UNIVERSITÀ DEGLI STUDI DI PADOVA

Department of Land, Environment Agriculture and Forestry

MSc in Sustainable Forest and Nature Management
(SUFONAMA)

Interactions between fluvial geomorphology, riparian vegetation, and invasive alien woody species in the Tagliamento River, in North-Eastern Italy

Supervisor:
Prof. Dr. Lorenzo Picco

Co-supervisors:
Dr. Thomas Campagnaro
Dr. Giacomo Pellegrini
Massimiliano Bedin

Submitted by:
Nathaly Valeria Fernandez Gomez

Matriculation No:
2104981

Academic year
2023/2024

Acknowledgment

First of all, I would like to express my immense gratitude to all the professionals who are part of the SUFONAMA consortium, thank you for all your efforts and for making this dream a reality for many of us.

To the coordinators and professors from the University of Göttingen and the University of Padova, thank you for contributing with your knowledge and expertise.

To my supervisor, Professor Lorenzo Picco, thank you for all the support provided from the first day, for your dedication during the different stages of the completion of this degree work, and for always having the willingness and patience to teach.

To my co-supervisors, Professor Thomas Campagnaro, Dr. Giacomo Pellegrini, and Massimiliano Bedin, for your dedication and valuable contributions to this work.

To my parents, Sonia Gomez and René Fernandez, for all your love and for supporting and encouraging me in every single step since I decided to take this wonderful journey.
To my family, uncles and aunts, and Romina for always believing in me.
To my grandpa, Miguel Angel Gomez, to whom I dedicate this work with infinite love.
I know you are always with me.

To my friends, all the wonderful people I have met during these two years, thank you for all the shared experiences and valuable moments and for making me feel at home even though I was thousands of kilometers away from Ecuador.

Thank you all.

Abstract

Biogeomorphology, an emergence subdiscipline, recognizes the meaningful bidirectional interplay between biological communities and geomorphic processes. Changes in hydrological conditions may facilitate the establishment of plant communities, and these latter, in turn, may act as natural engineers influencing the evolution of fluvial structures. Riparian ecosystems meet several characteristics that are considered hospitable for plant growth, such as exposed sediment areas, high levels of nutrients and organic matter, and propagules availability. However, precisely these conditions along with the removal of key elements that maintain the native vegetation, may favor invasions of non-native species. Non-native vegetation can alter the dynamics and structure of the affected ecosystem causing in the worst conditions, irreparable ecological damage. Hence, it is paramount to understand the relationships between fluvial processes and vegetation and invasive alien species (IAS) in order to conduct adequate management and control. The present study aimed to assess these interactions in two sub-reaches of the Tagliamento River in the Friuli Venezia Giulia region in North-Eastern Italy. A multi-temporal analysis was conducted using datasets from 2010 and 2024, obtained from field surveys and DTMs, to evaluate the changes over time and the influence of the IAS in the study area. The results revealed that in geomorphological terms, the Tagliamento River is, as many authors have described previously, less impacted compared to other temperate rivers affected by human interventions. Regarding the vegetation in the river system, its spatial distribution follows a clear pattern with pioneer species tolerant to inundation and disturbances close to the flowing channels, and more stable tree communities growing in upper elevations under more stable conditions. Finally, from the mutual interactions between fluvial morphology and vegetation, it was stated that variables such as the elevation above the thalweg and the way it evolves may be determinants for species richness. This work attempts to highlight the relevance of research conducted addressing the interplay between these elements within the river systems. Moreover, it points out the importance of considering the role and impact of IAS to define effective management strategies for the future.

Table of contents

List of figures

List of tables

1. Introduction

The emergence of biogeomorphology

Until the middle of the 20th century, most of the studies conducted in the field of fluvial geomorphology disregarded the multiple interacting variables controlling riverine processes (Osterkamp & Hupp, 2010; Gurnell et al., 2012). Researchers focused only on some specific aspects of these systems, and the assessment of the complex interplay of variables was often neglected, leading to the simplification of the studies (Osterkamp & Hupp, 2010). Within this context, one of those influencing variables was vegetation. Plant communities were merely considered the results of climatic settings, with a determined and spatially invariant effect. However, their crucial role in fluvial geomorphic processes gradually gained recognition from the geomorphological community in the subsequent decades (Corenblit et al., 2007; Osterkamp & Hupp, 2010; Gurnell & Bertoldi, 2024). Several conceptual models were proposed to provide a basis for understanding how river ecosystems work. For instance, the River Continuum Concept (RCC) proposed by Vannote et al. (1980) became a milestone for research in stream ecology mainly because it changed the studies in this field from a descriptive- to a predictive-based approach (Doretto et al., 2020). The RCC stated that the gradient of physical conditions of a river from headwaters to mouth leads to a continuum of biotic adjustments in both time and space (Vannote et al., 1980; Corenblit et al., 2007). Since physical changes are closely linked to determined ecological responses, differences can be observed in the type and availability of organic matter, the structure and role of invertebrate communities, and the partitioning of resources along the river longitudinal dimension (Larsen et al., 2019). The RCC maintained that changes in the distribution of biological communities can be predicted since their structural and functional characteristics are determined by a combination of many physical factors (Corenblit et al., 2007). Nevertheless, RCC limitations, primarily driven by constraints in its applicability, led to the development of new conceptual approaches and the inclusion of other biogeomorphology theories (Doretto et al., 2020). Subsequently, the Flood Pulse Concept (FPC) developed by Junk et al., (1989) included the lateral dimension, neglected by the RCC and other approaches, and considered the reciprocal interactions between biological communities and hydrogeomorphic disturbances (Corenblit et al., 2007). The FPC explored the relevance of seasonal floods on the ecosystem organization, in which the structure of the ecological communities under stable flood conditions is driven by the exchange of organic matter between the river and its floodplain (Baturina, 2019). Later, the 1990s was a crucial decade for acquiring new knowledge and reinforcing some aspects developed previously in this field. Interactions between wood and riparian vegetation, and fluvial landforms, as well as river channel dynamics and floodplain connectivity, were concepts that gained particular attention (Gurnell & Bertoldi, 2024). From the beginning of the 21st century, biogeomorphology, an emergent sub-discipline that integrates concepts of geomorphology and ecology, has become an important research topic. It recognizes not only the relevance of vegetation within fluvial environments but also considers the bidirectional interplay and feedback between biological communities and hydrogeomorphic processes (Corenblit et al., 2007; Gurnell & Bertoldi, 2024).

