Fiume Brenta's LIFE Brenta 2030 project represents a successful participatory approach example that aims at achieving territorial economic sustainability and improving its organizational structure. With the participation of several stakeholders, it is co-funded by various municipalities, and has different partners, such as Etra (the project's leader), Etifor, and the University of Padova. Included in the UE's LIFE program framework[14], this project started in 2019 and aims at maintaining biodiversity standards and protecting ecosystem services in the area of the Parco del Brenta. In particular, the LIFE Brenta 2030 project aims at achieving its outcomes through three fields of action: restoration of the river's green areas; testing of new financing and implementation models; and institution of sustainable governance. Within the context of river management, the LIFE Brenta 2030 project combines a participatory approach with research of innovative solutions for ecosystem preservation and for the maintenance of sustainable economic standards. Being due for 2030, it has already achieved partial outcomes in the field of habitat improvement, environmental rehabilitation, water quality, and agri-food sustainability[15].

Projects such as the one described above reveal a new vision for the management of the river and its green areas. The most recent global trends and the experience of local projects such as LIFE Brenta 2030 demonstrate the effectiveness of a non-conflictual approach to the river system. In conclusion,

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[13] A closer look at the initiatives: https://www.parcofiumebrenta.it/life-brenta-2030/.
[14] As seen in: https://cinea.ec.europa.eu/programmes/life_en, the LIFE program is the European fundamental tool for mitigating the effects of climate change and to ensure environmental protection.
[15] See note 12.

this approach is based on the institution of a governance that: includes the territorial stakeholders, carries an innovative drive, and represents a sustainable local development model, i.e. recognizes the needs, importance and function of the riverine environment.

5 METHODOLOGICAL APPROACH

This chapter outlines a methodological framework to test the paradigm that looks at the relationship between Brenta and Bacchiglione meanders on the one hand, and sylvan areas development in the riverbanks on the other. The description of the theoretical and methodological background makes use of the information and disclosures of the previous chapters, related to the meanders' geomorphological features and the riparian spontaneous vegetation's structural characteristics. Moreover, the relationship between human practices and riparian forests is considered, encompassing into the discourse the local development dynamics and their impact on the territorial configuration.

To describe the methodology procedure, this chapter initially outlines *what* is analyzed (5.1), providing a quantitative definition of those fluvial green areas that are referred to as 'sylvan' in this study. The tools through which the analysis is carried out are then listed, with reference to the geospatial analysis's theoretical framework (5.2). The final subchapter describes *how* the analysis is implemented, identifying the step-by-step procedure (5.3).

5.1 Qualitative and Quantitative Definitions of Riparian Sylvan Areas

To demonstrate the 'fluvial meanders as generators of sylvan' hypothesis, it is first necessary to specify what 'sylvan' means in a river context, both from a qualitative and quantitative point of view. This is a fundamental preliminary step to identify and perimeter the vegetated areas of this research. In the previous chapters, the concept of 'sylvan' has been associated with different definitions, related to the notions of 'riparian vegetation' and 'green area'. The latter, in particular, represents a comprehensive concept that is difficult to define and categorize – as stressed by Taylor and Hochuli (2017). Von Buttlar (2022) refers to the Oxford definition of green space, which is indicated as an «area of grass or other vegetation» (von Buttlar 2022), i.e. an open area populated with trees, meadows, and other vegetated elements. As this definition partially defines the environment of interest, it does not refer to the fluvial context. Therefore, we should stress an association between green areas and riparian vegetation, i.e. the green spaces «along a river network» (Riis et al. 2020). Finally, the definition of 'sylvan' needs to be addressed. This work makes use of the definition provided by Piovan and Luchetta (in press) that defines it as:

> «tree or multitude of plants, in relation to human and environmental dynamics which fill it with values, problems, meanings, contrasts and emotions»

Within the context of this research, this definition refers to a connection between humans, on the one hand, and living and non-living natural elements, on the other. In the river ecosystem, riparian green spaces are properly sylvan when they arise as the fruit of the combination of natural processes and human practices, charged with new values and meanings.

In order to identify riparian sylvan areas in the geographical space, it is also necessary to provide them with some quantitative parameters. In Italy, a specific law (3 April 2018, n. 34) states that, from a statistical point of view, the term 'selva' (It. for 'sylvan') has the same significance as the terms 'foresta' ('forest') and 'bosco' ('woodlands'). As other works did[16], this research uses this association as the starting point for defining the territory of interest, by indagating the quantitative parameters that different national and international organizations have provided to identify such areas (Table 6). In particular, the Global Forest Resources Assessment of the Food and Agriculture Organization (FAO) refers to forests as those areas that feature «tree canopy cover of more than 10% and an area of more than 0.5 ha» (FAO, 2000); trees should «reach a minimum height of 5 m' (ibid.) while the crown density should be of at least 10%» (ibidem). Even though this definition does not have a normative significance, it has been adopted by the EU as a standard for statistical analysis and intra-state comparison (Arrò 2023).

A second definition is provided during the UNFCCC conference in Marrakesh (2001). The Decision 11/CP.7 (*Land use, land-use change, and forestry*) states that forests' minimum area is 0.05-1.0 ha, with a tree cover not inferior to 10-30%. Trees should reach a minimum height of 2 to 5 meters at maturity. This definition features flexible parameters, especially when compared with the one proposed by the Global Forest Resources Assessment. This can be related to the context of the UNFCCC conference and to the attempt to highlight the forests' role in mitigating the effects of climate change (UNFCCC 2001).

In Italy, the third article (comma 3) of the Legislative Decree of 3 April 2018 (n.34) indicates that sylvan areas, forests, and woodlands should have a minimum area of 2.000 square meters (0.2 ha), a strip width of at least 20 meters and a tree cover higher than 20%. The Italian parameters have outlined the national standard and have been adopted by the Veneto region since 2013[17].

[16] A particular reference for the methodological approach to identify the forest areas is provided by the works of Arrò (2023) and Canfailla (2023). Both works analyze the presence and distribution of green areas under the influence of the Venetian Villas of the medium-high plain in the Padova Province.
[17] Reference to DL 3 April 2018, n° 34 of the Italian Republic, and to the DGR 23 July 2013, n. 1319 of the Veneto Region.

	FRA	UNFCCC	Italian law
Year	2000	2001	2018
Type	International	International	National (IT)
Min. area (ha)	0.5	0.05-1	0.2
Min. height (m)	5	2-5	/
Crown cover (%)	10	10-30	20

Table 6. Similarities and divergences between the different definitions of forest proposed by the main international bodies and the Italian State.

In light of these definitions, it is necessary to state which ones are considered in this analysis. The qualitative definition proposed by Piovan and Luchetta (in press) is adopted in this research and applied to the riparian context. From a quantitative point of view, this definition is associated with the above-mentioned quantitative parameters and with previous works by Arrò (2023) and Canfailla (2023). Accordingly, riparian sylvan areas in the digitalization process are considered to be the projections of tree canopies with a height of 5 meters or more, and a minimum width of 5 meters. As of the riverbanks, a maximum canopy discontinuity of 20 meters is accepted to define the forest as riparian.

5.2 The Tools of the Geospatial Analysis

Before outlining the procedures of the analysis, it is necessary to define the adopted methodology, i.e. *how* the research is implemented. The analysis procedure is fundamentally divided into two different moments: on the one hand, the identification and digitalization of sylvan areas; on the other hand, the analysis that leads to the assessment of the key hypothesis of this work. The methodological approach that is adopted during these two phases is only partially overlapping. The geospatial framework represents the common background, while the analysis's implementation follows different modalities and is achieved through various software. The first part of the research is carried out exclusively through the QGIS software. Two other applications are used in the second part: pdAdmin, software referring to the PostGRES system software (SQL language); and Jupyter, an Integrated Development Environment (IDE) based on Python programming language.

5.2.1 The Geospatial Analysis

The research is based on the geospatial theoretical background and the GIS (*Geographic Information System*) methodological framework. In the context of GIS techniques, we adopt an approach that combines something 'geographical' with a specific form of 'information' production. The geographic component of the GIS approach refers fundamentally to the geographic realities of the Earth. Such realities, in a GIS perspective, are made of two elements: classes of entities and terrain characteristics. Entity classes are the geographic reality in its 'essence' and represent concrete objects such as a house and a mountain, or in the specific case of the present research, a river and a vegetated area. Terrain characteristics provide a certain typology of feature, associated with the entity class: for example, the terrain characteristic of a river could be its channel width, sinuosity, or the concentration of PM10 particles in its waters (Longley 2015; Van Orshoven 2023).

The second part of the 'Geographic Information System' definition refers to the production of information. The practical GIS approach takes the form of database creation and the associated analytical tools. Following the classical input/output model, GIS software takes some data – i.e. facts and measurements – and transforms them into information through query, manipulation, and visualization tools. The information can be defined as a «structured collection of data» (Van Orshoven 2023) in a specific context. The information is therefore ready to be interpreted and used in decisional processes (Longley 2015).

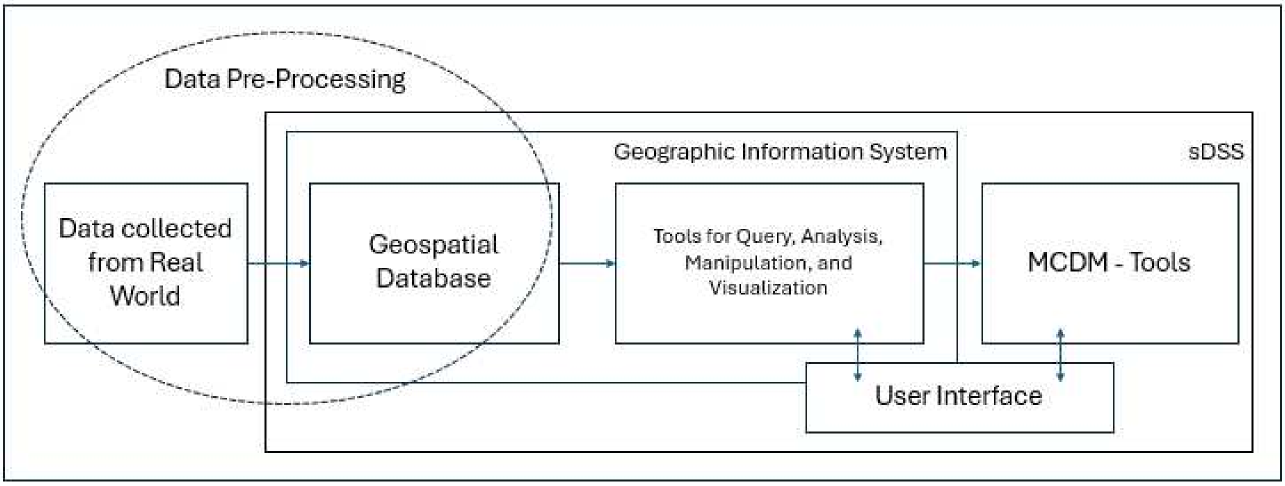

Figure 6. From geospatial database, to GIS, to sDSS. Credits: Van Orshoven 2003. Modified by the author.

As highlighted in Figure 6, the research's first objective is the geospatial database's creation (gDb). In the case of the present analysis, a gDb is built through a pre-processing process: the data collected in the real world are brought into the GI system. The geospatial entities of the geographic realities are initially modeled as geospatial objects, i.e. objects with a specific location, geometry, characteristics, and behavior. Once these objects have been digitalized, the gDb is created. The gDb is composed of data with a geometric component and a descriptive component. Such data is the object of analysis in the second phase of the research: through query, analysis, management, manipulation, and visualization tools, different GIS software and non-GIS software are used to structure and contextualize data, and to transform them into information. Information can be interpreted and used in multi-criteria decision-making (MCDM) processes (Van Orshoven 2023).

5.2.2 The Software

As previously mentioned, the present research utilizes various software during different phases of database creation, population, and data manipulation and analysis. In particular, three interfaces are used:

- *QGIS* (v. 3.22.11). Free open-source GIS application, first launched in 2009 (v.1.0). QGIS is a software to analyze, manipulate, and visualize geospatial data. Moreover, it is used to create, modify, and share maps. In the research (EPSG 3003 Monte Mario 1) it is utilized for the digitalization of the sylvan areas in the geographical context of interest, and for populating the dataset with the variables of interest.
- *pgAdmin* (v.4). Free C++ application, active since 1998 and with PostreSQL license (SQL programming language). It refers to a hybrid (geo-relational) database management system, that uses a File Management Software (FMS) for the geometry section, and a Database Management software (DBMS) for the attributes. Maintaining referential integrity between the two components, it manages geospatial datasets and performs complex queries. It does not have a visual interface, but it is easily linkable to QGIS. In this research (EPSG 3003 Monte Mario 1), it is used to manipulate and analyze data from different datasets, to create various variables utilized in the following stages.
- *Jupyter Notebook*. Since 2015, it is an open-source software (Python programming language). It is an Integrated Development Environment (IDE) that allows working with Python language exclusively on the web. Moreover, it enables its users to work with geographic datasets and to perform geoprocessing processes. In the present research, it is used as a query tool, and for the visualization of the results.

5.2.3 Data

The main source of the data that has been used in this research is represented by the Geoportale della Regione Veneto. Once the digitalization is completed and the variables of interest are added, the dataset created for the polygons representing the sylvan areas of the Brenta and Bacchiglione rivers becomes the main object of work and analysis. Generally, the used datasets are the following:

- Ortofoto digitale a colori AGEA 2021

The orthophoto of the Veneto region is a raster layer, available as WMS in the Geoportale della Regione Veneto. Photos were taken between March and June 2021, and the resolution is 20 centimeters. The layer is used for the creation of polygons, through remote sensing.

- Grafo Idrografia (elemento idrico)

  Polyline layer (RS Monte Mario 1) available in the Geoportale Veneto. It features all the main hydrological elements of the region, classified based on the typology and length. The layer is used to identify the main channel of the two rivers of interest and then select the segments on which the analysis focuses.

- Banca Dati della Copertura del Suolo della Regione Veneto

  Polygon layer (RS Monte Mario 1) available in the Geoportale Veneto. The layer displays the land of the region divided by polygons representing the typologies of soil use. These are indicated in the 'legenda' column in the attribute table. In the research, the layers are used mainly to observe the relationship between specific soil use typologies and the variation of the distribution of sylvan areas in the territory.

- Other vector layers from the Geoportale Veneto

  Other vector layers available in the Geoportale Veneto are used, mainly to create didactical maps. In particular:

  - WebGIS Natura 2000: polygon layer indicating the areas considered Special Areas of Conservation and Special Protection Areas under the Habitat Directive and Bird Directive.
  - Itinerari della rete escursionistica Veneta: polyline layer representing the bicycle paths inside the Veneto Region.

- Other sources

  During the digitalization phase, when unclear situations occurred, further sources of information were used to identify vegetated areas that comply with the parameters. In particular: OpenStreetMap (OSM), Google Earth, Google Maps, and Veneto region's previous orthophotos (2018 and 2015).

5.3 The Assessment Procedures

5.3.1 Digitalization and Classification of Riparian Sylvan Areas

Considering the terminological definitions outlined in the first part of the chapter, a specific individualization and digitalization approach is established. Such an approach relies, on the one hand, on the various parameters established by international and national institutions. On the other hand, it is based on previous works on the territory which, from the point of view of the methodology, feature some similarities with the present analysis. Regarding the latter, Arrò’s (2023) and Canfailla's (2023) research are considered: in particular, the digitalization procedure they implemented for the green areas of the Venetian villas in the medium-high section of the Padova province. Although based on these models, the present analysis makes use of some original methodological steps, adding parameters that are peculiar to the objectives of the research. In particular, vegetated areas are recognized as riparian based on territorial continuity criteria, highlighting their role as ecological corridors for the area of interest.

Definition of the Territory of Interest

The first step of the analysis is defining the territory within which the digitalization takes place. Firstly, rivers’ stretches of interest are identified, i.e. the meandering sections of the Brenta and Bacchiglione rivers in the upper part of the Padova province.

Regarding the Brenta River, the analyzed stretch starts right after the wide meander bend lying south of Peschiera, between the municipalities of Piazzola sul Brenta and San Giorgio in Bosco. Even though the braided section of the river ends further north – at the height of the Grantorto municipality – it is only from the indicated area that the Brenta River takes on its peculiar meandering and sinuous conformation. Therefore, the stretch between Grantorto and Piazzola sul Brenta is not considered. The southern border of the section is represented by the stretch of the river that touches the town of Stra, east of the Padova municipality. The choice of this border is driven by two main reasons: on the one hand, the attempt to respect the traditional partition of the Brenta River, which ends in Stra its medium section; on the other hand, the necessity of include a non-meandering river section, to add a comparative element to the analysis.

Concerning the Bacchiglione River, the western border of the Padova province represents the starting point of the analysis. Here, in Cervarese Santa Croce, the river features a highly curved course, which develops in the province until Padova. Only after entering Padova’s influential area, sinuosity decreases. Following a similar modality as the one adopted for the Brenta River, the stretch of interest of the Bacchiglione ends at the southern gates of Padova, at the height of the Scaricatore Bridge.

Once the river sections are identified, a buffer is created to delimit the digitalization area. A distance of 500 meters is assigned to the buffer, starting from the river lines. The value of 500 meters represents an element of continuity with the mentioned digitalization works of Arrò (2023) and Canfailla (2023). However, a difference needs to be highlighted. In the mentioned research, the buffer is created from a point element representing a building and is therefore circle shaped. The present analysis considers a buffer of two-line elements – the rivers' sections – affected by variable sinuosity. Therefore, the output is not a circle but an irregular polygon that follows the development of the line representing the river.

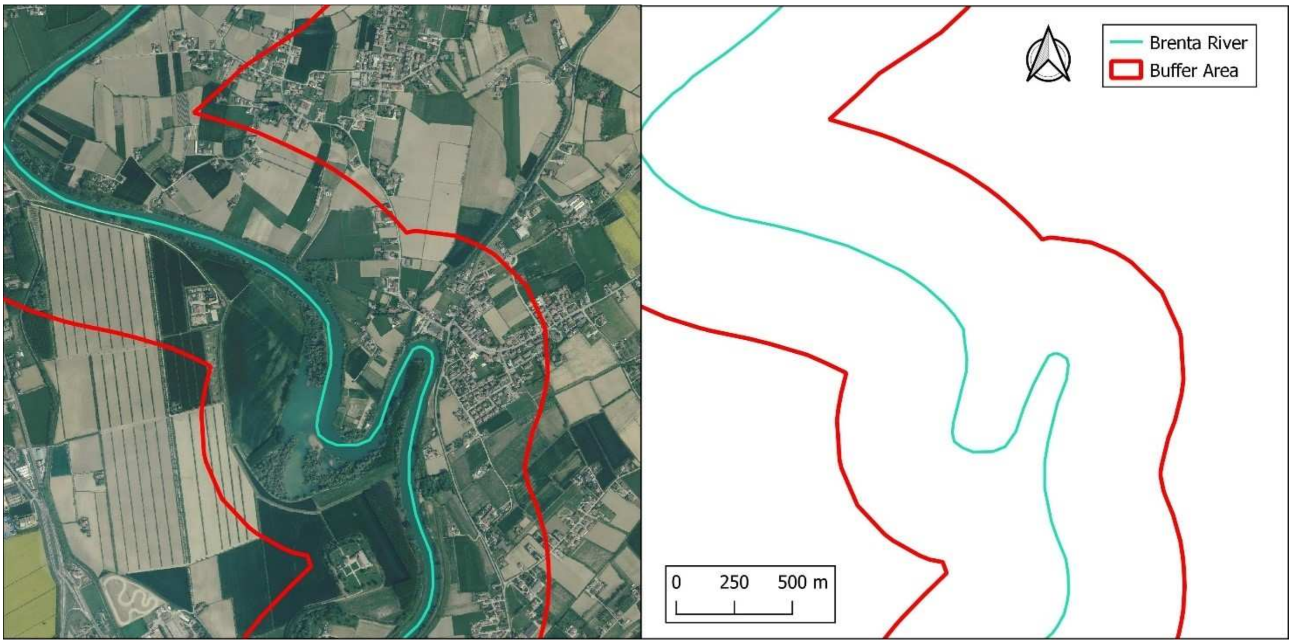

Figure 7. Detail on the Brenta River. The buffer (in red) follows the course of the river line (in blue).