Linkage between vegetation and fluvial processes

Interactions between biotic and abiotic elements take place when the organisms' life cycle and morphology are influenced by physical processes, and at the same time, these processes are regulated by the organism's activity (Corenblit et al., 2009). Riparian plant species are clear reflections of the broad environmental settings, e.g. climatic conditions, but also the local hydrological limitations (Gurnell, 2014). The structure and functions of riparian ecosystems vary along rivers and strongly depend on characteristics such as geomorphological settings, hydrological regime, sediment supply, and surface-groundwater connectivity (Gurnell et al., 2012). Fluvial landforms exhibit diverse physical and hydrological settings that create specific environments for vegetation with particular species composition, age, structure, and successional patterns (Gurnell & Bertoldi, 2024). Hence, plants are indicators of their landforms. They provide crucial information about hydrogeomorphic conditions, such as river energy and style, and specific disturbance regimes. Moreover, these mutual associations also affect the fluvial morphodynamics between and within reaches of the same river (Gurnell, 2014; Osterkamp & Hupp, 2010). Studies focused on river hydrology and ecology are helpful in identifying and understanding the relations between flow regimes and habitats that may be suitable for the diverse types of riparian vegetation (Osterkamp & Hupp, 2010).

The bidirectional interplay between vegetation and fluvial processes

Hydrogeomorphic processes and landforms exert a great influence on vegetation dynamics, especially in the early growing and development stages (Corenblit et al., 2007). Not only extreme events, but also natural events such as annual floods, their increment in frequency, and sediment transport are processes that influence the colonization by riparian species (Pattison et al., 2018). According to Corenblit et al. (2007), the main factors contributing to increasing site availability for the development of pioneer vegetation are high-magnitude and low-frequency floods. Nevertheless, lower magnitude and higher frequency floods control the mechanisms that maintain these communities within the river system influencing vegetation dynamics. In this regard, it is important to understand that plants interact with the development of landforms, but these latter can only be modified by disturbances with a higher magnitude than those that allowed their establishment in the first place (Gurnell, 2014). Thus, landform development, prevalence, and change are influenced by the interactions between fluvial disturbances and vegetation (Gurnell & Bertoldi, 2024). Elevation above the thalweg and grain size are variables that heavily influence the moisture characteristics of the vegetated areas within the channel. These morphological and sedimentary properties may support or not the development of plant species and habitat diversity (Sitzia et al., 2016). Some particular species can build pioneer landforms by colonizing areas with exposed sediment. Riparian ecosystems meet several characteristics that are considered hospitable for plant growth, such as exposed sediment areas characterized by high levels of nutrients and organic matter, and propagules availability which constitutes an adequate setting for pioneer species (Gurnell, 2014; Pattison et al., 2018).

Fluvial dynamics play an important role in the establishment and subsequent development of riparian vegetation. In the same way, riparian vegetation affects fluvial processes (Sitzia et al., 2016). Changes in hydrological conditions may facilitate the colonization of plant communities, and these latter, in turn, may act as ecosystem engineers influencing the evolution of fluvial structures (Gurnell, 2014). According to Jones et al. (1994), ecosystem engineers are organisms that cause physical changes in biotic or abiotic materials, and directly or indirectly modify the environment and control the resource availability for other species. Within fluvial corridors, in the zone dominated by vegetation, moisture supply regulates plant colonization and growth performance, and the competition among species is more intense. In the zone dominated by physical disturbances, flood frequency and magnitude determine plant survival (Gurnell et al., 2012). Plant engineers act just in the middle zone where the interactions and adjustments between vegetation and physical processes are stronger and the conditions favorable for their development (Gurnell, 2014). The characteristics of this interface zone change, not only along and between rivers, but also through time. They respond to changes in flood magnitude and frequency, moisture, sediment supply, vegetation growth performance, and the present species configuration (Gurnell et al., 2012). Once established, vegetation influences river morphology by contributing to diverse processes such as bank and floodplain stabilization, sediment retention, erosion resistance, main channel incision, reduction of the number of channels, and prevention of floodplain unraveling (Gurnell et al., 2012; Gurnell, 2014; Sitzia et al., 2016).

Main vegetation changes in river ecosystems

Vegetation dynamics within the fluvial context are closely related to the variations in hydrogeomorphic processes and fluvial landforms. In this regard, flow and sediment transport regimes can be considered major parameters controlling successional processes (Corenblit et al., 2007). Across the lateral flood frequency gradient, the control that hydrogeomorphic processes exert on vegetation dynamics decreases gradually from the active channel to the extent it gets closer to the floodplain (Corenblit et al., 2007). The location and spatial extent of the riparian zone within river systems are regulated by flood disturbances, which implies particular combinations of inundation and drought with diverse frequencies and durations (Bertoldi et al., 2011). The tolerance of riparian species to these conditions determines the limit between aquatic and terrestrial communities and thus, their composition and growth performance (Corenblit et al., 2007). However, the response of riparian species to hydrological disturbances is not homogeneous. Additional factors such as geomorphological settings, sediment supply, and groundwater dynamics influence the way biological communities are structured (Corenblit et al., 2007; Gurnell et al., 2012).

Species growing closer to the active channel often create young, small patches composed mainly of deciduous shrubs. These species are characterized by a high resilience to disturbances and the ability to resprout rapidly from stumps. Low and frequently flooded landforms are usually dominated by *Populus* and *Salix,* whose morphological and biomechanical characteristics allow them to grow within the active corridors of temperate rivers (Bendix & Hupp, 2000; Gurnell et al., 2012). Species growing in the floodplain are naturally less tolerant to flooding but withstand periods of inundation and are well adapted to more stable soil conditions. Usually, shrubs, herbaceous plants, and trees including species from the genera *Juglans, Ulmus,* and *Acer.* On the other hand, species growing in the terraces are intolerant to inundation and flood damage. They compose older plant communities with *Quercus, Fraxinus*, or *Carpinus* trees (Bendix & Hupp, 2000; Gurnell et al., 2012).

Effects of invasive alien species (IAS) on river ecosystems

Even though fluvial processes promote some species dispersion, colonization, and establishment, they may also lead to unfavorable situations. For instance, the same flow that mobilizes sediments may contribute to displacing currently growing native species (Osterkamp & Hupp, 2010). Considering the normal alterations of the hydrologic regime, plants require at least a certain level of adaptation in order to survive, independent of whether they are native or exotic (Schnitzler et al., 2007). Resilience is one of the most relevant characteristics of riparian species, especially under frequent and intense disturbances. These species are generally specialists in exploiting water resources associated with watercourses under these conditions. Their establishment and persistence likewise depend on morphological adaptations such as withstanding flooding, sediment deposition, physical abrasion, and structural breakages (Richardson et al., 2007). However, changes in local physical and hydrological conditions may facilitate the colonization and growth of IAS (Gurnell, 2014; Pattison et al., 2017). Their establishment depends on multiple factors such as environmental factors, propagule dispersion, founder effects, and competition with existing native or other non-native species (Flanagan et al., 2015). Hydrological alterations resulting from diverse mechanisms developed to regulate the stream flow, like dams, activities associated with land use in adjacent areas, logging, grazing, water extraction, and recreation often unleash their development (Richardson et al., 2007). In addition, when the key elements, crucial to maintaining native vegetation are removed, plants lose their ability to remain and, are often outcompeted and replaced by IAS with different hydrological and nutritional requirements and tolerances (Gurnell et al., 2012), which eventually results in less diverse and thus, less resilient plant communities (Pattison et al., 2017). Abiotic conditions determine and control the way riparian vegetation develops within river systems. Nevertheless, invasions by IAS exert an additional, often negative influence on native vegetation composition and phenology (Pattison et al., 2018). IAS have the potential to affect native species not only directly but also indirectly by altering the structure and functioning of the community, which in turn causes alterations in many ecological processes such as the water cycle or the nutrient cycle (Castro & Alonso, 2017). The management of IAS is strenuous and expensive for local and regional authorities, particularly when these species affect the river's proper functioning and providence of ecosystem services. Thus, understanding how riparian systems may facilitate the spread of non-native species is important for local and landscape scale management (Aronson et al., 2017).

2. Objectives

2.1. General

To assess the interactions between fluvial geomorphology, riparian vegetation, and IAS in two sub-reaches (Cornino and Flagogna) of the Tagliamento River in the Friuli Venezia Giulia Region, in North-Eastern Italy.

2.2. Specific

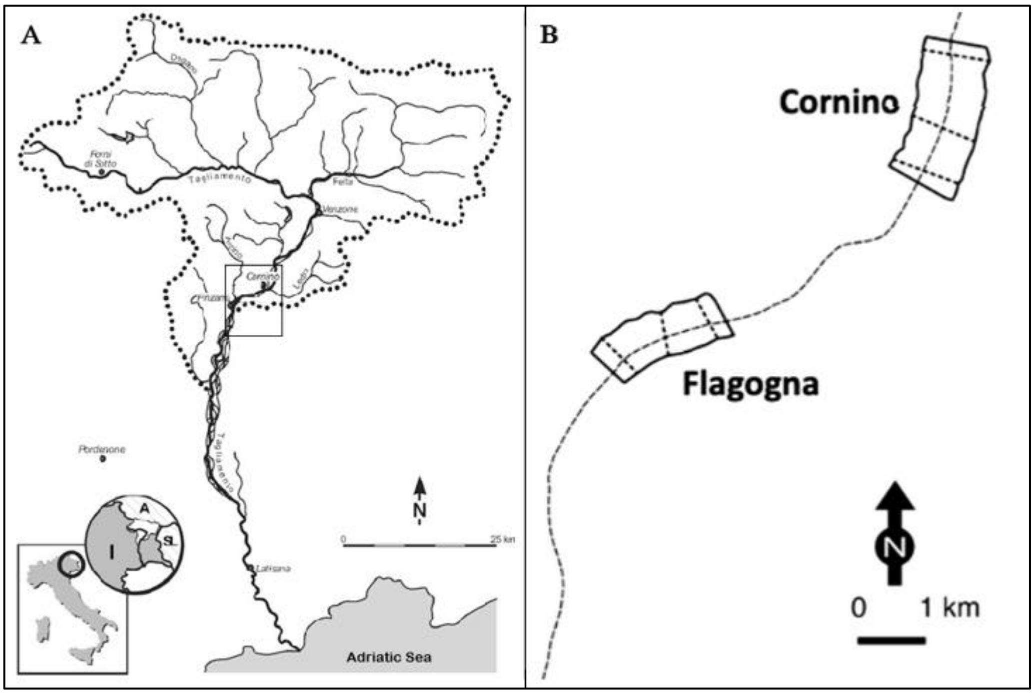
- To evaluate the changes in the river morphology based on the datasets from 2010 and 2024.
- To characterize the vegetation community in the study area.
- To analyze the relationship between the changes in the river morphology and the vegetation.

3. Materials and methods

3.1. Study area

The present study was conducted in the Tagliamento River, a gravel-bed river located in the Friuli Venezia Giulia Region, in North-Eastern Italy. The river flows about 172 km from the Carnic Alps to the Adriatic Sea passing through four different areas: the Alps, the Prealps, the upper and lower Friulian plain, and the coast. Its basin covers approximately 2600 km^2 (Figure 1A) with Mt. Coglians considered its highest peak at 2781 m.a.s.l. and a mean altitude of 987 m.a.s.l. (Tockner et al., 2003; Picco et al., 2013; Sitzia et al., 2023). According to Billi's (1994) planform-based classification, in the upper part, the river exhibits a straight course, which shifts to braided in the middle section and meandering in the lower part.

Figure 1.
A. Map of the Tagliamento River basin with its location in Italy. B. Location of the sub-reaches (after Tockner et al., 2003 and Sitzia et al., 2016).



The basin is characterized by transitional Alpine to Mediterranean climatic conditions, with variable precipitation, temperature, and humidity. The annual precipitation ranges from 1500 to 2800 mm and the mean annual temperature varies from 12 to 16ºC. The flow regime is highly influenced by the Alpine and Mediterranean snowmelt and precipitation; thus, showing a flow pattern with peaks in Spring and Autumn. The river corridor comprises five important landscape elements: surface water, exposed gravel bars, vegetated islands, riparian forests, and low unforested areas. The width of the active channel varies depending on the location, but it reaches up to 1.5 km (Tockner et al., 2003; Sitzia et al., 2023).

To elaborate a general description of the landscape in the area is challenging because climatic conditions are diverse, and soils are highly variable. The geology is mainly calcareous, from different ages, with the presence of diverse rock types from dolomitic to marlstone. In the same way, due to the complexity of groundwater drainage through the limestone karst, obtaining a precise delimitation of the basin is complex (Tockner et al., 2003; Sitzia et al., 2023).

The Tagliamento River is considered a near-pristine system and therefore, unique in the Alps since it retains its dynamic nature and morphological complexity. It is regarded as a model ecosystem not only for the Alps but also for large temperate rivers, mainly due to its river corridor, morphologically intact along its entire length. Moreover, it is characterized by unconstrained floodplain segments, strong longitudinal, lateral, and vertical connectivity, characteristic sequence of geomorphic types, and high habitat heterogeneity, which in turn, harbors high biodiversity (Tockner et al., 2003; Sitzia et al., 2023).

The vegetation distribution patterns vary considering the influence of the aforementioned characteristics along the basin. In the upper part, artic-alpine species are dominant but are often geographically limited due to specific habitat requirements or poor seed dispersal mechanisms. On the other hand, the sub-mediterranean species can be found in the lower sections of the basin. These are the most extended species, nevertheless, they have never been found in the upper sections (Tockner et al., 2003). In the zone where the Tagliamento leaves the Alps, the highest species richness has been registered due to the co-occurrence of alpine and lowland species. In addition, the number of endemic species is also high in this zone (Tockner et al., 2003).