Digitalization

Once the field of action is identified, we proceed with the QGIS digitalization, based on the photointerpretation of the Ortofoto Regionale (2021), available as a WMS in the Geoportale Veneto. The first step of digitalization is the creation of polygons for the green areas that: are inside the territory of interest; and comply with specific standards. In the second phase, green areas are classified as riparian or non-riparian, following a discontinuity criterium derived from Arrò's (2023) and Canfailla's (2023) work. Regarding the digitalization parameters, they are as follows:

- All forest areas inside the 500-meter buffer are initially digitalized (1).
- Forest area is intended as the ground projection of the trees' crown cover.

- Trees are included when they have a minimum height of 5 meters (at maturity).
- The following geospatial entities are included: tree crops and tree rows with width ≥ 5 m (2).

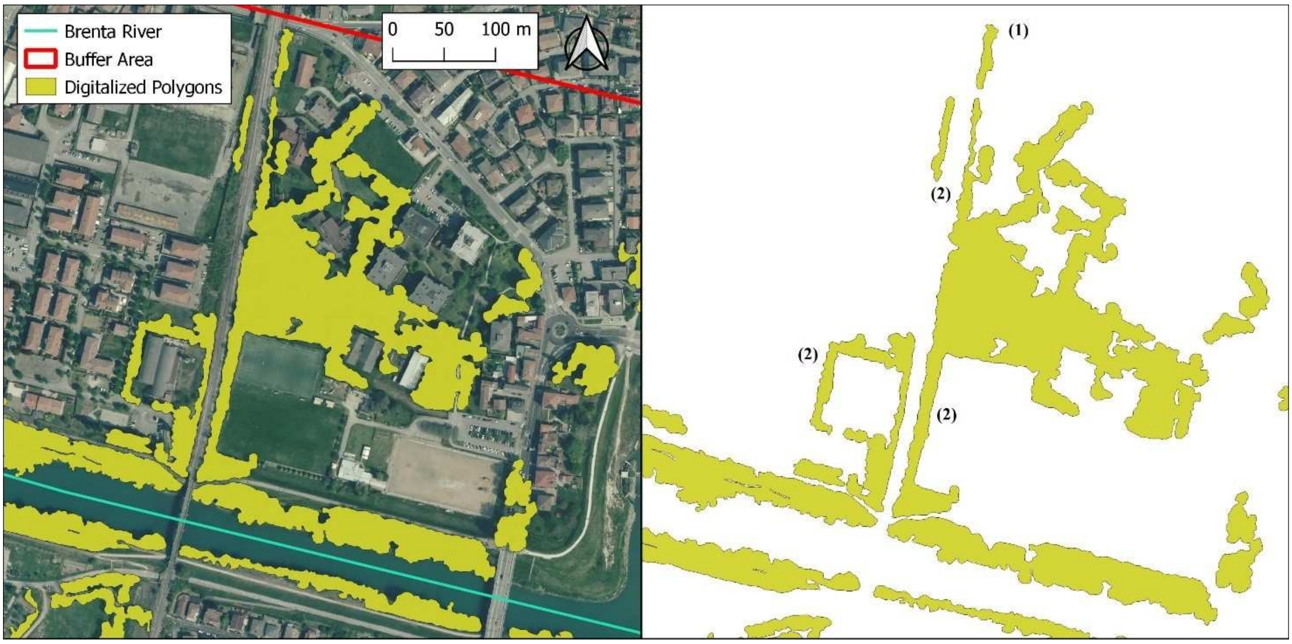

Figure 8. Detail of the digitalization method in the Brenta River, in the municipality of Padova.

Classification

When the digitalization is completed, the polygons inside the buffer are classified as riparian and non-riparian. In particular, two rules are followed to assign the value:

a) *Riparian polygons are distant ≤ 30 meters from the river line*

Areas that comply with this parameter are identified creating a 30-meter buffer from the river line. Subsequently, all polygons within or intersecting the buffer are selected. The 30-meter distance is arbitrarily chosen and aims at identifying the riparian polygons, i.e. referring to green areas in the surroundings of the river channel that are transitional between the river system and the upland.

A manual control follows this operation. Manual control is necessary because the data source's river line (Geoportale Veneto) is inaccurate in specific sections (Figure 9). The inaccuracy originates in the characteristics of the river channel, which is not a stable element: subject to constant migratory processes, it can frequently change its position in the floodplain, especially when flooding occurs. Fluvial entities that have been modeled as geospatial objects in the past, even in relatively recent times, may have changed their geometry and location. For this reason, even recent data sources can contain discrepancies with the reference orthophoto. The manual analysis allows for the individuation of such discrepancies and to check for deficits of the geospatial query.

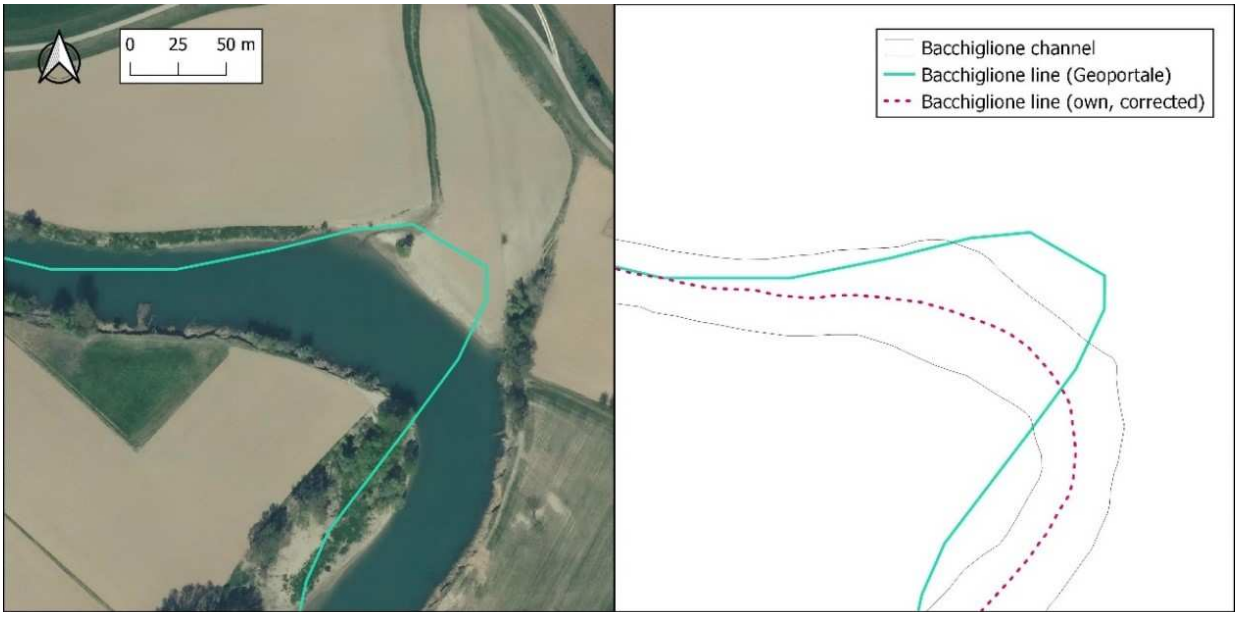

Figure 9. Visualization of the inaccuracy of the source layer (Geoportale Veneto) in a trait of the Bacchiglione, in proximity of Saccolongo. The river line (light blue) does not follow the actual direction of the meander bend. The red line – created by the author by way of illustration – displays what could be an improved way to describe the channel's curve.

b) Discontinuity between polygons is tolerated up to 20 meters

Once riparian polygons are identified, we verify which are distant ≤ 20 meters from the riparian ones. This second class of polygons is in turn considered as riparian. Implemented through pgAdmin, this procedure is repeated at different times. In conclusion, riparian polygons are those elements that are ≤20 meters apart and are directly or indirectly connected to the first class of riparian ones. The choice of a 20-meter continuity parameter is based on Arrò's work. Moreover, this criterion helps to outline the ecological corridors in the area of interest.

Figure 10. A glimpse at the results of digitalization and riparian/non-riparian classification in the Brenta River, in the municipalities of Vigodarzere and Padova.

5.3.2 Meander Quantitative Identification

Meander identification represents the next step to polygon digitalization. So far, the selection of the Brenta and Bacchiglione rivers' section has been based on literature and qualitative observation: these have pointed out the macro-areas in which the rivers feature a meandering course. However, the present analysis is interested in observing the processes of sylvan vegetation growth in a more circumscribed geographical context. In particular, we want to determine if the individual meanders are associated with a high presence of vegetation, compared to straight stretches. It is therefore necessary to define a method for quantitatively identifying meanders on a small scale.

In literature, meanders' presence is traditionally associated with channel sinuosity. As seen in Chapter One (2.2.1.), the sinuosity of a river's section is given by the *ratio* of its channel's length and the valley length (Figure 11).

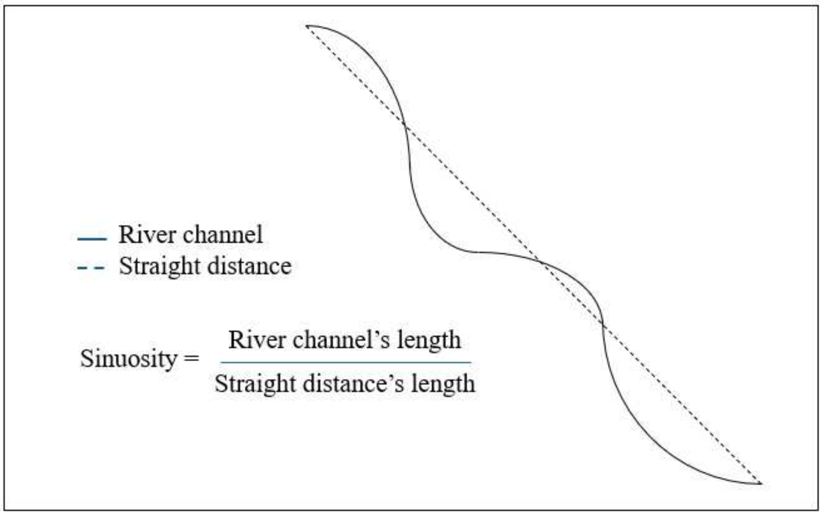

Figure 11. Scheme for river channel's sinuosity calculation.

Various authors such as Bridge (2007) propose the following river classification based on sinuosity:

- Sinuosity < 1.1: straight river
- Sinuosity between 1.1 and 1.5: sinuous (pseudo-meandering) river
- Sinuosity > 1.5: meandering river

This classification is applied to the context of analysis, to identify the micro-areas in which sinuosity is pronounced. Through both GIS and PostGIS analytical tools, the following steps are performed, as seen in Figure 12:

1) The river's vector line is divided into segments of 500 meters.
2) A point is placed at the beginning of each segment.
3) A straight line connects each consecutive point.
4) Sinuosity is calculated as the *ratio* between each river segment and the corresponding straight-line segment.

The value of 500 meters is arbitrarily chosen, based on a twofold reason. On the one hand, the line's fragmentation into too small segments would lead to the calculation of a low sinuosity, making it difficult to identify meanders. On the other hand, segments that are too wide hinder the identification of micro-area sinuosity rates.

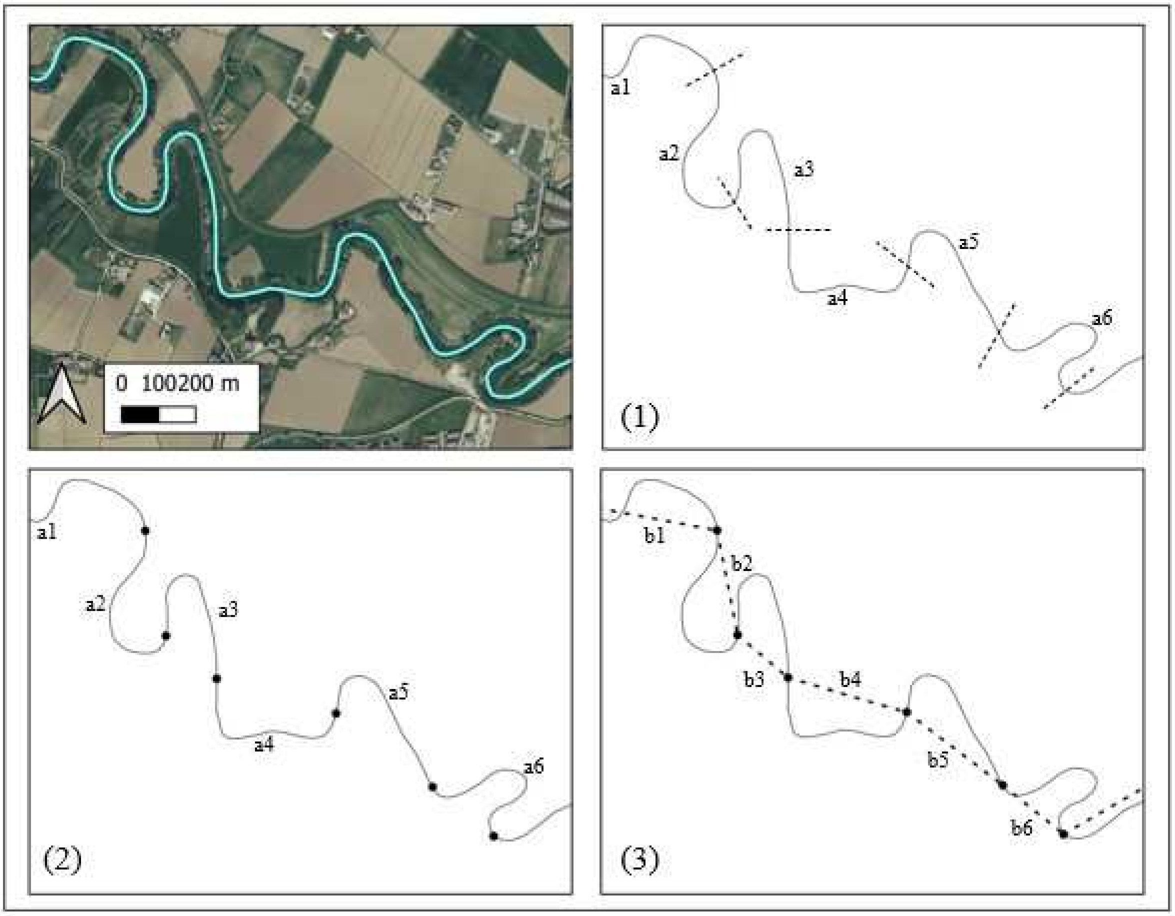

Figure 12. River segments sinuosity calculation. Detail of the Bacchiglione River in San Marco.

As stressed by Charlton (2008), flexibility is required when applying these procedures. In the specific case of this analysis, the necessity of a flexible approach is related to the intention of calculating sinuosity for relatively small segments. When implementing the traditional formula in a small-scale context, river stretches feature a relatively low sinuosity, even though they appear as meanders to the eye. Following the visualization of the results - matched with the literature review and orthophoto interpretation - the parameters of meander identification are slightly changed. River sections with sinuosity higher than 1.1 are considered meanders, while stretches with lower values are identified as non-meanders.

Self-evaluation and Improvement Possibilities

The adopted procedure follows the traditional approach for meander identification, adapting it to a small-scale context. This is one of the reasons for which parameters have been slightly modified, considering as meanders those stretches that traditionally are considered 'sinuous' or 'pseudo-meandering'. Although the results of this procedure are confirmed by empirical observation, it is necessary to stress that it is the product of a subjective choice. Literature has provided the researcher with alternative methods to quantitatively identify meanders. For example, Yogendra, Biju, and

Ganapathy (2016) highlight that meander classification can be based on different criteria, such as the river's channel direction changes or the analysis of the erosion-sedimentation process.

A second element of discussion is related to step 1 of the above-described approach. The vector line is cut into equally long segments through a GIS procedure. This determines that, starting from one of the extremities, the line has been divided into segments of equal length, without considering the progressive curvature of the section. If the segments have a short length, this characteristic represents a problem for the sinuosity calculation. In the present research, the complication is solved through the literature overview, particularly the manuals of Bondesan (2003), and Selmin and Grandis (2008). However, future analyses in the same field could try to improve the procedure, to avoid the need for manual control.

5.3.3 Buffer Units and Variable Creation

Before proceeding with the spatial analysis, it is necessary to add a further step. The territory of interest is summarized in smaller units, considering the difference between areas under the influence of meandering and non-meandering sections. The procedure was discussed with Professor Silvia E. Piovan and PhD student Leonardo Mora, which outlined the research direction. In particular, the analysis is preceded by creating a 250-meter buffer along the river line. The buffer length is chosen based on literature overview, which indicates this distance as the correct standard one for assessing the influence range of a river, without considering the width of its channel (Argano 2012; Bennett and Simon 2004). This buffer is cut each time the river course changes from meandering to non-meandering, and vice versa (Figure 13). This procedure allows for individuating smaller, non-uniform buffer units. Since the units carry different features in size and shape, the methodological approach is oriented towards analyzing relative data more than absolute data. This allows to overcome the difference between the buffer units and assure comparison.

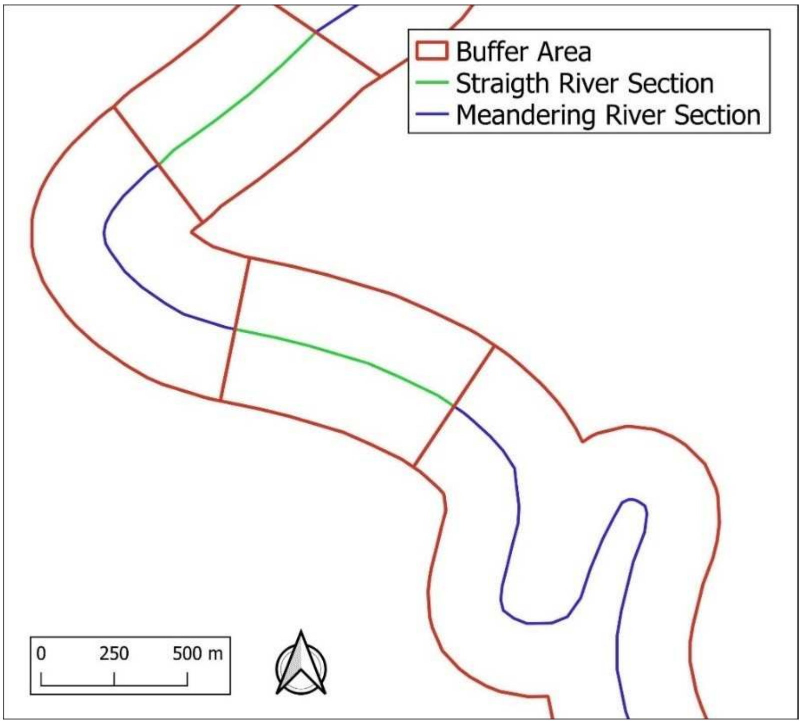

Figure 13. Buffer creation. Detail of the Brenta River in Tavo. The outline of the buffer follows the division of the river segments in meandering (in blue) and non-meandering (in green), as exposed above.