The riverbanks are characterized by alternated frequent inundation periods and some sporadic long dry periods where herbaceous pioneer annual plants dominate. When inundation is infrequent, perennial tall grasses grow. Species such as *Salix purpurea* and *Salix triandra* take place as a narrow scrub strip along sand or low gravel banks. *Salix alba* and *Alnus incana* woodlands commonly develop in the flooded riverside, whereas hardwood woodlands dominated by *Fraxinus*, and *Quercus* grow in areas with fertile soils where inundation is very unlikely (Sitzia et al., 2023). *A. incana* is the dominant riparian species in the basin's upper sections but can also be found in the middle reaches. *Populus nigra*, can be found in the middle and lower reaches. This species and some willow species (*Salix daphnoides, S. alba, S. purpurea,* *S. triandra*), different from *A. incana*, grow along the river and establish more easily due to their regeneration mechanisms such as growing from uprooted trees or even wood fragments (Karrenberg et al., 2003; Gurnell & Petts, 2006).

The research was conducted in two sub-reaches along the Tagliamento River: Cornino and Flagogna (from upstream to downstream) (Figure 1B). Both sub-reaches have similar flow conditions, longitudinal bed slope around 0.003 m m^{-1}, and bed sediment grain size of D_{50} = 0.035 m. The Cornino sub-reach length is around 3 km, and the mean width is 800 m. The Flagogna sub-reach has a similar length, and its mean width is 600 m (Ravazzolo et al., 2015a; Ravazzolo et al., 2015b; Sitzia et al., 2016). Following Billi (1994) classification, Cornino presents a bar-braided configuration, whereas Flagogna is wandering.

3.2. Data collection

Field surveys were conducted in the two sub-reaches in July 2024. In each sub-reach, three cross-section transects were sampled using a Differential Global Positioning System (dGPS) with an average accuracy of ± 0.025 m, and Google Earth Pro. The lateral extent of the floodplain determined the cross-section length. Along the cross-sections, 4 x 4 m plots spaced 10 m apart were considered the sampling units, following the methodology applied by Sitzia et al. (2016). The plots positioned within the study conducted in 2010 were identified obtaining 355 plots in 2024. However, the plots that lay on the flowing channel were not surveyed, resulting in a total of 291 plots (Table 1).

Table 1.
Number of plots surveyed in the two sub-reaches in two different years.

Sub-reach	Cross-section	Nº plots 2010	Nº plots 2024
CR	1	66	69
	2	62	57
	3	63	53
FL	1	38	33
	2	43	36
	3	53	43
Total		325	291

The type of morphological unit (i.e. flowing channel, floodplain, bar, island) where the plots lay was registered considering the following aspects. Flowing channels are low-relief areas with exposed running water. Floodplains are surfaces covered with diverse deposited fine material outside the active channel and submerged during floods that occur with a recurrence interval of more than two years. Bars are high-relief sedimentary structures within the active channel emerging at low flows. They may be bare or covered with annual vegetation. Islands are also located within the active channel, surrounded by either flowing channels or exposed gravel, supporting pluriannual vegetation (Sitzia et al., 2016).

On the plots with fine sediment, the procedure was digging a small trench into the soil where the layer depth was measured. For the coarse sediment, the Grain Size Distribution (GSD) was evaluated by measuring the b-axes of 30 coarse elements. In the vegetated plots, the woody species were counted and identified, the diameter at breast high (DBH > 3 cm) was measured, and the vegetation cover percentage was estimated per plot and species considering three different levels: herb (H), shrub (S), or tree (T) layer.

3.3. Data analysis

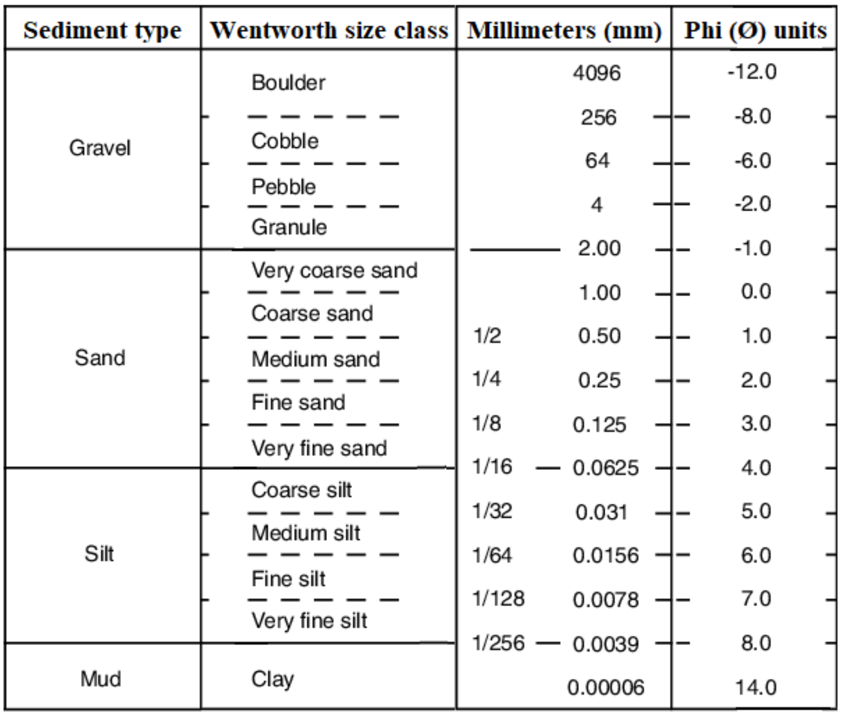
A multi-temporal analysis was conducted using the datasets from 2010 and 2024. The information was obtained from field surveys and DTMs. Consequently, a further comparison was made to analyze the changes in the river system.

3.3.1. Geomorphological analyses

First, the geomorphic persistence of the morphological units was evaluated by comparing the information from the field surveys and the aerial photographs from both years. Later, the GSD analyses were conducted with a total of 6240 samples from 2024 and were computed separately for the two sub-reaches with 4500 samples for Cornino and 1740 for Flagogna. Sediments can be classified following the Wentworth (1922) scale which divides the size ranges into textural classes from boulders (> 200 mm) to clay (< 0.004 mm) (Figure 2).

Figure 2.

Grain size classification (after Wentworth, 1922).



Sediment type	Wentworth size class	Millimeters (mm)	Phi (Ø) units
Gravel	Boulder	4096	-12.0
		256	-8.0
	Cobble		
		64	-6.0
	Pebble		
		4	-2.0
	Granule		
		2.00	-1.0
Sand	Very coarse sand		
		1.00	0.0
	Coarse sand		
		1/2 0.50	1.0
	Medium sand		
		1/4 0.25	2.0
	Fine sand		
		1/8 0.125	3.0
	Very fine sand		
		1/16 0.0625	4.0
Silt	Coarse silt		
		1/32 0.031	5.0
	Medium silt		
		1/64 0.0156	6.0
	Fine silt		
		1/128 0.0078	7.0
	Very fine silt		
		1/256 0.0039	8.0
Mud	Clay	0.00006	14.0

The size particle which is based on the nominal diameter is often reported in millimeters (mm), micrometers (µm), or phi (Ø) units (López, 2017). For this study, the phi units were calculated using the formula by Krumbein (1936):

$$\text{Ø} = -\log_2 d$$

Where:
Ø = phi value
d = the particle diameter (mm)

The percentiles of the GSD were computed from the cumulative frequency and the corresponding phi units. Percentiles are represented as D_p, where D is the particle diameter (mm) and p is the percentile of interest (Eaton et al., 2019). Therefore, they are indicators of the diameter at which the specific percentage of the sample is finer. For this study, the percentiles D_5, D_{16}, D_{40}, D_{50}, D_{84}, D_{90}, and D_{95} were calculated. They may give information about the material composition and behavior and thus, are often used for sediment transport, flow resistance, and channel stability calculations (Eaton et al., 2019).