The buffer's attribute table in QGIS is populated with the variables of interest for the analysis that tests the initial hypotheses. The choice of variables reflects, on the one hand, an attempt to demonstrate the correlation between the vegetation distribution and the geomorphological characteristics of the river (i.e. the presence of meanders). On the other, the variables are chosen based on the attempt to demonstrate the second hypothesis of this work, i.e. to assess the impact that human practices have on this dynamic. Regarding the first aspect, the included variables are listed as follows:

- *Meander*

  Binary variable based on sinuosity. Each buffer unit is located either in a meandering or in a straight river segment, as previously established (5.3.3). Based on this relation, the buffer units inherit a binary value that indicates if they are referring to a meandering section (1) or a non-meandering stretch (0).

- *Forest area*

  Quantitative variable given by calculating the intersection area between buffers and digitalized polygons representing the forest areas. The procedure is implemented with PostGIS procedure, and the output is an absolute number representing the vegetated area in square meters for each buffer.

- *Forest percentage area*

Quantitative variable given by the *ratio* between the buffer area and forest area for each buffer. PostGIS is used to implement this operation, too.

A similar procedure to the one adopted for calculating the forest's relative presence inside each buffer unit is adopted for assessing the distribution of human-generated environments in the area of interest. The theoretical framework for this operation is represented by the European Copernicus project 'Land Monitoring Service', which provides a guideline for identifying and defining different soil use typologies that national databases utilize for classification purposes. Based on such insights, the non-riparian areas inside the buffer units are divided according to their usage by man, which can be artificial, agricultural, or be represented by artificial, non-agricultural vegetate areas. The considered soil use typologies are highlighted in Table 7.

Class 1	Class 2	Class 3
Artificial Surfaces	Urban Fabrics	Continuous urban fabric Discontinuous urban fabric
	Industrial, commercial and transport units	Industrial or commercial units Road and rail networks and associated land Airports
	Mine, dump and construction sites	Mineral extraction sites Dump sites Construction sites
Agricultural Surfaces	Arable land	Non-irrigated arable land Permanently irrigated land
	Permanent crops	Vineyards
	Heterogeneous agricultural practices	Complex cultivation patterns Annual crops associated with permanent crops
Green Spaces	Artificial, non-agricultural vegetated Areas	Green urban areas Sport and leisure facilities

Table 7. Classification of the soil use typologies of interest for the analyzed territory. The classification is proposed by the Copernicus program: https://land.copernicus.eu/content/corine-land-cover-nomenclature-guidelines/html/. The Veneto Region, as well as all national administrative bodies, have standardized to this classification.

Once the surface typologies are identified, the Geoportale Veneto's soil use database is queried by selecting the polygons that refer to each of the three surface types. As a consequence, three multi-polygon layers are created, displaying the distribution of artificial, agricultural, and human-generated green areas inside the buffer units. The final step is represented by incorporating the data in the buffer dataset, through the creation of three more variables:

- *Artificial surface percentage*

  Quantitative variable indicating the relative presence of artificial areas within each buffer unit. The values are determined through PostGIS procedure, calculating the *ratio* between the buffer units' area and the area of the intersecting polygons representing artificial surfaces. The same method is applied to the other two classes previously identified creating two more variables, namely:

- *Agricultural surface percentage*
- *Artificial green surface percentage*

Other variables were initially considered, but they have been discarded based on the absence of satisfying data sources. In particular:

- *Water area and percentage area*

  Quantitative variable given by the intersection of the buffer with a polygon layer representing the river channel. The variable was initially included to test the relationship between water quantity in each buffer and the presence of vegetated areas. However, the reference layer for the river channels – taken from the Geoportale Veneto – displays inaccuracies and mistakes that threaten the analysis's accuracy.

- *Air quality*

  A variable related to air quality is not included, because data are available per municipality and refer to a territory too wide to be considered significant for the area of interest.

- *Soil permeability*

  This variable identifies the soil permeability level. It is discarded for the same reason as the air quality variable. Moreover, almost all the areas of interest feature the same value of hydraulic conductivity (between 0.36 and 3.6 mm/h).

In conclusion, six variables are identified. One first variable refers to the geomorphologic characteristic of the soil inside the buffer units, i.e. the presence or absence of a meandering section. Two other variables point out the vegetated area inside each buffer unit, indicating the total and percentage area of the digitalized polygons. Finally, three variables display the relative distribution of human-originated surfaces, i.e. artificial urban and industrial zones, agricultural lands, and artificial green spaces. Few other variables (water capacity, air quality, and permeability per buffer unit) are discarded, based on data inconsistency or for practical reasons. Once the buffer is populated with the variables, it is possible to proceed with the next step, i.e. the spatial analysis.

5.3.4 Steps of the Spatial Analysis

The analysis phase represents the attempt to demonstrate the hypothesis for which the Brenta and Bacchiglione meanders favor the development of riparian sylvan areas. It is articulated in two stages, highlighting and testing different theoretical notions exposed in the first part of the work. In this phase, the geoprocessing activities are conducted through Jupyter Notebook, using various libraries to analyze, manipulate, and visualize spatial data.

Summary statistics tools are firstly used, to verify if buffers lying on meandering sections host a level of vegetation higher than buffers on straight segments, from a relative point of view. The analysis is based on basic statistics notions and the creation of frequency tables. Moreover, tables and maps are created to present the results.

The second step of the analysis looks back at the theoretical findings of Chapter 4, i.e. the fundamental role of territorial management in determining the aspect and shape of fluvial green areas. The local development discourse is inserted in the analysis identifying the buffers that feature favorable or unfavorable conditions for the growth of the forest area, based on natural and anthropic factors. This is achieved by creating a new variable, called ‘selva generator’, based on variables related to the human practices in the territory of interest. This variable is created through Jupyter procedure (Python programming language): the datasets of the two rivers are merged and, once the values are standardized, a formula is assigned that tests the better correlation between the explanatory variables and the response one. The final output is a new numerical value for each buffer unit, indicating their level of suitability to host riparian sylvan areas in percentage terms.

6 RESULTS

Once the theoretical and geo-historical frameworks are described, and a clear methodological approach is outlined, the results of the investigation are exposed in this chapter. The presentation makes use of varied visualization tools, such as maps, tables, graphs, and drone photographs.

The first part of the chapter displays the results from the quantitative perspective (6.1). In particular, the product of the digitization process is initially shown (6.1.1), emphasizing the trends related to the two river areas. The result of the river sinuosity analysis is exposed (6.1.2), with the meandering and non-meandering buffer units identification. The research then investigates the relationship between river meanders and sylvan areas (6.1.3); the analysis especially considers the data of the forest area percentage within each buffer unit. Finally, the anthropogenic factor is included in the discourse (6.1.4), through the creation of a new variable that takes into account the dynamics of human pressure and indicates the level of suitability for each buffer to host spontaneous riparian vegetated areas.

The second part of the chapter offers a qualitative analysis of the case studies represented by the Brenta and Bacchiglione rivers (6.2). In the first part (6.2.1), the different types of riverine sylvan areas are presented, with a focus on the influence and impact that humans have exerted in the past and present times. In conclusion (6.2.3), three 'treasures' hidden in the meanders of the Brenta and Bacchiglione are presented to emphasize the aesthetic and ecosystem role these environments exert in the area.

6.1 Quantitative Analysis

6.1.1 Riparian Sylvan Areas along the Brenta and Bacchiglione Rivers

The identification of the vegetated polygons within the buffers of the two rivers is the first output of the digitalization process, based on the photointerpretation of the 2021 Ortophoto provided by the Veneto Region. Once the digitalization is finalized, the total number of polygons identified in the two rivers is 1274, with a total area of 565.55 ha (Table 8).

River	Polygons (N)	Total area (ha)	Mean area (ha)	Min area (ha)	Max area (ha)
Brenta	770	454.72	0.59	0.01	24.48
Bacchiglione	504	110.83	0.21	0.01	2.81
Total	1274	565.55	0.45	0.01	24.48

Table 8. Digitalized polygons per river, reporting frequency of the polygons, total area, mean area, and minimum and maximum area values.

Regarding the Brenta River, the selected river section is the one between Piazzola sul Brenta to the north and Stra to the south, for a total length of 33.66 km. The buffer created from this section extends 500 meters from the riverbanks, delimiting a total territory of 3085.49 ha that touches nine municipalities: Piazzola sul Brenta, Campo San Martino, Curtarolo, Limena, Vigodarzere, Padova, Cadoneghe, Noventa Padovana, and Vigonza. Table 8 shows that 770 arbored areas are identified within the buffer, with a total area of 454.72 ha. Although the average area of the digitalized polygons is 0.59 ha, the range of this value is between 0.01 ha and 24.48 ha. Figure 14 visualizes the results of the digitalization for the Brenta River, highlighting all the polygons identified as arbored surfaces inside the buffer in the selected section.

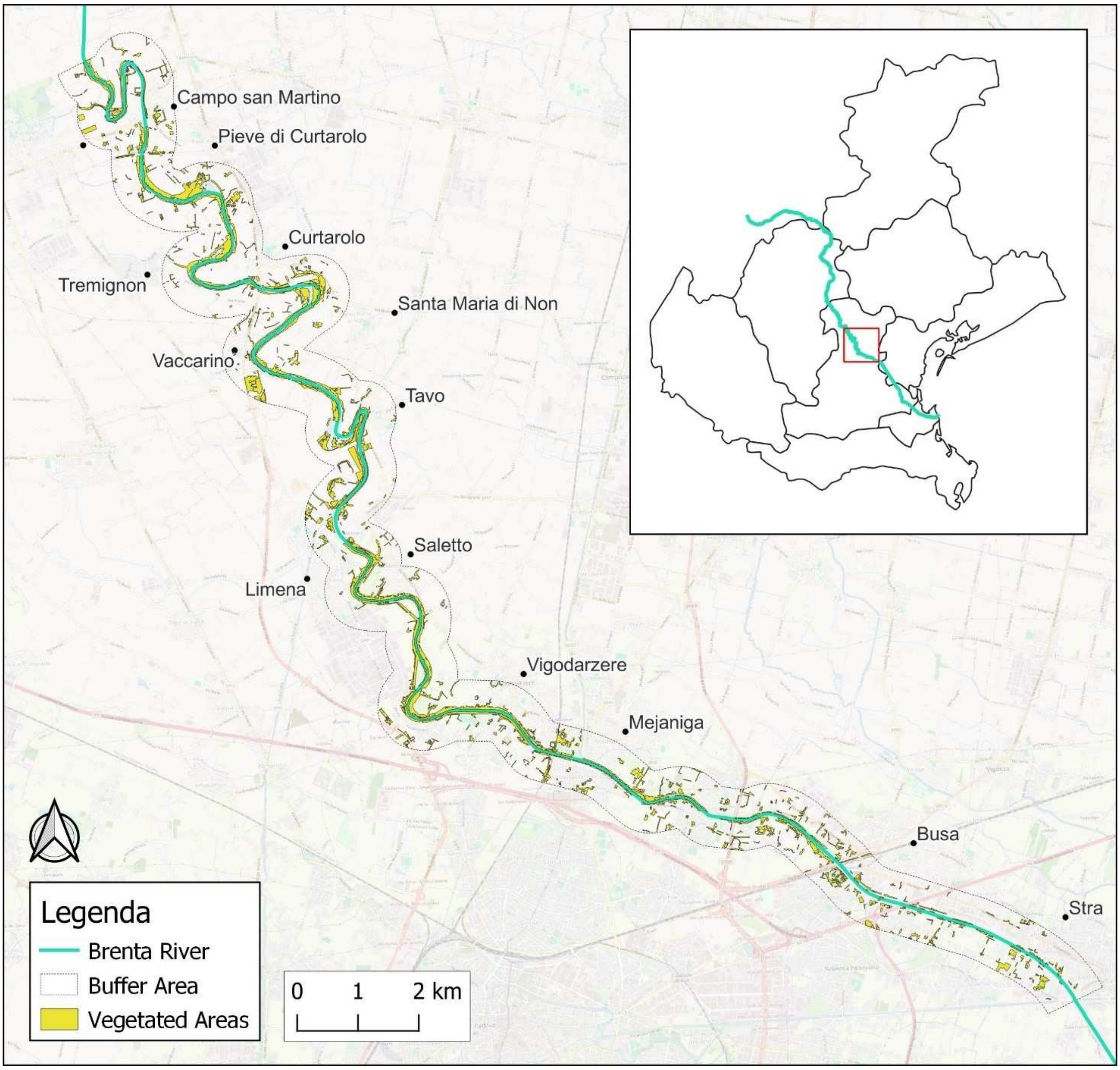

Figure 14. The surface of forested polygons in the selected section of the Brenta River, based on digitalization from Ortophoto 2018.

The selected section of the Bacchiglione River starts from Cervarese Santa Croce and arrives at the southern gates of Padova. The stretch between these two cities is 25.92 km long. The buffer created from the river channel has a total area of 2013.46 ha and crosses five municipalities: Cervarese Santa Croce, Veggiano, Saccolongo, Selvazzano Dentro, and Padova. A total of 504 polygons are identified within this territory, with an area of 110.83 ha (Table 8). On average, the digitalized polygons starting from the Bacchiglione River have a lower average area than the Brenta, equal to 0.21 ha. The range of values is also shorter, with a minimum value of 0.01 and a maximum value of 2.81 ha. The map below (Figure 15) displays the distribution of the digitalized polygons inside the area of interest.

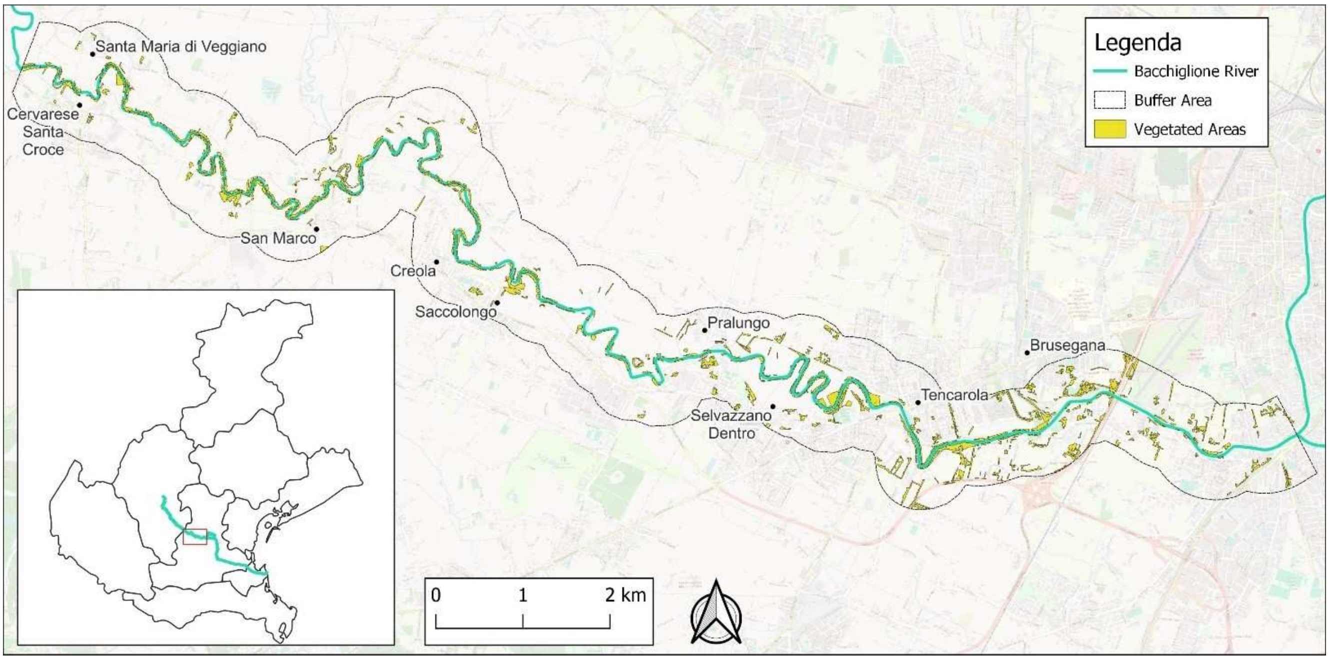

Figure 15. The surface of forested polygons in the selected section of the Bacchiglione River, based on digitalization from Ortophoto 2018.

As pointed out in Chapter 5, the vegetated areas' identification within the two buffers is a preliminary step to defining the areas that are described as riparian. The established filters (see 5.3.1) are applied, reducing the number of green areas and maintaining only the ones that meet the criteria. Finally, 638 riparian polygons are included in the selection, decreasing the number of green areas by 49.92% (Table 9).

River	Riparian polygons (N)	Percentage frequency (f)	Total area (ha)	Mean area (ha)	Min area (ha)	Max area (ha)
Brenta	346	54.23	355.20	1.03	0.01	24.48
Bacchiglione	292	45.77	70.46	0.24	0.01	2.80
Total	638	100.00	425.66	1.27	0.01	24.48

Table 9. Riparian polygons per river, considering absolute and relative frequency, total and mean area, and minimum and maximum area.

As highlighted by Table 9, the riparian areas referring to the River Brenta have a frequency of 346 units. Riparian surfaces have a total area of 355.20 ha in the river, i.e. 78.11% of all the digitalized polygons in the Brenta study area. The average area per polygon is 1.03 ha, representing an increase of 74.57% compared to the total buffer average in the Brenta section (0.59 ha). Figure 16 shows the distribution of riparian sylvan areas in four different sections of the analyzed stretch of the Brenta River, at the height of Campo San Martino (1), Curtarolo (2), Limena (3), and Cadoneghe (4). Different polygons (in white) are excluded, as they are not considered riparian based on the standards established in the methodological chapter of this study.

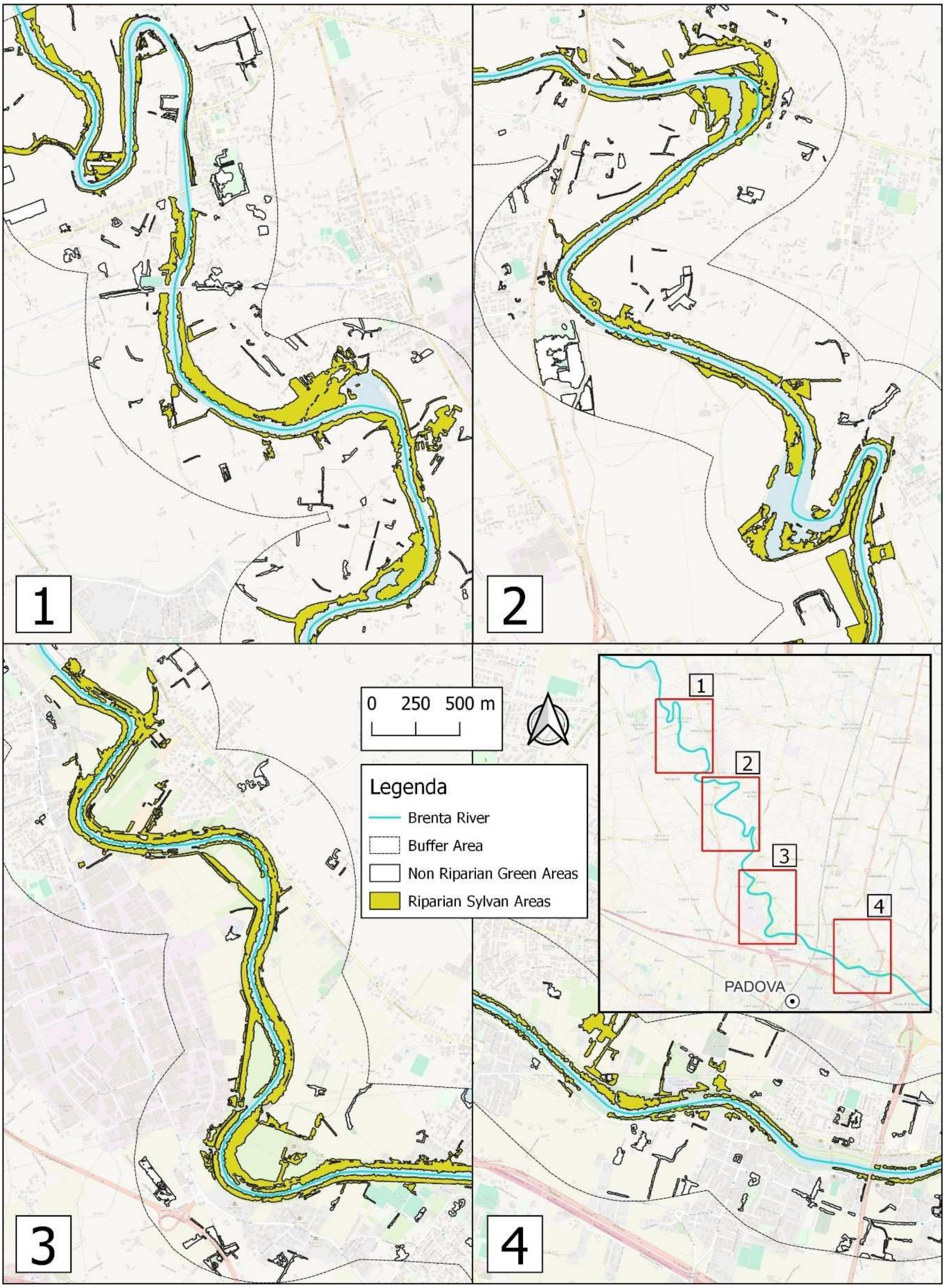

Figure 16. Details of the digitalization result in the Brenta River. In particular, the selected sections lie in 1) between Campo San Martino and Curtarolo; 2) in Tavo; 3) in Limena; and 4) between Cadoneghe and Padova.

The Bacchiglione River, on the other hand, hosts 292 riparian sylvan polygons. The total area of these polygons is 174.12 ha: it represents 63.57% of the total area of the digitalized polygons in the

Bacchiglione study area - meaning that more surface was excluded during the filtering compared to the Brenta case. Nevertheless, the average value for the riparian polygons' area is increased compared to that of all the Bacchiglione study area polygons: from 0.21 to 0.24 ha, i.e. an increase of 14.28%. Figure 17 displays the distribution of riparian green areas (light green) in the localities of San Martino (1), Creola (2), Selvazzano Dentro (3), and Brusegana (4). Excluded polygons are also displayed in white.

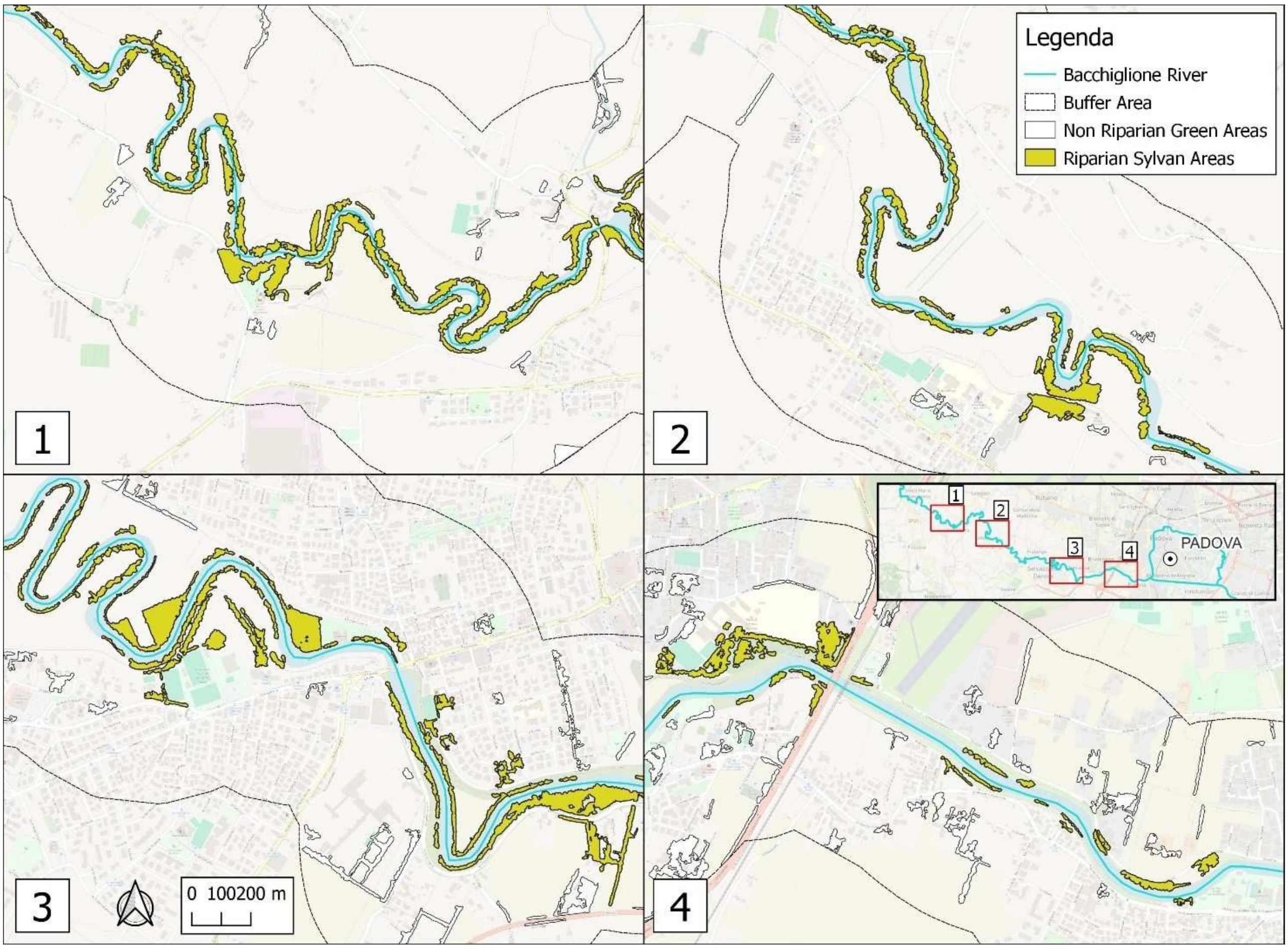

Figure 17. Details of the digitalization result in the Bacchiglione River. In particular, the selected sections lie in 1) between Cervarese Santa Croce and Santa Maria; 2) in Saccolongo; 3) between Selvazzano Dentro and Tencarola; and 4) in Padova.

6.1.2 Meandering and Non-meandering Sections

As stated in the methodological chapter (5.3.2), the research questions' investigation requires the meandering sections of the selected river stretches to be clearly and quantitatively identified. Calculating the sinuosity of short river stretches makes it possible to define sinuosity variations and, consequently, to identify meandering and straight sections.

The analyzed section of the Brenta River has a sinuosity of 1.51 in the stretch between Piazzola sul Brenta and Stra. However, the proper meandering section lies between Piazzola sul Brenta to the north and Vigodarzere to the south (sinuosity 1.77). The section between Vigodarzere and Stra is classifiable as a straight river (sinuosity 1.05) and is included in the analysis as a comparison case. After implementing the analysis tools to identify meandering and non-meandering stretches of the river Brenta, 26 sections are identified, equally divided between the two values. Starting from each section, a buffer extends 250 meters from the river line. As highlighted by Table 10, the buffer units referring to meandering and straight sections are rather balanced regarding the share of the total area of the buffer: meandering buffer units cover, in total, a surface of 846.66 ha (equal to 53.35% of the total buffer area); straight sections, on the other hand, sum up for 774.14 ha of surface, i.e. the 46.64% of the total.

Typology	Buffer unit (N)	Total area (ha)	Total area (%)	Mean area (ha)
Meandering section	13	846.66	53.35	65.12
Straight section	13	774.14	46.65	59.54
Total	26	1617.8	100.00	62.22

Table 10. Basic statistics of the identified meandering and non-meandering units for the Brenta River's sections of interest.

Table 11 proposed below shows the characteristics of each buffer unit in the Brenta River. In particular, the area of the individual sections varies considerably, with a range of 365 ha. Buffer unit No. 26 - corresponding to the southernmost section of the buffer - has a significantly larger area than the others, amounting to 23.02% of the total area. The number of digitalized sylvan areas also varies by section (range of 77), mainly reflecting the size of the buffer unit.

ID	Municipality (main)	Typology	Area (ha)	Area (%)	Polygons
1	Campo San Martino	Meandering	99.91	6.16	14
2	Campo San Martino	Straight	54.67	3.37	9
3	Curtarolo	Meandering	114.33	7.05	24
4	Piazzola sul Brenta	Straight	24.78	1.52	4
5	Piazzola sul Brenta	Meandering	72.38	4.46	3
6	Piazzola sul Brenta	Straight	70.10	4.32	18
7	Curtarolo	Meandering	46.64	2.87	14
8	Curtarolo	Straight	35.29	2.17	4
9	Piazzola sul Brenta	Meandering	44.20	2.72	11
10	Curtarolo	Straight	39.97	2.46	6
11	Limena	Meandering	123.30	7.61	20
12	Vigodarzere	Straight	14.77	0.91	6
13	Limena	Meandering	29.99	1.85	13
14	Limena	Straight	15.00	0.92	2
15	Vigodarzere	Meandering	28.90	1.78	5
16	Limena	Straight	8.7910	0.54	4
17	Limena	Meandering	35.67	2.20	12
18	Limena	Straight	9.99	0.61	5
19	Vigodarzere	Meandering	159.46	9.84	29
20	Padova	Straight	30.07	1.85	6
21	Padova	Meandering	24.67	1.52	7
22	Padova	Straight	10.06	0.62	5
23	Padova	Meandering	30.14	1.86	11
24	Padova	Straight	69.62	4.29	17
25	Padova	Meandering	55.07	3.39	18
26	Vigonza	Straight	373.03	23.02	79

Table 11. Display of the buffer units of the Brenta River, divided by typology. Information about the area of the buffer units and the number of polygons inside each unit are also shown.

The graphical representation of the identified buffer units corroborates the trend discovered by analyzing the river's sinuosity (Figure 18). The meandering stretches are concentrated, in size and number, in the first part of the river section. Straight stretches in this section are mainly configured as transition parts between meander bends. After the Brenta passes Vigodarzere, the channel takes on a straight conformation as far as Stra, while sporadic curved stretches are present in Vigodarzere and Mejaniga.

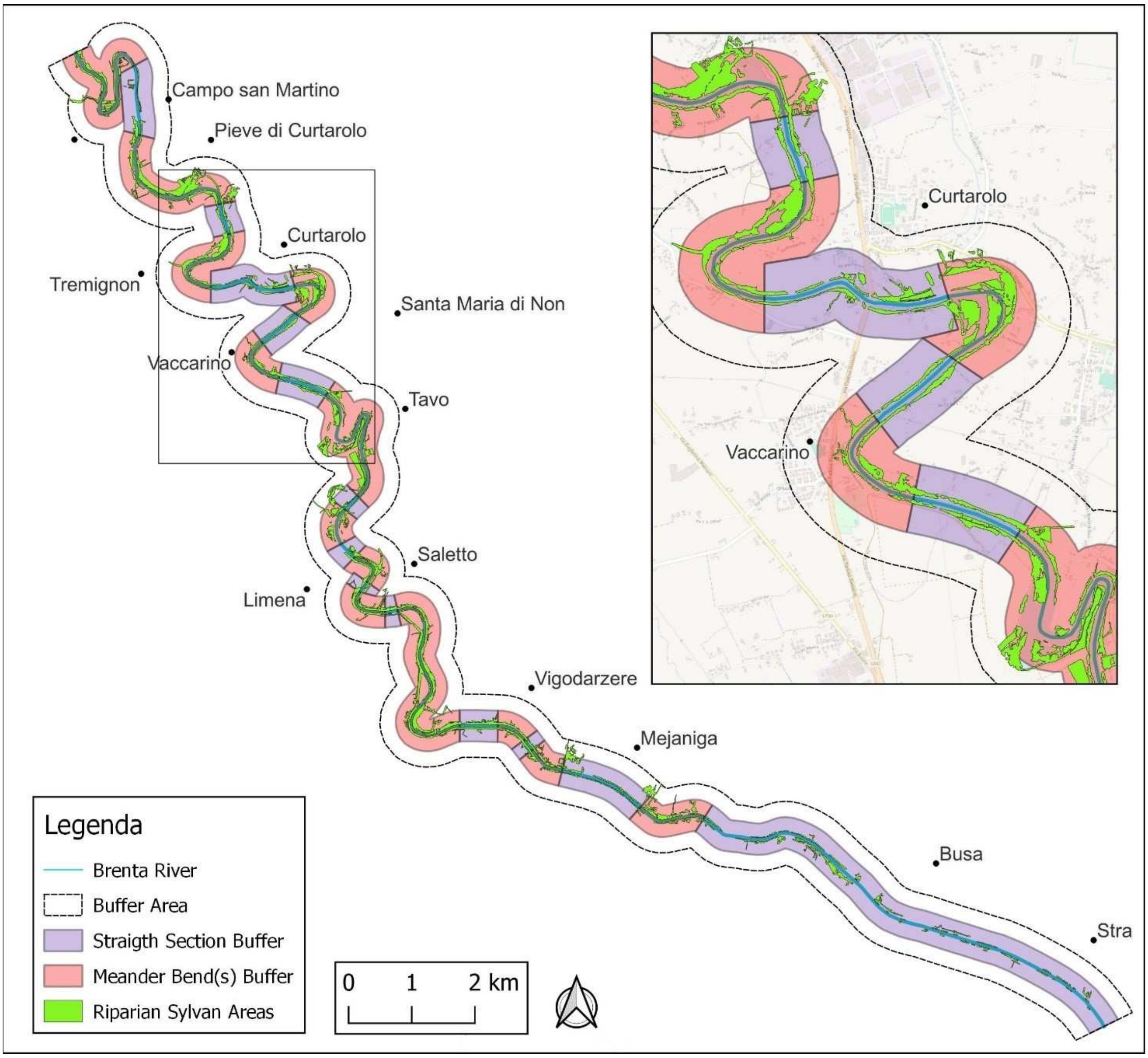

Figure 18. Visualization of the meandering and straight buffer units created in the selected stretch of the Brenta River.

On the other hand, the analyzed stretch of the Bacchiglione River shows a marked sinuosity between Cervarese Santa Croce and the southern gates of Padova, equal to 1.78. The final straight stretch between Brusegana and Padova represents an exception to the curvilinear course of the river throughout the Paduan plain. Straight sections, excluding the final one, are sporadic and of very limited length, in the localities of Cervarese Santa Croce, Saccolongo, and Pralungo. Once the straight and meandering stretches are identified, the river line is divided, and different buffer units are created based on these sections. The derived output is represented by 13 buffer units, of which 7 belong to non-meandering sections and 6 belong to more curvilinear sections. As seen in Table 12, the meandering buffer units have a significantly larger area than the straight ones, consisting of 74.43%

of the total buffer area in the Bacchiglione study area. These data reflect the pronounced sinuosity of the river and the relative scarcity of straight stretches.

Typology	Buffer unit (N)	Total area (ha)	Total area (%)	Mean area (ha)
Meandering section	6	1098.60	74.43	183.10
Straight section	7	377.28	25.57	53.89
Total	13	1475.88	100.00	113.52

Table 12. Basic statistics of the identified meandering and non-meandering units for the Bacchiglione River's sections of interest.

Table 13 shows the characteristics of the individual buffer units. As can be seen, the area of the units varies considerably, with a maximum of 333 ha and a minimum of 9 ha. Similarly, the digitalized polygons representing riverine sylvan areas are unevenly distributed within the buffer units: a significant concentration of polygons is found within buffer No. 4, prevalently located within the municipality of Saccolongo.

ID	Municipality (main)	Typology	Area (ha)	Area (%)	Polygons
1	Cervarese Santa Croce	Straight	9.48	0.64	2
2	Veggiano	Meandering	86.13	5.83	29
3	Cervarese Santa Croce	Straight	30.88	2.09	6
4	Saccolongo	Meandering	333.39	22.58	96
5	Saccolongo	Straight	19.65	1.33	6
6	Saccolongo	Meandering	38.04	2.57	12
7	Saccolongo	Straight	27.00	1.82	7
8	Selvazzano Dentro	Meandering	90.17	6.10	22
9	Selvazzano Dentro	Straight	55.87	3.78	16
10	Selvazzano Dentro	Meandering	134.41	9.11	42
11	Selvazzano Dentro	Straight	15.38	1.04	6
12	Padova	Meandering	39.09	2.64	7
13	Padova	Straight	219.02	14.83	41

Table 13. Display of the buffer units of the Bacchiglione River, divided by typology. Information about the area of the buffer units and the number of polygons inside each unit are also shown.

The exhibited data are visualized in the map below (Figure 19), which shows the distribution of riparian sylvan areas within the buffer for the Bacchiglione case study. The buffer is divided into the units described above, in an arrangement that alternates meandering stretches with straight stretches. The Bacchiglione has a higher sinuosity than the Brenta (1.77 against 1.51), developing pronounced curves as far as Tencarola. As previously emphasized, east of Tencarola the river assumes a straighter course: this is where the largest buffer unit relative to the non-meandering sections is found.