The standard deviation, also known as the sorting index (S_o), measures the dispersion of the diameters and was calculated using the formula by Kondolf & Wolman (1993):

$$S_o = \sqrt{\frac{D_{84}}{D_{16}}}$$

Finally, from the 6240 samples collected in 2024, the mean grain size was calculated per plot and subsequently per cross-section to obtain more detailed results. These values, also with the corresponding values from 2010 were depicted through box plots for further comparisons.

The profile graphs for the river cross-sections were obtained to better illustrate the changes that have occurred within 14 years in the Tagliamento River. The Digital Elevation Models (DEMs) and aerial photographs of the six cross-sections were loaded in QGIS. The *Sample raster values* tool from the *Processing Toolbox* was used to extract the elevation values for the plots. Then, the *VoGIS-ProfilTool* plugin was used to obtain the elevation values for the entire profile cross-section. This step was paramount to determine the thalweg, which is the lowest point along the profile, i.e. the deepest point that corresponds to the main channel. With that information, the elevation above the thalweg and distance from the thalweg to each one of the plots were calculated to compute the profile graphs for 2010 and 2024.

3.3.2. Vegetation analyses

First, the proportion of the plots in which plant species were found was determined both in number and percentage. Also, the number and percentage of the plots that harbored woody species were determined. The results were expressed in total but also more specifically, per cross-section and sub-reach to allow making comparisons afterwards.

Later, the total number of species was recorded, and a primary classification was made, in which the species were divided into native or alien species based on the information provided at the *Portal to the Flora of Italy*. In the case of the alien species, the terminology proposed by Richardson et al. (2000) was considered for a secondary classification (Table 2). The origin was registered considering both the national (Italy) and regional (Friuli Venezia Giulia) levels. The total number of species and the proportion of native and alien species per strata were determined, also their corresponding percentages were calculated.

Table 2.
Terminology used for plant invasion ecology (after Richardson et al., 2000).

Term	Initials	Definition
Casual alien species	CAS	Reproduction takes place occasionally in an area, cannot create self-replacement populations, and relies on constant introductions to persist.
Naturalized alien species	NAS	Reproduction is consistent, populations can be sustained over several life cycles without direct human intervention.
Invasive alien species	IAS	Reproductive offspring can be propagated, often in large numbers with the potential to spread over considerable areas far from the parents.

Afterward, the mean number of species was calculated per strata, plot, cross-section, and sub-reach. The occurrence, which represents how often a certain species was found within the field surveys, was computed in total and per sub-reach. Finally, the information regarding the woody species was recorded, including the total number of species, the mean number of individuals per plot, and the most common woody species. From the data collected, the mean DBH per species was calculated, and the diameter classes were defined.

A deeper analysis of species composition between sub-reaches was carried out to better understand the woody species communities in the Tagliamento River. The composition of the ecological community was analyzed through Non-metric Multidimensional Scaling (NMDS) to visualize possible patterns. Then, a Permutational Multivariate Analysis of Variance (PERMANOVA) was carried out to assess significant differences in the community composition between groups based on the Bray-Curtis dissimilarity matrix. Finally, the aim was also to identify if some species may be indicators of specific groups. For this, only the data from the vegetated plots was considered. The analyses were performed using the software R (R Core Team, 2013). The function "metaMDS" of the vegan package was used to conduct the NMDS, and the function "adonis2", to perform the PERMANOVA test (Oksanen et al., 2007). The function "betadisper" was used to evaluate whether there was heterogeneity of dispersion between the groups, followed by an ANOVA test to determine if the dispersion was significantly different across the groups (Oksanen et al., 2007). The function "multipatt" of the indicspecies package was used, applying the Indicator Value (IndVal) method which determines which species are the most characteristic of particular groups (De Cáceres & Legendre 2009).

3.3.3. Combined analyses

As stated previously, the values for the elevation above the thalweg were obtained for 2010 and 2024, likewise, the values for the distance from the thalweg and the number of species found per plot. Then, the difference between the two years for the three variables was obtained by subtracting the values of 2010 from the values of 2024. In addition, the evolution of the morphological units was registered using the geomorphic persistence information. Each morphological unit was given a key, as follows: flowing channel (fc), floodplain (fp), bar (ba), and island (is). Later, the evolution of the morphological units was recorded using a code created by joining the keys in 2010 and 2024. The relationship between the evolution of the morphological units and the difference in the number of species per plot was depicted through a box plot graph. Finally, correlation functions were employed to assess the relationship between the elevation above the thalweg and the distance from the thalweg, with the number of species. Specifically, the degree of association between these variables was examined considering the changes that occurred from 2010 until 2024.

4. Results

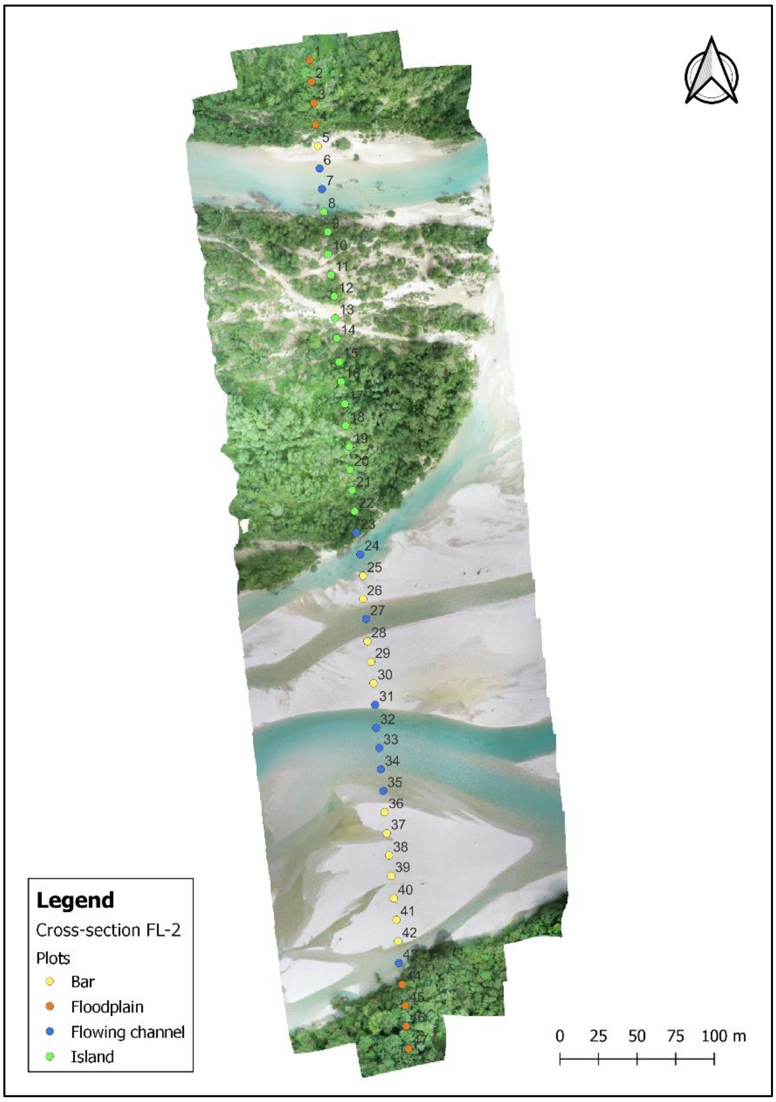
4.1. Geomorphological analyses

4.1.1. Geomorphic persistence

In 2024, among the 291 plots surveyed, 223 lay on bars, 36 on islands, and 32 on the floodplain, representing 76.63%, 12.37%, and 11.00% of the total, respectively (Figure 3).

Figure 3.

Plots lying on the different morphological units in the FL-2 cross-section.



For the comparison of the datasets from 2010 and 2024, the geomorphic persistence was calculated and expressed in percentage (Table 3). In general terms, persistence in bars had the most prominent values for the majority of the cross sections (four out of six), followed by persistence in the floodplain, and lastly islands.

Table 3.
Geomorphic persistence of the morphological units in percentage.

	Floodplain	**Bar**	**Island**	**Mean**
CR-1	33.33	91.67	0.00	41.67
CR-2	0.00	74.00	0.00	24.67
CR-3	66.67	62.96	50.00	59.88
FL-1	40.00	92.31	0.00	44.10
FL-2	57.14	21.43	25.00	34.52
FL-3	0.00	38.24	25.00	21.08
Mean	32.86	63.43	16.67	

At the cross-section level, CR-3 and FL-1 presented the highest values for the mean persistence. Nevertheless, persistence in bars was outstanding in CR-1 and FL-1 compared to the other cross-sections but there was no persistence in islands. Similar results were obtained at the sub-reach level, no major differences were found in the mean persistence between sub-reaches. However, Cornino presented a higher value than Flagogna. For both, the values for persistence in the floodplain and islands were barely distinguishable between them, whereas the persistence in bars was superior for Cornino.

4.1.2. GSD analysis

The samples collected to compute the GSD analyses encompassed different types of sediments, ranging from sand to gravel. As a part of the analyses conducted for the two sub-reaches, the main percentiles were calculated (Table 4).

The mean value obtained from the percentiles was -4.93 phi units and 31 mm for Cornino, and -4.72 phi units and 26 mm for Flagogna. Although the values for Cornino are evidently higher, these results suggest that on average the material in both sub-reaches present similar characteristics, and the main sediment type is gravel, more specifically pebbles according to the Wentworth (1922) grain size classification.

Table 4.

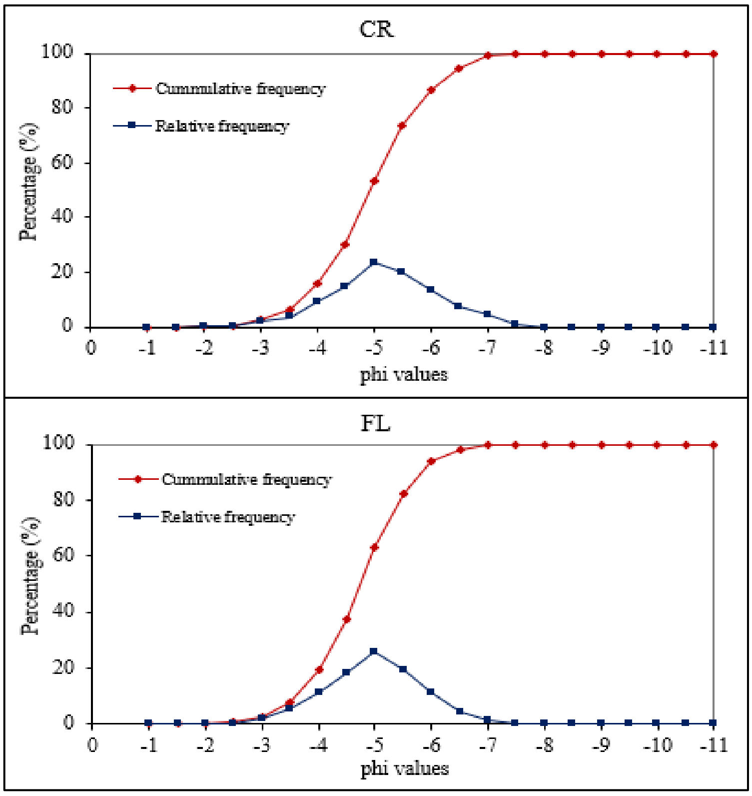
Percentiles of the GSD analyses for the two sub-reaches.

Percentiles	CR		FL	
	phi$_x$	D_x (mm)	phi$_x$	D_x (mm)
D_{5}	-3.32	10	-3.23	9
D_{16}	-4.01	16	-3.86	15
D_{40}	-4.71	26	-4.55	23
D_{50}	-4.92	30	-4.75	27
D_{84}	-5.89	59	-5.56	47
D_{90}	-6.21	74	-5.83	57
D_{95}	-6.55	94	-6.12	69

In the lower percentiles, below the median (D_{50}), both sub-reaches indeed presented similar results. However, in the upper percentiles, above the median (D_{50}), there is a clear differentiation between Cornino and Flagogna since the first one exhibited a significant proportion of particles with larger diameters. The values obtained for the standard deviation were 1.92 and 1.81 for Cornino and Flagogna respectively. According to Folk & Ward (1957), they indicate that the material in the two sub-reaches is heterogeneous and poorly sorted (Figure 4).

Figure 4.