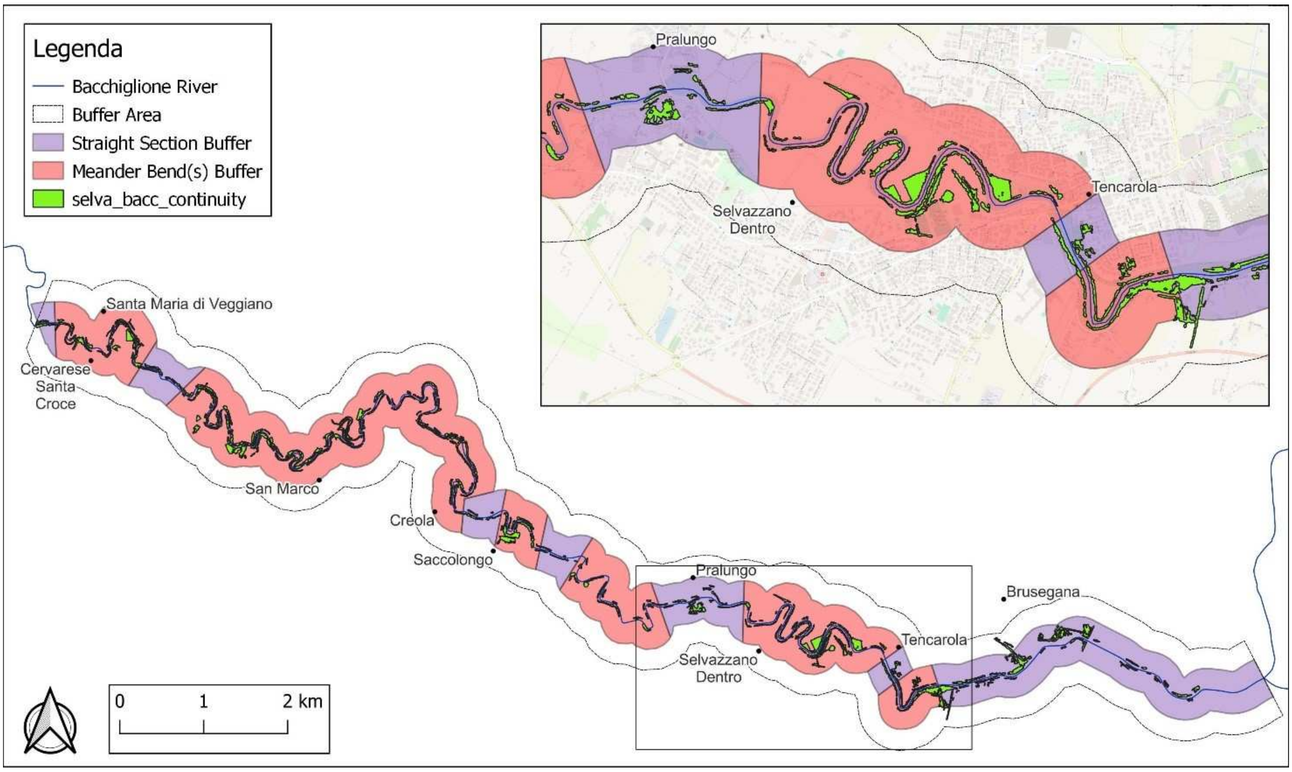

Figure 19. Visualization of the meandering and straight buffer units created in the selected stretch of the Bacchiglione River.

6.1.3 Fluvial Meanders as Generators of Sylvan

As stated in the opening chapter of this work, one of the two main objectives of the research is to investigate and evaluate the nature of the relationship between two specific elements of the Paduan territory: on the one hand riparian sylvan areas, and the other river meanders. The results found up to this point, described and visualized in the first part of this chapter, represent the starting point for testing the accuracy of the first research question. The data analysis approach relates to relative numbers, rather than absolute data, since the units of analysis are buffers of different lengths. In this way, it is possible to find comparable information between different areas, without the result being biased by the difference in the characteristics of the investigated geospatial entities.

The first case is that of the Brenta River. Figure 20 shows the spatial distribution of digitalized areas in the buffers, indicating the percentage of buffer area occupied by riverine green areas. As can be seen, the highest values are found at the meander bend located south of Curtarolo. Here riparian forest occupies more than 22 percent of the total buffer area. The vegetated area is also very present at other locations, especially in the large meander bend between Piazzola sul Brenta and Tremignon, in the very sinuous meander at Tavo, and in the river's section in Limena. Opposite situations occur in other areas. In particular, the stretch bordering Campo San Martino shows little riparian vegetation.

Similarly, the long straight stretch reaching Stra is inhabited by sparse riverine forest, especially in the final part of the section.

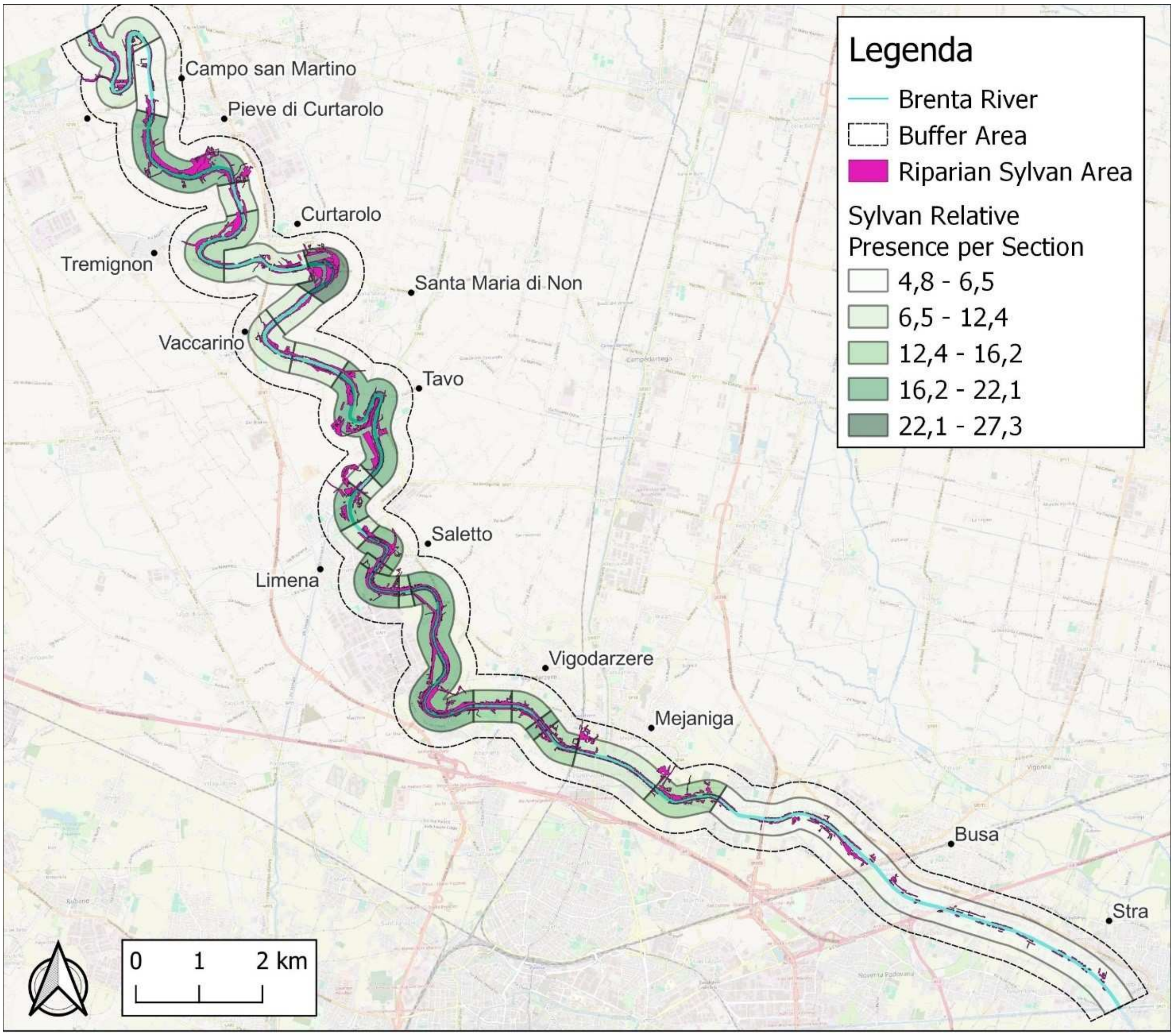

Figure 20. Riparian sylvan area percentage in the Brenta River per buffer unit.

Although the graphical visualization of the results may reveal interesting trends for the present study, a comprehensive answer to the first research question relies primarily on the interpretation of the statistical data that the analysis returns. To do this, the dataset composed of the buffer units is divided according to whether they belong to meander or straight sections. The analysis and comparison of the basic statistical data of these two groups highlights their fundamental characteristics and differences.

Meander	Count	Riparian sylvan area: min (%)	Riparian sylvan area: max (%)	Riparian sylvan area: standard dev.	Riparian sylvan area: mean (%)
N	13	4.79	19.21	4.2	11.57
Y	13	11.56	27.32	4.5	17.88

Table 14. Basic statistics regarding the percentage of riparian sylvan areas in the Brenta's buffer units.

As can be seen in Table 14, the Brenta buffers related to meandering and non-meandering sections have very different values regarding the percentage distribution of fluvial forest within their boundaries. The buffers created from straight sections show a percentage of fluvial sylvan areas ranging from 4.79% to 19.21% (range 14.42). Units related to meandering portions, on the other hand, have a minimum value of 11.56% of the total area and a maximum value of 27.32% (range 15.76). The difference related to the average percentage of riparian forested area in the two types of sections is crucial: near straight river stretches, the forested area covers, on average, 11.57% of the total area, while in the presence of meander, the value averages 17.88%. The t-test assessment reports a very low value (0.001), far below the conventional threshold of 0.05. Therefore, the difference in value between the two types of buffer units is statistically significant in the analyzed Brenta sections.

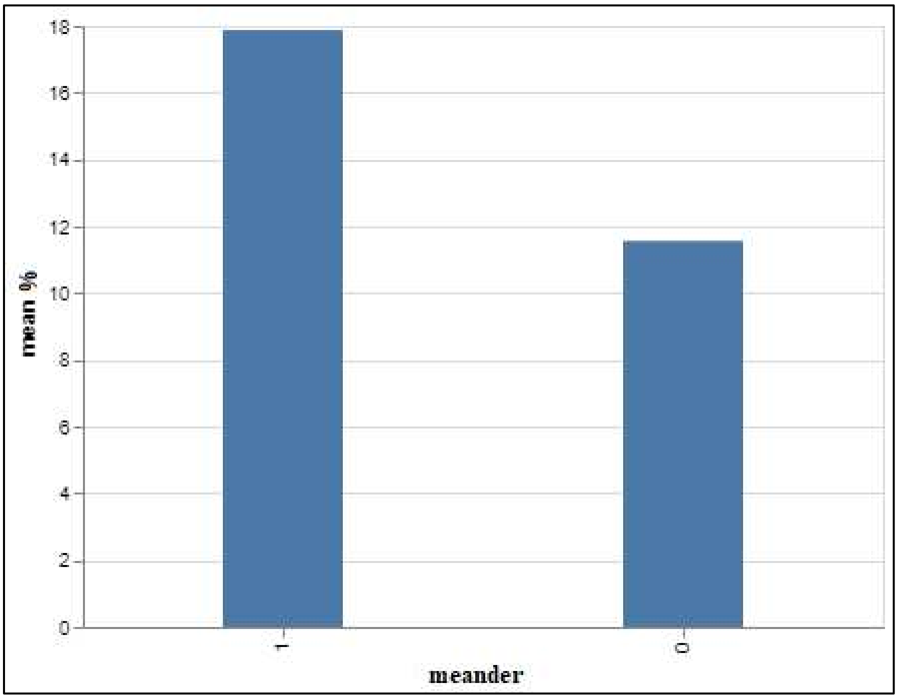

Figure 21. Bar chart highlighting the difference between mean percentage sylvan area in meandering units (1) and in straight units (0) in the Brenta River.

Regarding the Bacchiglione River, the geospatial analysis produces different results, if the graphical and visual representation is assessed. Figure 22 suggests that the percentage of riparian sylvan area in the banks of the Bacchiglione is generally lower than that of the Brenta. The buffer units with higher values are depicted in dark green in the map: the meander near Saccolongo, and the curvilinear stretch south of Tencarola. Both areas have a percentage presence of riparian forest higher than 7.9% but still much lower than the highest values observed for the Brenta. The area with the lowest relative presence of forest corresponds to the final stretch of the Bacchiglione, near Padova (1.7%).

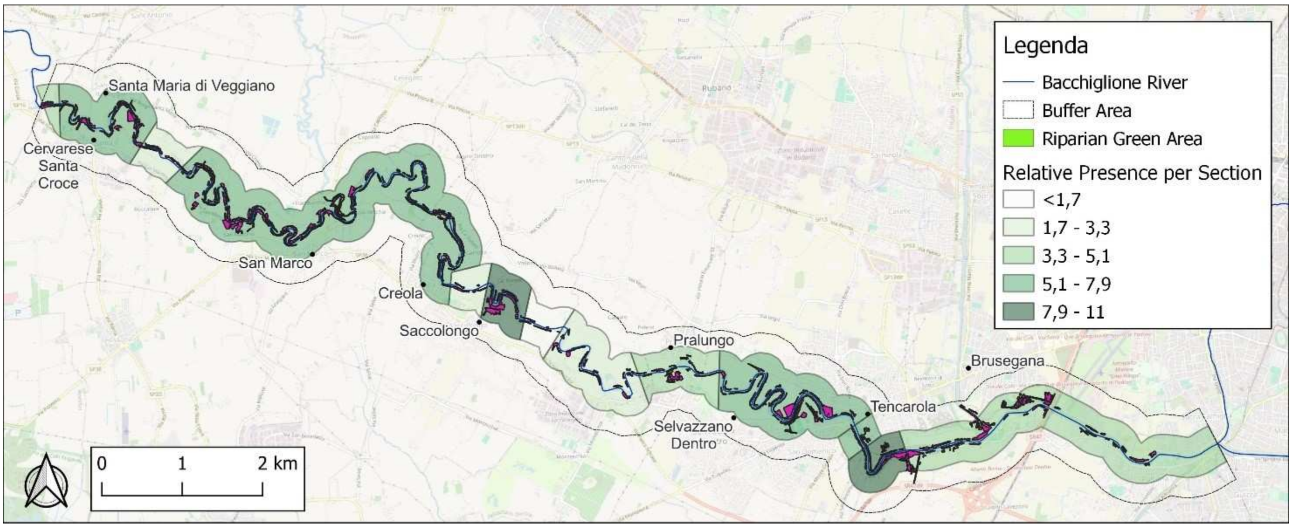

Figure 22. Riparian sylvan area percentage in the Bacchiglione River per buffer unit.

Basic statistical analysis on the Bacchiglione reveals similar results to those obtained for the Brenta in terms of differences between meandering and non-meandering types. At the same time, as noted above, the percentage numbers are generally lower than for the Brenta River. Buffer units afferent to non-meandering sections of the Bacchiglione have a percentage presence of riparian forest areas ranging from 1.73% to 7.38% (range 5.65). Meandering areas have a minimum relative presence of riparian forests of 3.14% and a maximum of 11.01 (range 7.87). If the former units have a mean percentage area of forests of 4.32%, the latter on average have a value of 8.84%. Again, as for the Brenta River, the percentage difference in the presence of riparian forest is substantial, corroborated by the t-test result <0.05 (equal to 0.009).

Meander	Count	Riparian sylvan area: min (%)	Riparian sylvan area: max (%)	Riparian sylvan area: standard dev.	Riparian sylvan area: mean (%)
N	7	1.73	7.38	1.8	4.32
Y	6	3.14	11.01	2.8	8.84

Table 15. Basic statistics regarding the percentage of riparian sylvan areas in the Brenta's buffer units.

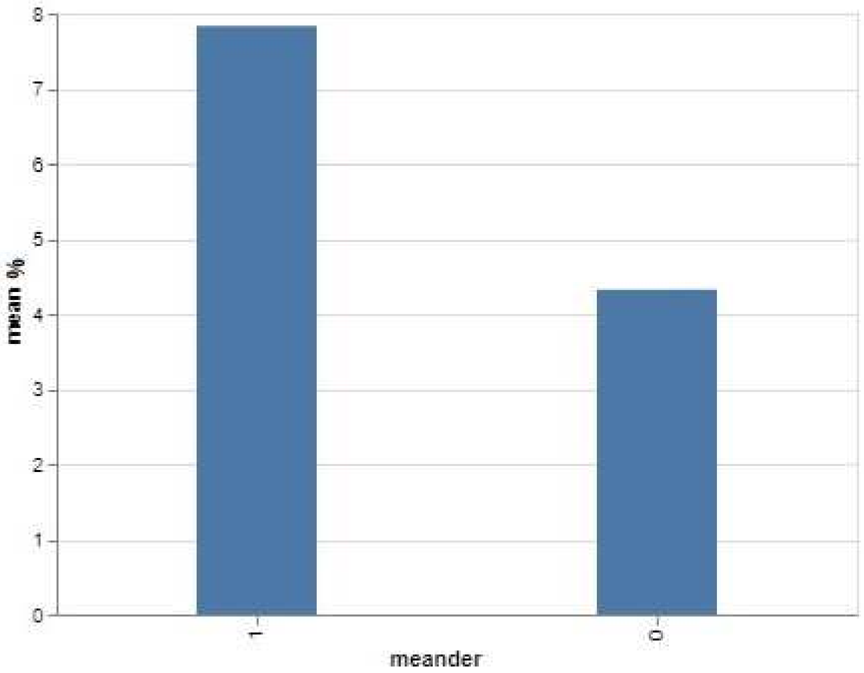

Figure 23. Bar chart displaying the difference between mean percentage sylvan area in meandering units (1) and in straight units (0) in the Bacchiglione River.

The average percentage of riparian sylvan areas in the Brenta and Bacchiglione sections differ significantly concerning meandering and straight stretches. The analysis proves that this variation is statistically significant. In both cases, the buffer units afferent to the meandering stretches of the two rivers generally harbor a higher percentage of riparian forest in relation to the total buffer area.

6.1.4 Assessing Human Impact: A New Variable

As suggested in Chapter 5, various factors contribute to explain the spatial distribution of riparian sylvan areas. They are here analyzed with the aim to corroborate the previous findings and to assess the impact of human practices in the area. The latter are embodied in the study through the analysis of the appropriation by local population of riparian lands for a wide variety of uses, as highlighted in Chapter 4 (Figure 24).