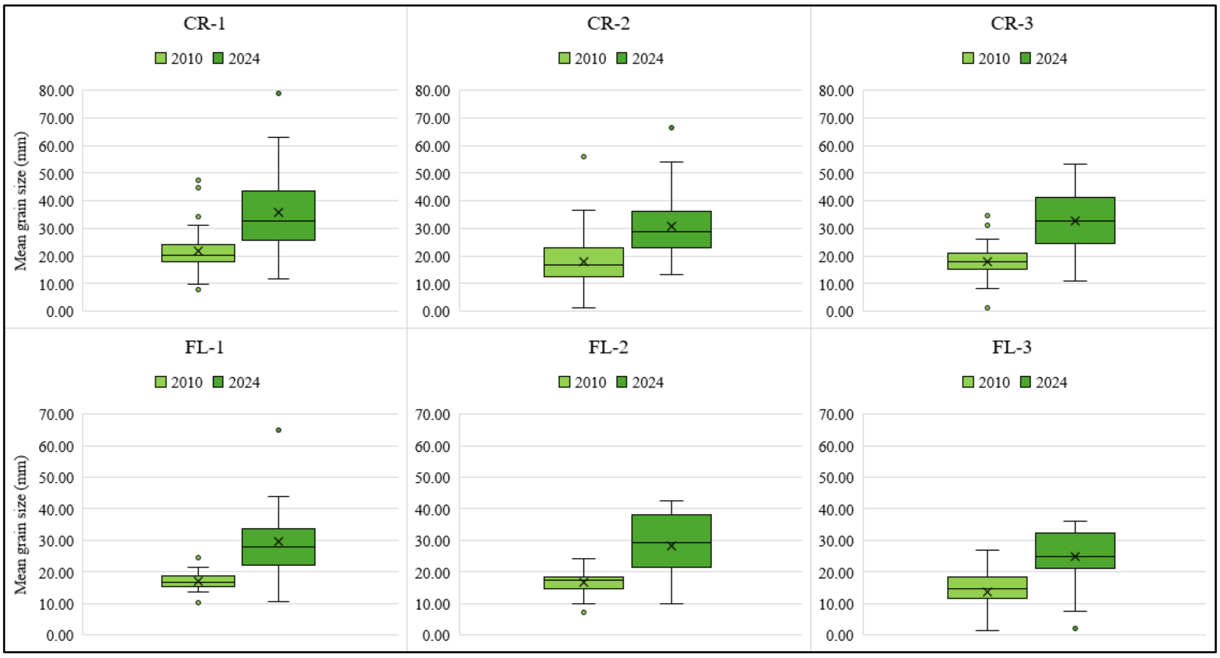
GSD for Cornino and Flagogna.



4.1.3. Mean grain size comparison

At the cross-section level, the mean grain size calculated from the samples followed a trend in which the values were notably higher in 2024 than in 2010 in the six cross-sections (Figure 5).

Figure 5.
Mean grain size for the six cross-sections.



In 2010, CR-1 was the cross-section that presented the highest mean grain size of the sub-reach, followed by CR-3 and CR-2. Interestingly, that pattern persisted in 2024 (Table 5).

Table 5.
Mean grain sizes (mm) in the cross-sections.

Cross-section	2010	2024
CR-1	21.66	35.89
CR-2	17.85	30.59
CR-3	17.94	32.80
Mean	19.15	33.09
FL-1	16.93	29.59
FL-2	16.65	28.28
FL-3	13.71	24.84
Mean	15.76	27.57

In 2010, likewise FL-1, the cross-section on the upper part of the sub-reach presented the highest mean grain size. Conversely, the mean grain size exhibited a descending pattern from the upper to the lower cross-sections of the sub-reach in Flagogna. However, in 2024 the pattern persisted as was the case for Cornino (Table 5).

At the sub-reach level, the mean values obtained from the GSD analyses for 2024 can be compared with the values calculated in this section. With the first approach, the mean grain size was 31 mm and 26 mm for Cornino and Flagogna respectively. On the other hand, the computed mean grain size was 33.09 mm and 27.57 mm for Cornino and Flagogna. The results obtained from both approaches did not differ considerably between them and proved to be accurate for obtaining the mean grain size.

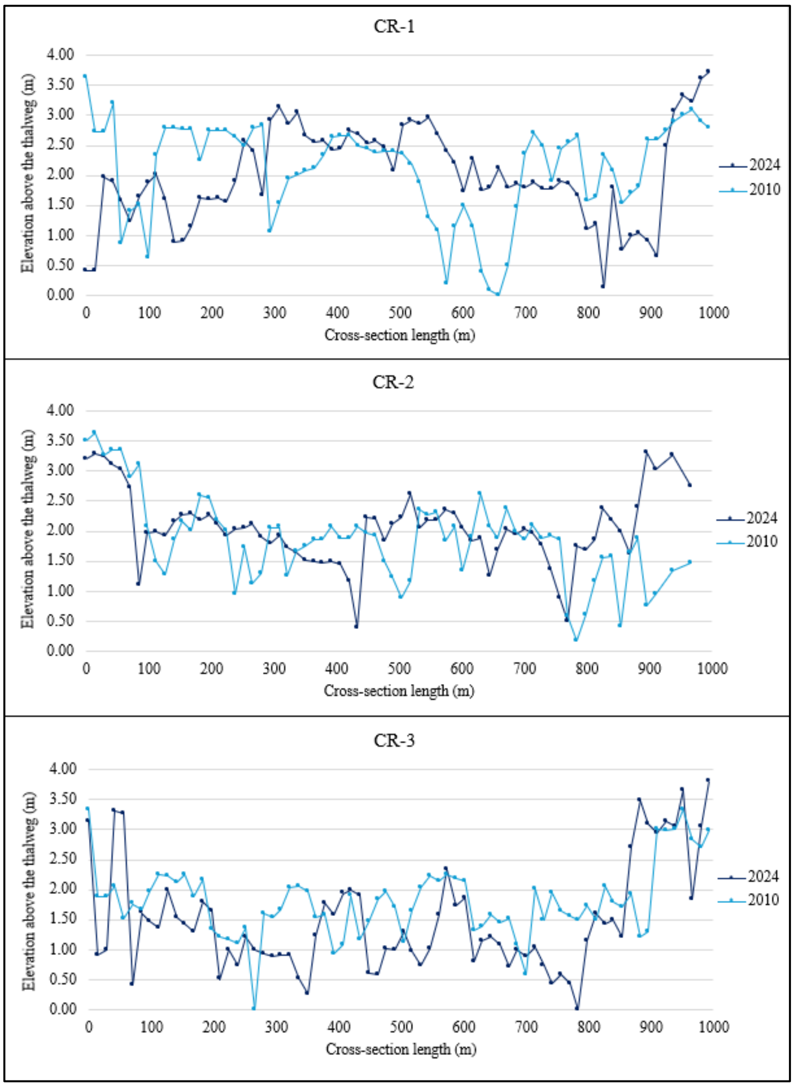
4.1.4. Cross-section profiles

The cross-sections depict the dynamics inherent to the river systems in which processes of erosion and deposition can be observed in the Tagliamento River over the years. In the profile graphs, it is possible to evince the evolution of the morphological units and the changes in the main channel. Moreover, the aerial photographs helped with the interpretation of these changes. The cross-section profiles are plotted from right to left (looking downstream), which means the first plot is considered the starting point for the cross-section measurement.