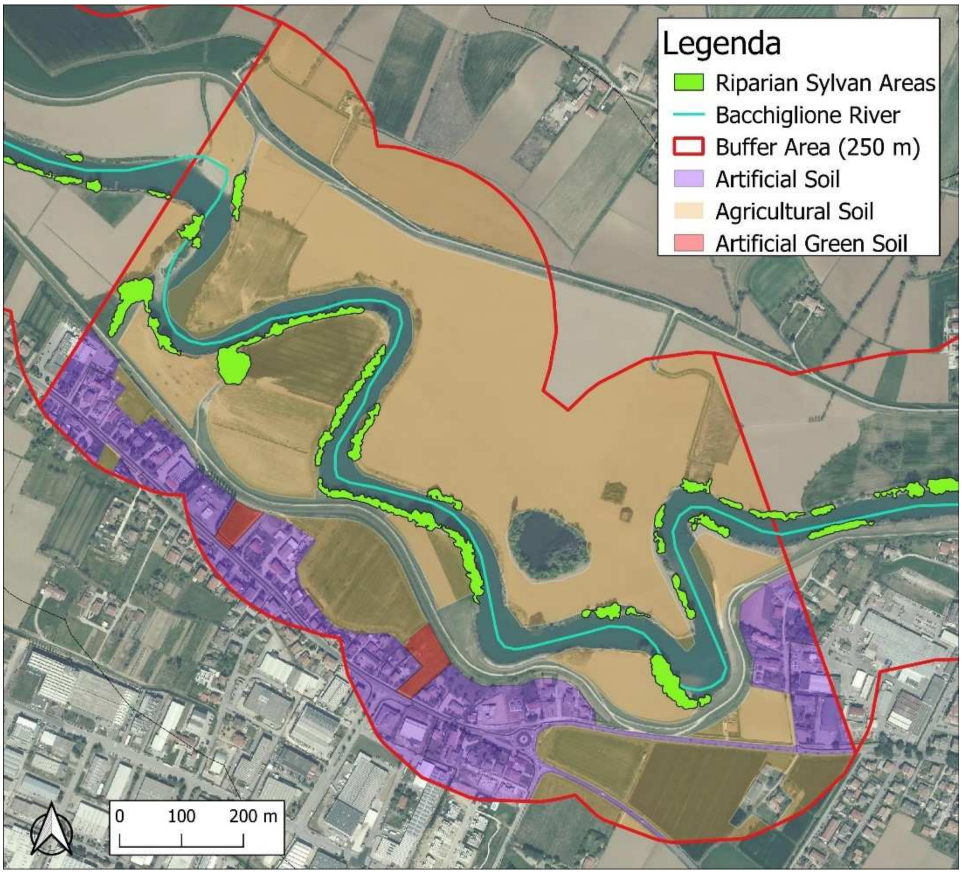

Figure 24. Human land use of the riparian area in the Bacchiglione River, north of the Industrial Zone of Saccolongo. The three types of land surfaces pointed out in Chapter 5 are displayed based on the Geoportale Veneto data source.

The assessment of the degree of anthropogenic impact in the riparian area of the Brenta and Bacchiglione rivers is concretely implemented through the creation of a linear regression model. This model is built using the Jupyter software (Python language) and the sklearn library, which allows to automate the various procedures. During this phase, the datasets of the two rivers are merged, as the goal is to identify a new variable called 'selva generator,' which refers to the degree of suitability of each buffer unit in the overall area of interest to host riparian sylvan areas. This process is structured in several steps, each with different objectives. To facilitate the understanding of the analytical process, an Annex has been appended to the research, showing the original codes in the Jupyter notebook (Annex I).

The first step of the analysis is the preparation of the dataset. The variables of interest are selected according to the classification proposed in the previous chapter (5.3.3). Especially three independent variables - 'artificial surface percentage', ‘agricultural surface percentage' and 'artificial green surface percentage' per buffer unit - are isolated. The response variable is the percentage of riparian sylvan area per buffer unit. These variables are the features of the linear regression model (Annex I, Step 1).

Secondly, the explanatory variables are standardized. Standardization is implemented to minimize the mean of the variables and to make the standard deviation equal to one. In regression models, this ensures that the estimated coefficients are not affected by the different measurement scales of the variables (Annex I, Step 2).

Having prepared and standardized the data, the simple linear regression model is built. It estimates the linear relationship between the explanatory variables - urban, agricultural and artificial green areas - and the response variable, i.e. riparian sylvan areas. As a result, a coefficient is assigned to each of the explanatory variables (Annex I, Step 3).

The estimated coefficients of each explanatory variable are used to calculate the value of the new variable, 'selva generator.' The latter represents the linear combination of the explanatory variables, weighted based on the coefficients obtained in the previous step (Annex I, Step 4).

These coefficients are interesting as they provide information regarding the relative importance of each type of soil use in influencing the distribution of riparian sylvan areas in a positive or negative manner. For this reason, an explicit representation of the linear regression model formula found through the above process is proposed below. The new variable 'selva generator' is calculated as a linear combination of the independent variables and the intercept. The latter, with a value of 11.80, represents the value of the response variable ('forest percentage') when all independent variables have a value of zero (Annex I, Step 5).

*selva_generator = 11.80 + (-4.46 * artificial) + (-5.72 * agricultural) + (2.97 * artificial_green)*

In light of these findings, the formula shows important trends for assessing the impact of human activity on the riparian soils of the Brenta and Bacchiglione rivers. In particular, the coefficient reveals the nature of the relationship between the different explanatory variables and the response variable, emphasizing whether it is positive (+) or negative (-). It is observed that:

- A negative influence on riparian sylvan area development is exerted by artificial (urban and industrial) areas and agricultural areas.
- A positive influence is exerted by artificial green areas, such as urban green spaces.

The last step of the analysis is to test the correlation between the variable 'selva generator' and the response variable, relating to the relative presence of riparian sylvan area per buffer unit (Annex I, Step 6). As seen below (Figure 25), the correlation between the two variables is strong (0.79), even though not perfect.

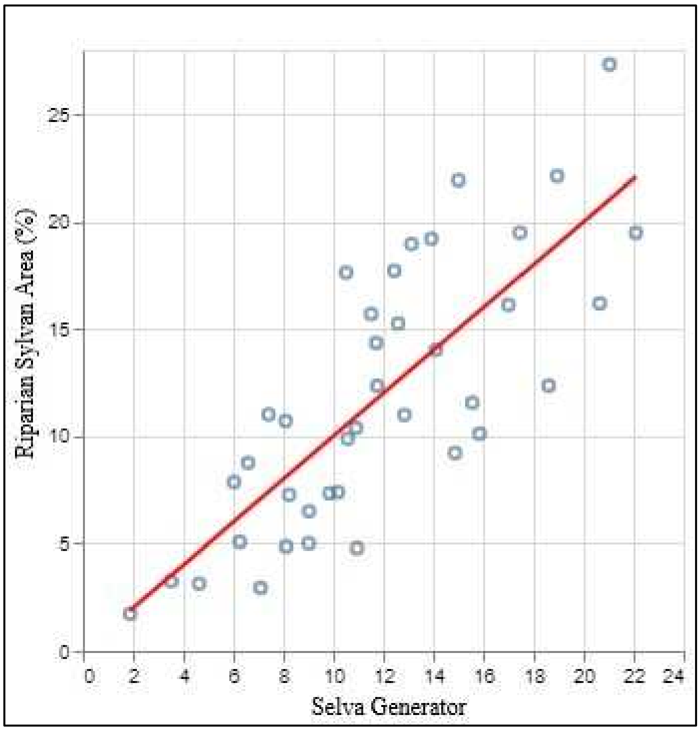

Figure 25. Scatter plot showing the correlation (0.786) between the newly found 'selva_generator' variable and the riparian sylvan area percentage presence for each buffer unit of the Brenta and Bacchiglione rivers.

Finally, the graphical visualization of the distribution of the 'selva generator' value in the studied section of the Brenta and Bacchiglione allows for defining the buffer units most suitable for hosting riparian vegetation, based on the theoretical insights and findings of the analysis. Specifically, the most favorable areas for riparian vegetation development in the Brenta River (Figure 26) are associated with three buffer units: the meander south of Santa Maria di Non, a section north of Limena, and a stretch between Vigodarzere and Padova. Lower values (indicating less suitability for the development of spontaneous vegetation) are found near Campo San Martino, in the straight section at Curtarolo, in the stretch between Santa Maria di Non and Vaccarino, and finally in the final section up to Stra. Comparing the results with those of Figure 20, it can be seen that the values for 'selva generator' generally match the relative distribution of sylvan areas.

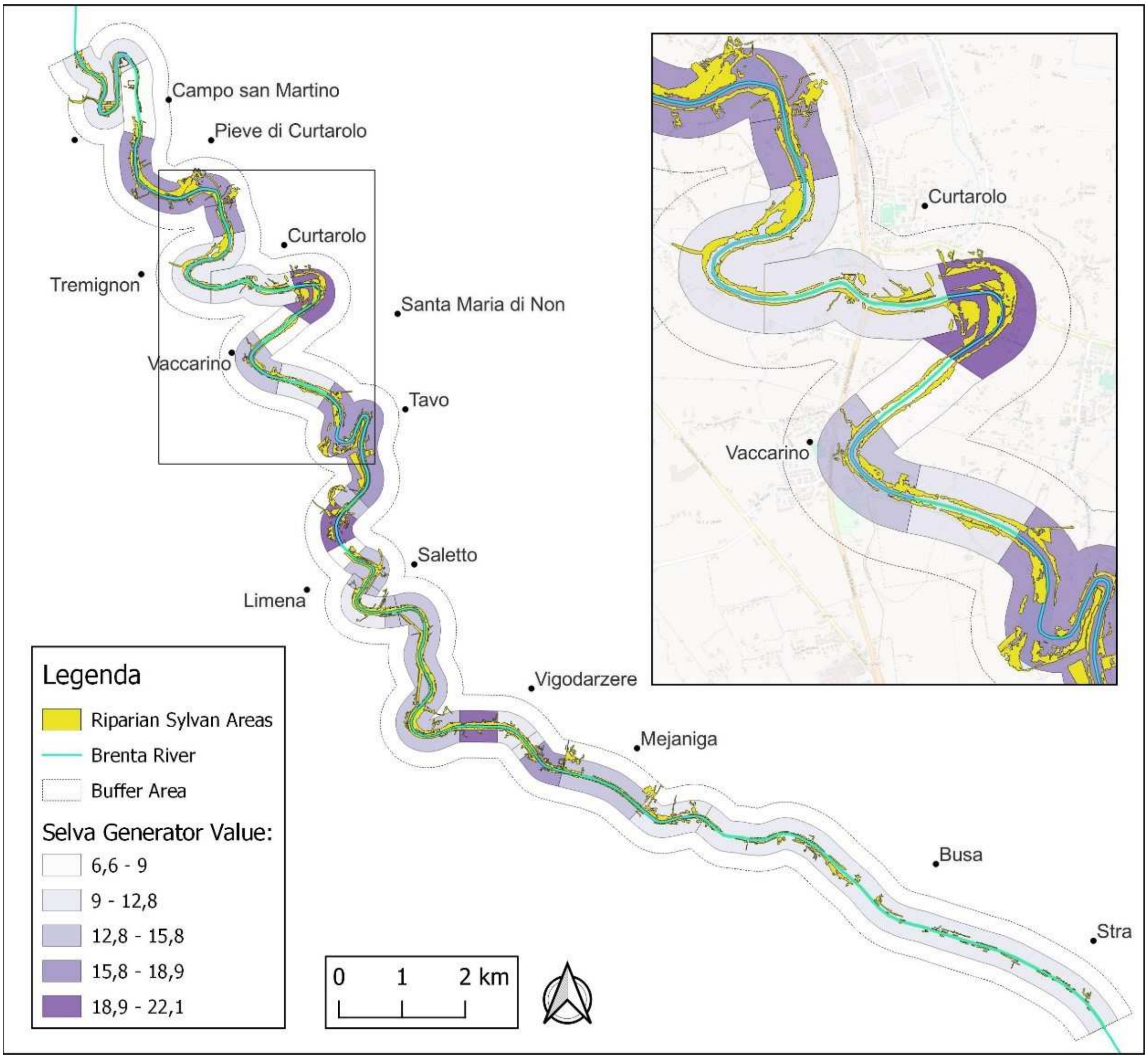

Figure 26. Visualization of the selva generator values for the buffer units of the Brenta. Darker units are interpreted as more suitable to host a higher percentage of riparian sylvan areas within their boundaries.

Regarding the Bacchiglione, the distribution of buffers that are suitable for the growth of riparian sylvan areas in the Bacchiglione is quite uneven, ss seen in Figure 27. High values are reported in the units at the end of the analyzed Bacchiglione section, starting from Tencarola. The easternmost unit, the one south of Brusegana, seems to be particularly suitable to host riparian sylvan vegetation, even though the previous spatial distribution analysis (Figure 22) showed that spontaneous forested areas are relatively low in this portion of territory.

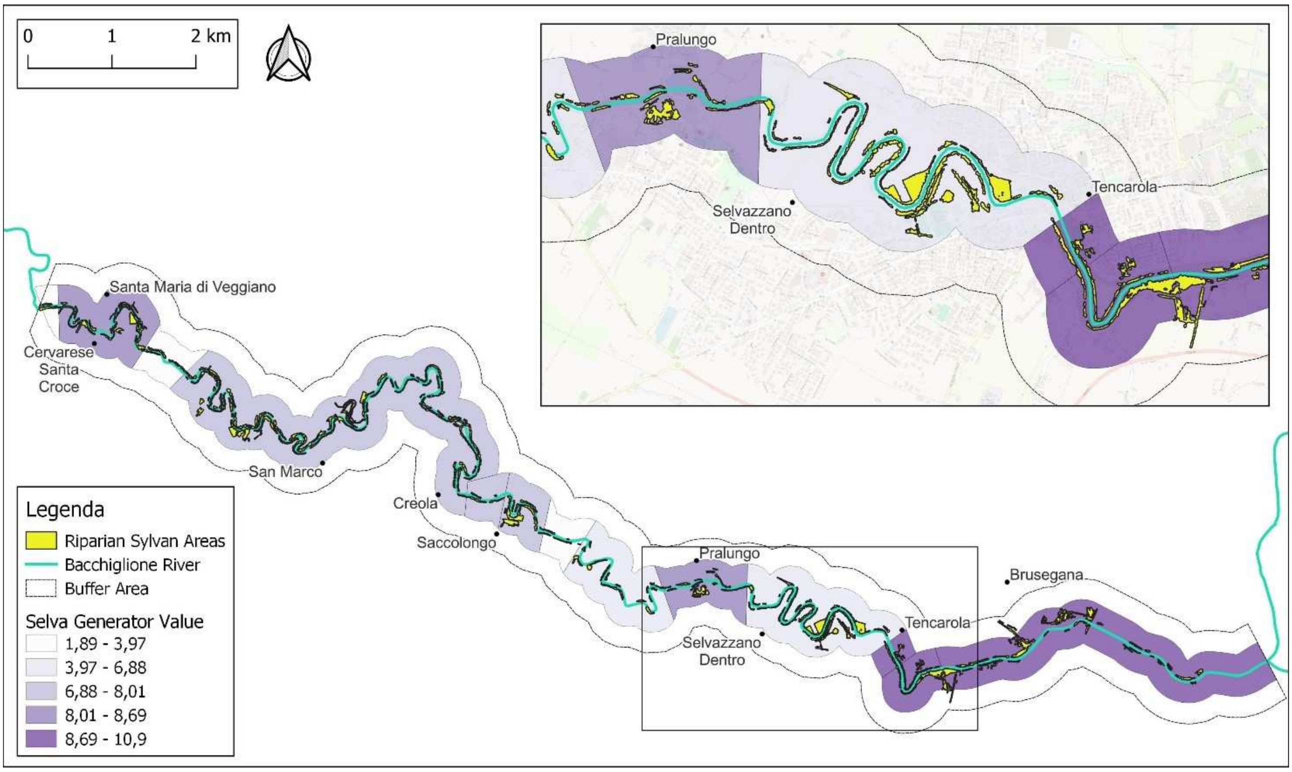

Figure 27. Visualization of the selva generator value distribution in the Bacchiglione's buffer units.

6.2 Qualitative Analysis

6.2.1 A Wide and Rich Variety of Riparian Areas

Riparian forests represent transient and variegated elements of the territory. They arise from the interaction with the landscape, humans, and river dynamics. They are also the result of the history of localities and towns, are linked to traditions, and are the subject of interest in a wide variety of study fields, such as geology, botany, and ornithology. This linkage with historical, territorial, and managerial dynamics determines their variety (Bennett and Simon 2004; Bondesan 2003).

Riparian forests can be buffer strips, i.e. vegetated areas that run along the riverbank for several kilometers and separate the river system from the upland (Figure 28).

Figure 28. Example of buffer strip on the Bacchiglione River, in San Marco. Credits: Geoportale Veneto

These strips are important ecological corridors for local wildlife and allow the creation of an environment of transience and containment against the development of agricultural activities or urban expansion. Sometimes, especially in the presence of meanders, these ecological corridors expand over the riparian surface, forming dense and wild forests that interrupt the continuity of the Veneto agricultural landscape (Figure 29).

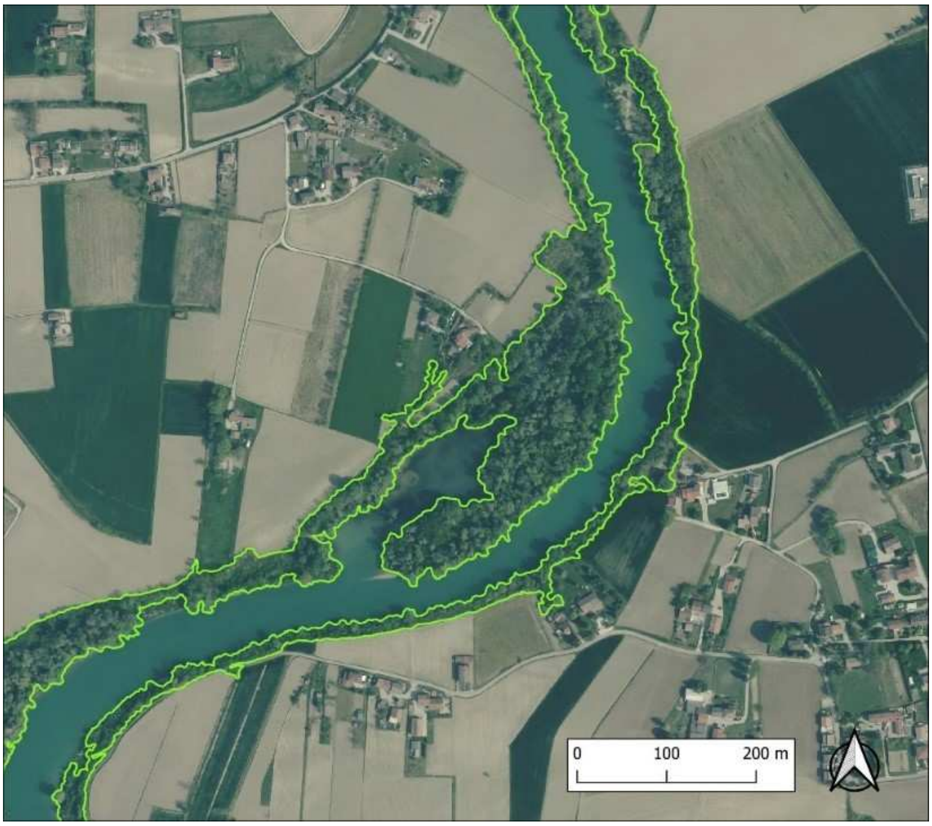

Figure 29. Concentration of riparian trees along the Brenta River, forming a riparian forest near Curtarolo. Credits: Geoportale Veneto.

Elsewhere, riparian forests are connected to public parks, private gardens, and green areas of historic buildings. Even today, for instance, it is possible to identify a direct connection between the gardens of Villa Contarini, or of the Certosa di Vigodarzere, and the riparian vegetation of the Brenta River (Figure 30).

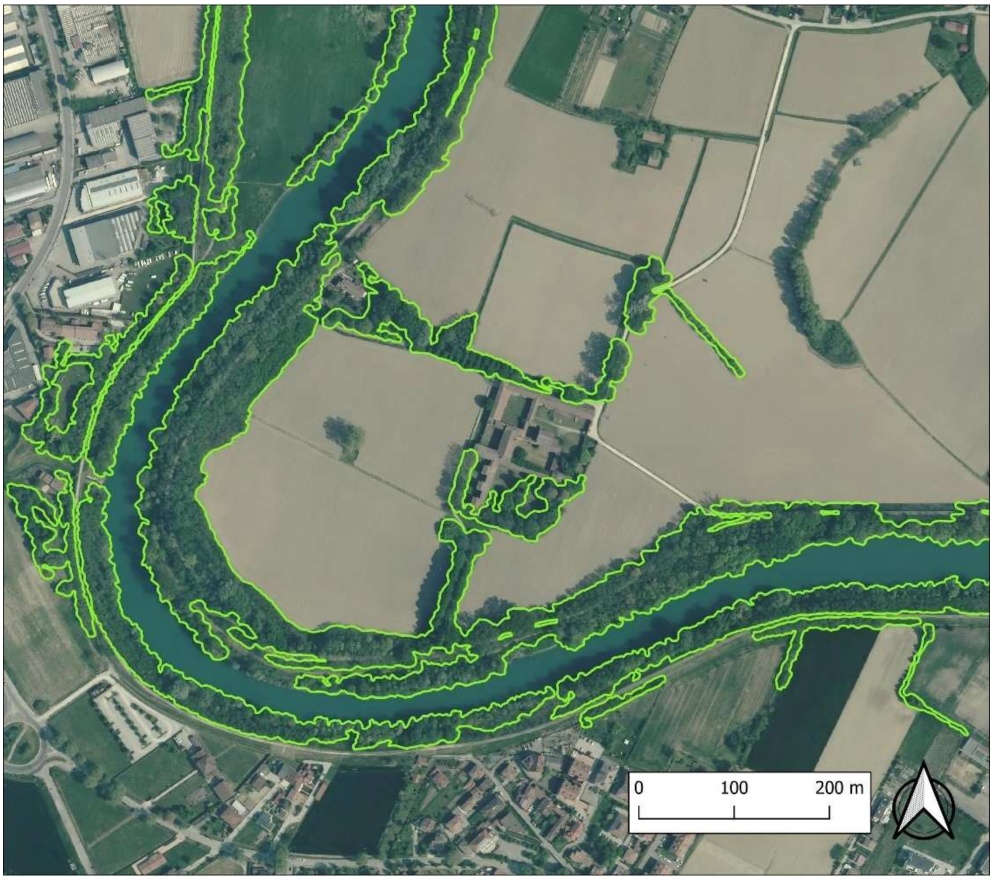

Figure 30. Detail of the riparian forest surrounding the Certosa in Vigodarzere. The tree strips connect the monastic building with the riparian vegetation of the Brenta River. Credits: Geoportale Veneto.

As highlighted by Figure 31 and Figure 32, venetian villa gardens, natural parks, and bathing beaches are some of the forms that riparian forests take along the stretches of the Brenta and Bacchiglione rivers. They are crossed by a dense network of trails and cycle paths, which capitalize on the fresh and picturesque river environment. Urban farms, guesthouses, and sporting activities spread along the riverbanks, shaping the forest as a meeting and refuge place for local populations. Nevertheless, they continue to maintain - especially in the protected areas (Special Protection Areas, or SPA) of the Brenta – a wild and unspoiled naturalistic character that leads to the creation of habitats of fundamental importance for the local fauna (Fogliato 2022; Mihaila and Vallerani 2014).

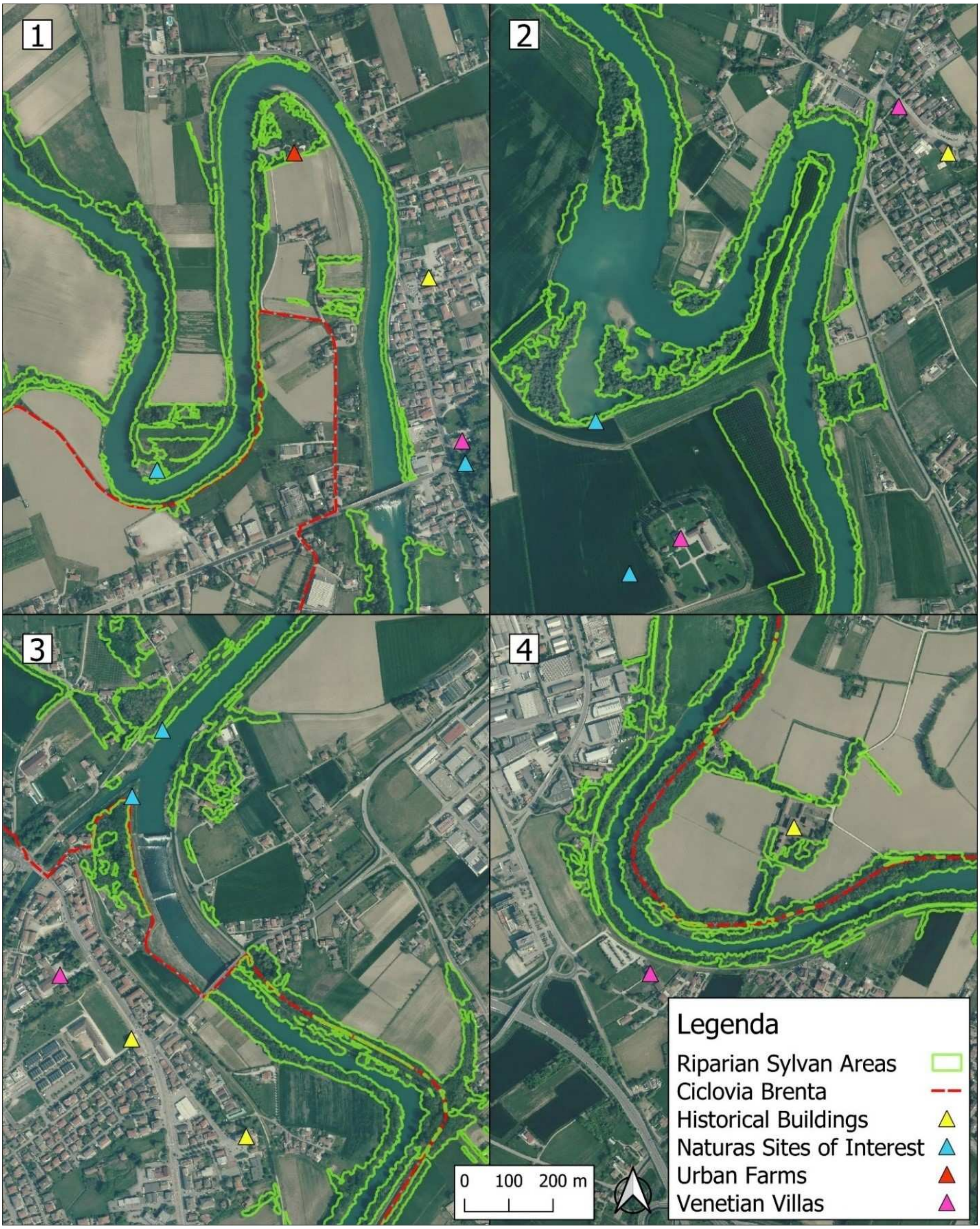

Figure 31. Riverine forests and their treasures: Brenta. In particular: 1) Meander at Campo San Martino, where there are, among others, several naturalistic sites (especially, the 'Bagni del Sole' beach) and the 1800s Villa Breda. 2) Brenta River course near Tavo, where two villas (Villa Pacchierotti De Benedetti, Villa Mussato) and sites of naturalistic interest lie along the river. 3) Along the meandering course of the Brenta near Limena, several beaches are found, as well as the Barchessa di Villa Fini and historic religious buildings. 4) South of Limena, on the border with Padova, is a meander that hosts the Certosa di Vigodarzere on the left side and Villa Zaguri on the right side. Credits: Geoportale Veneto.

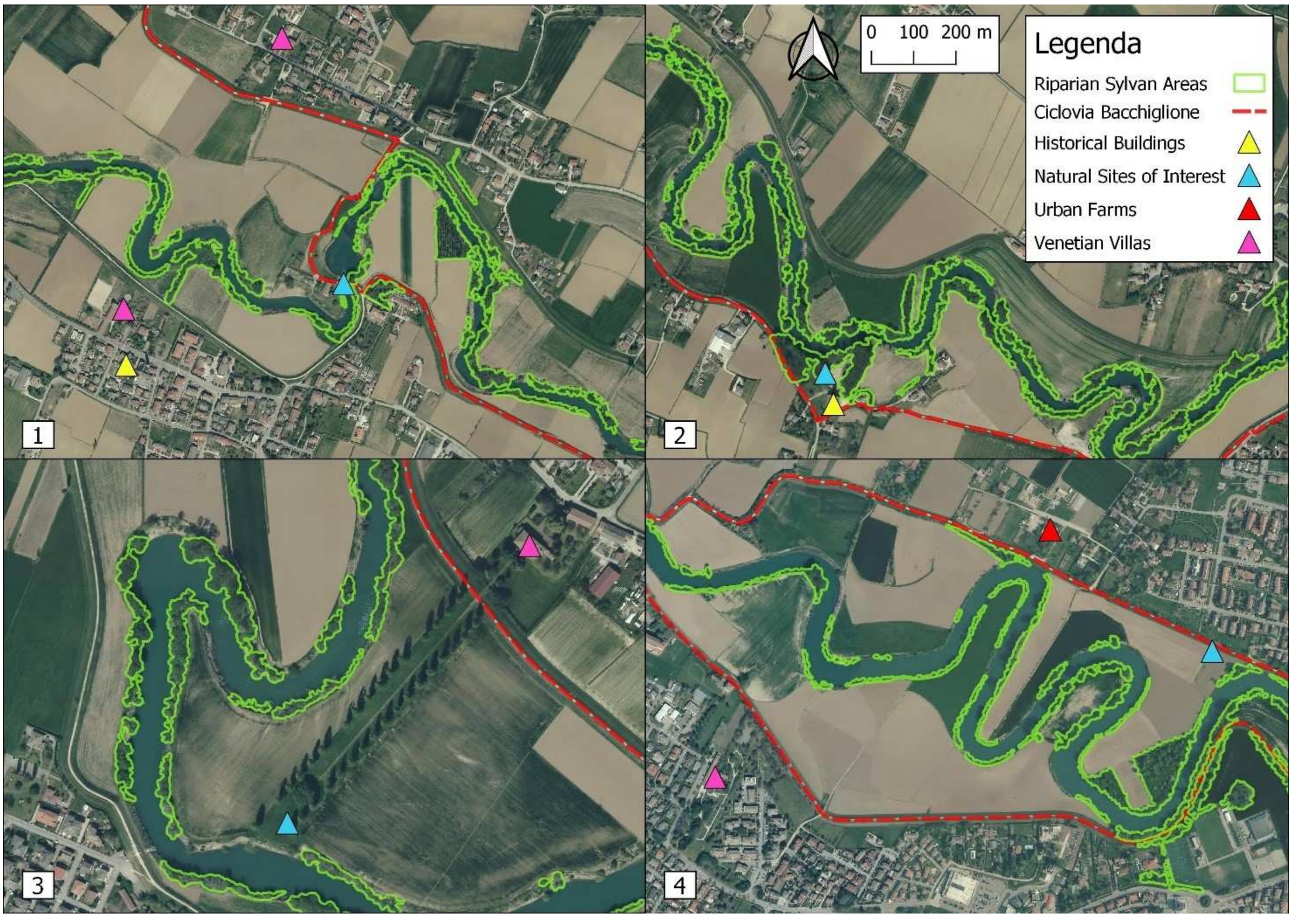

Figure 32. Riverine forests and their treasures: Bacchiglione. 1) Along the Bacchiglione course between Cervarese Santa Croce and Santa Maria, a panoramic point is located at the intersection of the river and the cycle route. Several ancient religious buildings lie in the area: the Oratorio della Santa Croce in Cervarese and the Antica Chiesa di Santa Maria. 2) The Castle of San Martino della Vaneza is located on the banks of the Bacchiglione River, in San Marco. The castle is now a museum that displays the story of the Bacchiglione River since the earliest human settlements. 3) The Montagnola di Villa Carretta represents a striking feature of the rural landscape of Padova, as described in Piovan and Luchetta (in press). 4) Between Selvazzano Dentro and Tencarola, the Bacchiglione River flows through an agricultural area, rich in urban farms and historic buildings, such as Villa Melchiorre Cesarotti (with adjoining Barchessa). Credits: Geoportale Veneto.

6.2.2 Hidden Treasures lie in Meandering Bends

The last step of the qualitative analysis focuses on the description of three meandering river micro-contexts that, for various reasons, are considered significant for the present research. The photographs in this section are taken using drone technology, to capture the peculiarities of these environments.

The first selected section displays the Bacchiglione stretch that divides the towns of Tencarola on the left, and Selvazzano Dentro on the right. In such a context, the Bacchiglione develops through a highly meandering course, interrupting the agricultural and urban expansion. As seen in Figure 33, concentrations of vegetation and tall riparian trees develop in the meander bends, finding a balance with the surrounding environment. Located just outside Padova, this stretch of the Bacchiglione is bordered by the Ciclovia that connects the provincial capital with Vicenza. These meander bends of the Bacchiglione River represent transient but highly distinctive landscape elements, providing disparate ecosystem services to local populations.

Figure 33. Detail of a meander bend of the Bacchiglione, between Selvazzano Dentro and Tencarola. The riparian forest fits into the agricultural and urban context of the two towns. Own photo.

Near Tavo, a sinuous meander harbors a concentration of riparian trees that shape a very peculiar environment. Here the channel of the Brenta River enlarges at the height of the meander bend, forming an anomalous landscape environment. As seen in Figure 34, the waters of the Brenta digress once the channel curves, creating a semi-palustrine area where wild vegetation flourishes. Located in the vicinity of the Villa Pacchierotti Di Benedetti, visible in the distance, this meandering area is nowadays subject to reforestation, to preserve a unique panoramic corner.

Figure 34. The digression of the river channel represents the starting point for the creation of a unique environment in this Brenta's meander. Riparian trees develop in the banks, while behind them it is possible to see a tentative reforestation process. Own photo.

The last area of interest is the meanders near Piazzola sul Brenta. Here the vegetation is thicker than in other locations, shaping wild and unspoiled forests. A riparian ecosystem forms in these areas, whit willows and poplars reaching considerable size, while local wildlife finds refuge from urban pressure. In this site, the lake called 'Busa de Bastianeo' is a characteristic feature, derived from the flooding of a ceased gravel quarry in the last century. In this area, many recreational activities are provided for the population: regulated fishing, hiking and running, canoeing, and bathing in the so-called locality of 'Paradise Beach' (Figure 35).

Figure 35. Aerial photo of the Brenta River and the lake 'Busa de Bastianeo', in Piazzola sul Brenta. The concentration of riparian vegetation creates unspoiled forests. On the lake's banks, it is possible to see a sandy clearing, 'Paradise Beach', where residents and tourists refresh themself on hot summer days. Own photo.

7 DISCUSSION

The analysis results are inspected in this chapter to fully understand their meaning. An overview of the research is carried out, to interpret the aspects and relationships that emerged as significant in the previous chapters. The discussion on the results is addressed using the theoretical framework outlined in the research on the one hand and emphasizing the peculiarities of the local geographical context on the other.

Firstly, the answer to the first research question is discussed (7.1), referring to the relationship between the presence of meanders and the spatial distribution of riparian forest area. The inclusion of a new variable in the process is analyzed (7.2), with particular attention to cases in which this variable does not fully explain the distribution of riparian forests in the two rivers; this gives rise to a reflection on the role of the ‘sylvan’ element in the riverine environment. In conclusion, some final considerations are taken into account (7.3), regarding the goals, limitations, and legacies of the research.

7.1 Spatial Distribution Results

The first part of this chapter concerns the in-depth analysis and comprehensive understanding of the findings of the research. The results are described and discussed to shed light on the dynamics hypothesized in the opening of the work, and especially to answer the question:

Are the meanders of the Brenta and Bacchiglione rivers generators of sylvan areas?

The statement by geographer Waldo Tobler proposed in the introduction of the study, which suggests that «everything is related to everything else, but near things are more related than distant things» (Tobler 1969, as cited in Porthiuus 2023) may provide a clue to answer this question. This pivotal concept in computer geography provided the theoretical context for carrying out an analysis of the proximity effect in the riparian area of the Brenta and Bacchiglione rivers. The results obtained from the spatial dependence analysis between the two geospatial entities of this research – i.e., meanders and riparian sylvan areas – confirm the presence of the proximity effect. The relative distribution of riparian forests supports the initial hypothesis that meanders are generators of this type of environment in the riverine areas of the Brenta and Bacchiglione rivers. From a theoretical point of view, this means that the research conforms to the strand of literature (Perucca et al. 2006, Ielpi et al. 2022, Finotello et al. 2024) that observes a dependency relationship between riverine meanders and riparian forests, as seen in Chapter 2 (2.2.2). Moreover, the results show that this research field is applicable to the context of the Brenta and Bacchiglione rivers. In recent times, the analysis of these two rivers has focused on other aspects of their geomorphology, neglecting to fully investigate the influence that the river system exerts - especially in its more sinuous sections - on the aspect of the surrounding riparian environment. The analytical findings warrant a change of direction, in an attempt to bring new global geospatial research trends within the local area.

The analysis concretely reveals significant trends in the analyzed stretches of the two rivers. As the data query process shows, the riparian landscape of the Brenta River is inhabited by lush and variegated flora. The forest concentration on the banks of the Brenta is exhibited by the results, with more than 350 ha of riparian forest identified. This is due to several aspects that are not only of geomorphological nature. Most part of the Brenta riparian area belongs to the Natura 2000 network, undoubtedly contributing to shaping its flourishing and unspoiled appearance. Vegetation concentration and high rate of biodiversity (Bondesan 2003; Selmin and Grandis 2008) are particularly pronounced where meanders develop. These represent, during the middle course of the river in the upper Paduan territory, a characteristic and peculiar element that shapes the riparian landscape and influences its features. The analysis conveys an image of the Brenta River’s meanders as generators of environment with high naturalistic value, that give rise to the formation of distinctive riparian landscapes. This is the case, for example, of the meanders’ riparian environment in Pieve di Curtarolo and in Santa Maria di Non (Figure 36), where riparian trees expand starting from the banks of the river and form a significantly large forested area.

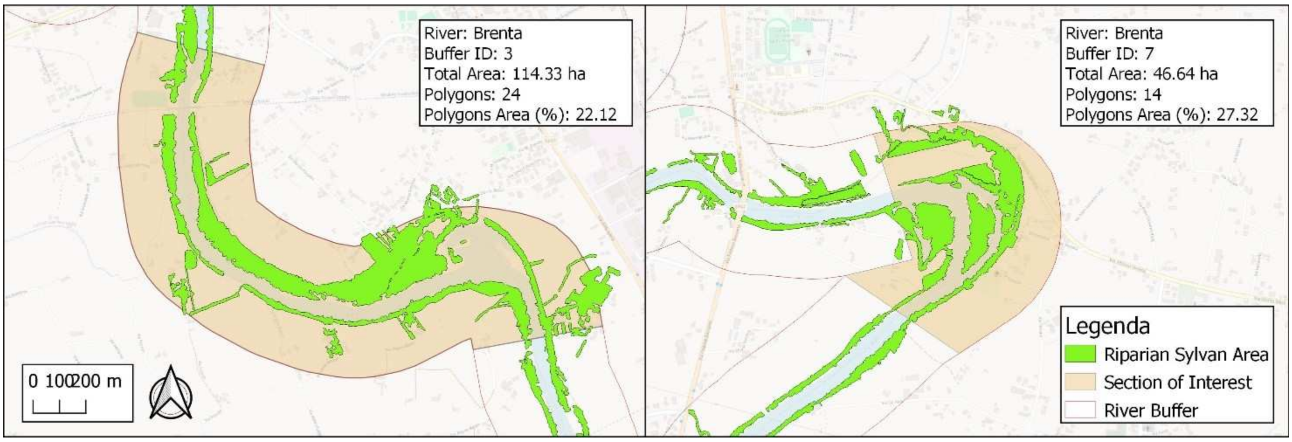

Figure 36. Detail of the riparian sylvan areas on two stretches of the Brenta River. Near Piazzola di Curtarolo (on the right), the forested area expands in the proximity of the meander bend, where the waters of the Brenta flood part of the plain on the left of the river. In Santa Maria di Non (on the left), the riparian forest expands in coincidence with the maximum curvature point of the river.

The riparian area of the Bacchiglione River reflects the trend observed for the Brenta. The physical space created by the meandering sections of the river allows for spontaneous riparian vegetation to grow and develop, as demonstrated by the cases of San Marco and Selvazzano Dentro (Figure 37). However, the Bacchiglione River generally features less vegetation in proportion to the Brenta River, even considering the different sizes of the channels. This research has addressed the difference between trends by including another variable in the discourse, that assesses the degree of influence exerted by humans in the riparian area of these two rivers, as will be seen in the next subchapter.

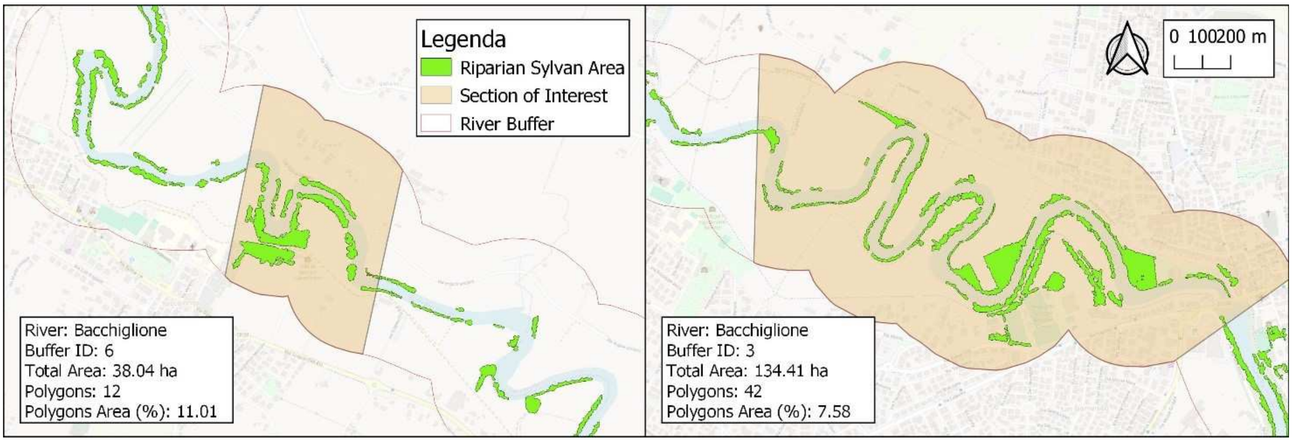

Figure 37. Two of the units that are more populated with riparian sylvan areas in the Bacchiglione River. On the left is the area corresponding to the park of the Castello di San Martino della Vaneza in San Marco. On the right is the area between Selvazzano Dentro and Tencarola, in which the spontaneous vegetation develops between the two towns, creating a peculiar environment in the urban landscape.

It is necessary to stress that the difference in the distribution and extension of riparian sylvan areas of the two rivers of interest may be due to several factors of disparate nature. As pointed out above (5.3.3), the choice of the variables investigated in this research reflects the objectives of analysis and does not consider the presence of additional elements that may explain the distribution of the forested analyzed areas. The availability of water in a given terrain, for example, is a determining factor in delineating the suitability of an area for the development of spontaneous vegetation. The present research does not consider other factors, such as the difference in air quality of various sections in the area of interest, or the diversity of soil permeability. As suggested during the exposition of the theoretical background (Chapter 2) and methodological framework (Chapter 5), these factors are recognized as determinants in explaining the distribution of riparian forests. However, the present research faced a lack of specific sources for data analysis concerning these topics. Future studies investigating the area could focus on integrating the findings of this work with new insights related to the geomorphological and atmospheric characteristics of the analyzed territories.

7.2 Interpretation of a New Variable

The identification of a new explanatory variable in the second part of the research is motivated by several choices. Firstly, the new variable allows for a better understanding of the spatial distribution of sylvan areas in the territory of interest. There are several cases in which, despite the presence of highly sinuous courses, the riparian areas of the two rivers are sparsely populated by forests, as displayed by Figure 38 and Figure 39. This suggests that other factors explain the spatial distribution of spontaneous vegetation formations. The nature of these factors is manifold, and this research has focused on examining one in particular, namely anthropogenic pressure.

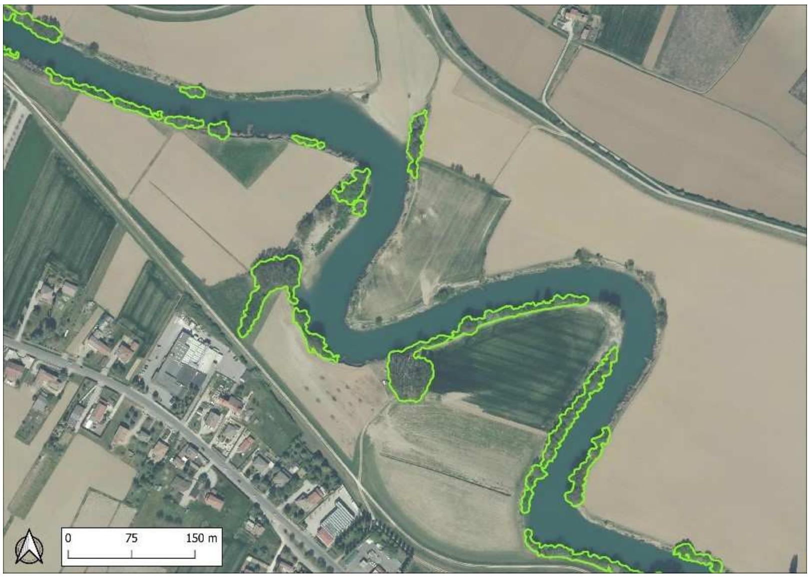

Figure 38. Riparian sylvan areas (light green) in the stretch of the Bacchiglione River close to the industrial district of Selvazzano Dentro are rarefied and strongly limited by the agricultural expansion and, with relatively less intensity, industrial and urban development.

Figure 39. In Vaccarino, the Brenta River crosses cultivated fields on its left, and the dense urban fabric on its right. Consequently, the space for riparian sylvan elements (light green) to expand is significantly reduced.

The assessment of the impact of human activities in these areas represents an attempt to analyze not only the spatial distribution of riparian sylvan areas but consequently how local population manages and uses these spaces. For this reason, a further step in the research is to assess the weight that different types of human practices - industrial, agricultural, or urban processes - exert on the analyzed area. This has been implemented through the creation of the ‘selva generator’ variable, which assesses the suitability of a portion of territory to host riparian sylvan areas. Once the data is collected and the correlation demonstrated (6.2), it is necessary to dive into what this result means for the research.

The analysis results show that all the studied spatial units feature significantly anthropized soils: intensive crop cultivation, industrial districts, and medium-dense urban fabric are an integral part of the riparian landscape in the upper Padova province. Where human activity is most present, it is logical that the extent of spontaneous forest is quantitatively reduced in space. This finding, confirmed by the analysis, should not be misleading. The present work identifies 'sylvan' as a concept that, as stressed by Piovan and Luchetta (in press), results from the relationship between the human and natural worlds. In contexts of significant human pressure, the riparian forests’ value is enhanced by their transient and precarious situational feature.

Interpretation of the ‘selva generator’ variable must be cautious and weighted, for it explains the spatial distribution and concentration of sylvan spaces but does not give information regarding the quality of such areas. A second key to interpreting this variable is to look at cases where it is unable to explain the relationship between geospatial entities. In principle, the results of this research take for granted the fact that the relationship between this variable and the extent of a forest in a territory is positive, expecting that a high value in the explanatory variable predicts a high value in the response variable, and vice versa.

However, if the analysis shows a low value of relative forest presence when the ‘selva generator’ value is high (Figure 40), then the explanation of the spatial distribution of riparian forest areas is incomplete: new factors must be considered, and research must dig deeper to explain the phenomenon. Finally, if a low value of forest generator corresponds to a high value of riparian forest occurrence, a challenging-to-explain relationship is defined for the identified procedure. If this relationship were a trend, it would suggest that something in the theoretical framework of the work is wrong. If, on the other hand, it is represented by isolated cases, it demonstrates the value of sylvan spaces as they are understood in this work, i.e. spontaneous elements whose emergence and development are the unpredictable result of the relationship between varied spatial dynamics.

Figure 40. Detail of the Brenta River in Campo San Martino. The river meander is not associated with flourishing vegetation development, as it is limited by the urban fabric expansion on one side and agricultural pressure on the other.

The results of the correlation analysis between 'selva generator' and the relative presence of forests for each study case take on two interpretative significances. On the one hand, quantitative analysis deepens knowledge about a particular type of environment and the forces, actors, and dynamics exerting influence on it. On the other hand, interpretive analysis locates data in their geospatial context and analyzes them in detail, multiplying the horizon with new stimuli. The correlation between two features of the territory - suitability to host riparian forests and actual spatial distribution of riparian forests - is not more important than the analysis of situations where this correlation is lacking. In this dynamic lies the incentive to expand the discourse, which is made more complex by introducing new elements, factors, and variables into the analysis. In attempting to provide further explanations for a phenomenon, research finds ground to develop and reproduce itself.

7.3 Limits, Future Directions and Legacy of the Study

Data is manipulated through analysis. Contextualization and structuring processes transform data into information (Van Orshoven, 2023). The next step involves using this information in decision-making processes (Longley, 2015). This paper is only partially concerned with analyzing the dynamics related to land management as the ultimate end, looking at them primarily as causal factors to explain the distribution of natural elements and the appearance of the riparian landscape in the studied areas. The research concerns a subject of which studies are still in the preliminary stages in the upper Padova area. The lack of specific data for some aspects of this environment demonstrates this. At the same time, the University of Padova is developing renewed and creative interest in the area, studying it historically, geomorphologically, and culturally. The work by Piovan and Luchetta (in press) mentioned above represents an example of this trend. Other organizations and associations - such as Etifor, Parco Fiume Brenta, and Etra - are further important players in the management of the area and in the deepening of knowledge related to it (4.2.2).

The novelty of the subject determines both the original character of the work and its limitations. Some aspects, in particular, could be considered in the future to expand and refine the research. First of all, the distinction of the river course into meandering and non-meandering sections is established following objective parameters but not without shortcomings; the calculation of sinuosity is not as accurate in the analysis of short river sections as is an approach that looks at the variation in degree of river direction, as proposed by O'Neill and Abrahams (1986). Another future research direction is the analysis of new factors influencing the spatial distribution of riparian sylvan areas, as outlined above. This could result in the definition of a unified expression that considers all the factors analyzed and predicts the distribution of forests in relation to them, as the variable 'selva generator' did for few explanatory variables. Not only geomorphological and physical factors should be considered: other spatial dynamics can be analyzed, such as those related, for example, to the active participation of the population in decision-making processes, or the renewed interest of outside academic and environmental actors.

The last step in the discussion is to define the contents, concepts, and ultimate results left by this research:

- First, a new definition of riparian sylvan area is proposed, linked to the one outlined by Piovan and Luchetta (in press), and applied to the riverine context.
- Second, a new dataset is provided for future research, that can be freely manipulated, refined, and visualized to increase knowledge about the area.
- The results return new information, linked to the relationship and correlation between different natural and non-natural elements of the studied area, and of the river system in particular.
- A creative geospatial approach is outlined, linking theoretical findings learned by the author in different academic contexts and implemented on a local scale.

8 CONCLUSION

As announced in the introductive chapter, the primary goal of this work was to implement a spatial correlation analysis to explain the distribution of riparian sylvan areas of the Brenta and Bacchiglione rivers in the upper Padova province. This goal was concretely translated into investigating whether this clustering phenomenon is influenced by the presence of meander bends in the course of the two rivers, and to assess the degree of impact of agricultural, industrial, and urbanization practices in defining the expansion space of these areas. From a theoretical point of view, these questions were translated into two research questions, the answer to which can now be formulated.

Within the context of the meandering stretches of the Brenta and Bacchiglione rivers in the medium-high plain of the Padova province …

1) … are fluvial meanders generators of sylvan areas, …

In both the analyzed river sections, meander bends prove to be geomorphological entities near which extended forested areas are generally found. The analysis of the international and local literature allowed for the identification of theoretical factors to explain this trend, while data analysis and result interpretation confirmed what was hypothesized in the first place. On the one hand, this phenomenon is pronounced in the Brenta River, which hosts an extensive and elaborate park in its riparian environments. The park's administrative body manages its protection and conservation practices in collaboration with external partners, as well as through creative and participatory approaches. On the other hand, the riparian areas of the Bacchiglione River are less lush, and the forest concentration near the meanders is less evident than in the Brenta - although the results show that the trend is still statistically significant. The lack of a unified organization managing and protecting its riparian areas contributes to explaining this dynamic. Overall, the analysis based on the outlined methodology successfully answered the first research question and the meanders of the Brenta and the Bacchiglione in the analyzed stretches can be considered as generators of favorable environments for the development of spontaneous sylvan areas.

2) … and how much do human practices influence this dynamic?

Human influence is a constant for the riparian areas of the Brenta and Bacchiglione rivers. In both analyzed contexts, the results highlight how industrial and urban expansion on the one hand, and agricultural development on the other, negatively affect the growth of riparian forests, depriving them of their vital space and reducing the biodiversity of their environments. Corroborating the findings of the first research question, the riparian area of the Bacchiglione River emerges as particularly exposed to the recent expansion of the urban fabric and agricultural fields towards the river's banks. Although the degree of impact of this dynamic is variegated across the study area, the relationship between society and the river ecosystem represents a fundamental explanatory integration of the distribution of riparian sylvan areas in the Brenta and Bacchiglione rivers.

A second level of interpretation moves from the concrete findings of this research, investigating the modalities through which the analysis was implemented, and exploring future possibilities for knowledge expansion. According to the model underlying this research, the information created from the contextualization of the data is subject to interpretation, which is expected to address the question: how can the findings be concretely used?

From this perspective, this work featured three latent outcomes. The first one is the provisioning of an original methodology to study the problem, combining various quantitative and qualitative approaches, using diverse software, and merging international and local literature on only partially overlapping topics. Used to address the research questions, this methodology is the result of an individual study and experiential process, and its stimuli and correction possibilities have not yet been extinguished. As pointed out in Chapter 7, the study's methodological approach is effective but refinable. Innovative tools and perspectives that address various factors need to be considered in order to produce an all-encompassing discourse on the study area.

This discourse relates to the second latent outcome of this research, which is to provide an own contribution to the development of knowledge and valorization of the riparian territory of the Brenta and Bacchiglione rivers in their upper Padova province. In its means, this thesis provides a new dataset, information, interpretations, and insights for a research field that has the *local* as its object of interest and the *global* as its theoretical framework.

The last veiled goal of the thesis is to reflect on the very foundations of the research, which originate from the empirical observation of the phenomenon of clustering - or spatial correlation - of a specific and often academically neglected element of the natural landscape in the upper Padova province. This consideration refers to Tobler's First Law of Geography proposed in the opening of the work and now recalled to bring the argument full circle. In the scholar's eyes, the notion that states that near things are more related than distant things is ultimately anything but a law. Rather, it should be looked at as a stimulus to look beyond the immediate appearance of one's surroundings, observe geophysical reality, and contribute to the problematization of research 1) developing interpretations, 2) formulating objectives, and 3) articulating the approach necessary to pursue them.

9 ANNEXES

9.1 Annex I

The Python code implemented in Jupyter and used to create the variable 'selva generator' is proposed below. The code is broken into the various steps described in Chapter 6, Subchapter 6.1.4, and it is associated with comments to facilitate the reading and understanding.

Step 1: Isolation of the variables of interest

Identification of the response variable (‘y’):

- ‘forest_pct’: riparian sylvan area per buffer unit

Grouping of the three explanatory variables (‘X’), that are named as:

- ‘artificial’: artificial surfaces percentage area per buffer unit
- ‘agricultural’: agricultural surfaces percentage area per buffer unit
- ‘artificial_green’: artificial green surfaces percentage area per buffer unit

```
y = data['forest_pct']
X = data[['artificial','agricultural', 'artificial_green']]
```

Step 2: Standardization

The isolated explanatory variables (‘X’) are standardized (‘X_scale’), so that they feature:

- mean = 0
- standard deviation = 1

```
standardize = StandardScaler()
X_scale = standardize.fit_transform(X)
```

Step 3: The linear regression model

Based on the isolated standardized variables, the regression model (‘linear_model’) is build, setting the explanatory (‘X_scale’) and the response (‘y’) variables as the parameters.

```
linear_model = LinearRegression()
linear_model.fit(X_scale, y)
```

Step 4: 'Selva generator' creation

A new variable is created based on the regression model ('linear_model') previously built. The variable is added to the dataset and named 'selva_generator'.

```
my_variable = linear_model.predict(X_scale)
data['selva_generator'] = my_variable
```

Step 5: Determine the coefficients and the intercept

In order to have a clear understanding of the weight of each variable, appropriate functions are run to identify the coefficients ('coef_') and the intercept ('intercept_'). Provided with all the values, it is possible to extrapolate the formula for the creation of the new variable. This is implemented through the creation of a function ('f') that associates the coefficient to the respective explanatory variable ('expl_variable') and brings them together in a single expression, representing the linear regression.

```
coefficients = linear_model.coef_
intercept = linear_model.intercept_

expl_variables = ['artificial','agricultural','artificial_green']

formula = f"selva_generator = {intercept:.2f} "
for coef, expl_variable in zip(coefficients, expl_variables):
    formula += f"+ ({coef:.2f} * {expl_variable}) "

formula
```

Step 6: Determine correlation

Finally, correlation between the new explanatory variable ('selva_generator') and the response variable ('forest_pct') is tested.

```
data['selva_generator'].corr(data['forest_pct'])
```

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