From the Cornino cross-sections (Figure 6), in CR-1, the thalweg moved 162.91 m to the left and the bed incision was nearly negligible (0.02 m). There is a river lateral shift on the right side (around 45 m) in which the floodplain was replaced by a flowing channel. Moreover, regarding the morphological units, there are some relevant changes depicted in which the elevation above the thalweg has decreased where the plots laying on islands in 2010 are lying on bars in 2024. In CR-2, on the contrary, the thalweg moved 29.28 m to the right and the bed incision was 0.41 m. In this cross-section, there is the largest lateral shift of the sub-reach (around 180 m), where the floodplain from 2010 was removed and the area in 2024 corresponds to bars on the right side of the river. Besides, there is a considerable presence of some secondary channels in 2024. In CR-3, the thalweg moved noticeably 521.10 m to the left and there was no bed incision but accretion in the riverbed since the elevation above the thalweg increased 0.31 m. There is also a lateral shift on the right side (around 90 m) and the presence of several secondary channels in 2024.

Figure 6.

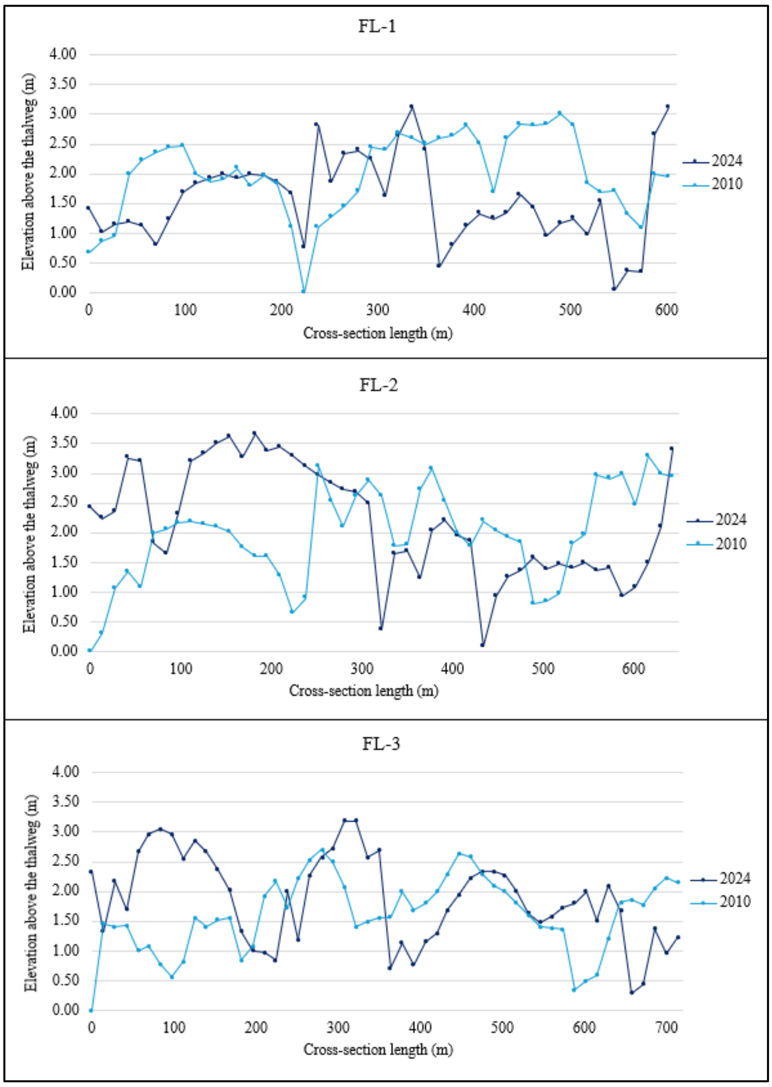
Cornino cross-sections.



From the Flagogna cross-sections (Figure 7), in FL-1, 328.89 m was the distance the thalweg traversed toward the left side, and similarly to CR-3, there was accretion instead of bed incision with a value of 0.25 m. Among some notable characteristics, the main channel in 2010 became a secondary channel in 2024. Moreover, an area covered by islands is nowadays occupied by bars and a flowing channel, thus it is possible to identify the changes in the elevation above the thalweg. In FL-2, the thalweg changed drastically its position 433.18 m to the left, and the value for the bed incision was 0.35 m. In this cross-section, some vegetation developed over the years and formed islands where there used to be bars. In FL-3, likewise, the thalweg moved 662.02 m to the left allocating the main channel on the opposite side, while the bed incision was 0.19 m. A relevant characteristic in these last two cross-sections is that the lateral shift of the main channel allowed the development of the floodplain on the right side of the river.

Figure 7.

Flagogna cross-sections.



In both sub-reaches, changes in erosion and deposition processes can be observed in the graphs. Cornino is characterized in its majority by bars and the presence of several flowing channels. The average for the elevation above the thalweg between 2010 and 2024 was -0.10 m, 0.18 m, and -0.31 m for CR-1, CR-2, and CR-3 respectively, with an average per sub-reach of -0.07 m. On the other hand, in Flagogna, there is a higher presence of islands and therefore also vegetation compared to Cornino. The elevation above the thalweg changed by -0.42 m, 0.21 m, and 0.27 m for FL-1, FL-2, and FL-3 respectively, whereas the sub-reach average was -0.02 m.

4.2. Vegetation analyses

4.2.1. Overview of the vegetation

In 2024, 291 plots were surveyed in the Tagliamento River, from those 139 were vegetated plots which represent 47.77% of the total, and 43 of them contained at least one woody species, which is 14.78% of the total number of plots. At the sub-reach level, Cornino presented a higher number of vegetated plots than Flagogna (Table 6). However, it must be pointed out that Cornino comprises a larger number of plots in general due to the length of its cross-sections. Despite that, interestingly in Flagogna, more woody species were found.

Table 6.
Vegetated plots per cross-section and sub-reach.

	Vegetated	**Including woody spp**	**Total**
CR-1	33	2	69
CR-2	22	2	57
CR-3	26	11	53
Total CR	81	15	179
FL-1	13	1	33
FL-2	20	13	36
FL-3	25	14	43
Total FL	58	28	112

4.2.2. Species richness, composition, and origin

The occurrence of the plant species was registered in percentage and for the case of the sub-reaches, it may be interpreted as an indicator of the vegetation diversity closely related to the river geomorphology (Annex 1). Among the most common species found during the field surveys in general and in both sub-reaches are *P. nigra, S. purpurea, Rubus caesius, Amorpha fruticosa, and Hedera helix*. Of the alien species, *A. fruticosa* stood out with its presence in 38.85% of the total number of vegetated plots, this value is located distant from the next listed alien species *Lonicera japonica* with 8.63%. In total, 57 species were found during the field surveys, from them 47 species were classified as native, and 10 species, as alien (Table 7).

Table 7.
Species found in the two sub-reaches of the Tagliamento River.

Code	Species	National	Regional
ace.cam	*Acer campestre*	N	
ace.pse	*Acer pseudoplatanus*	N	
aln.glu	*Alnus glutinosa*	N	
aln.inc	*Alnus incana*	N	
amo.fru	*Amorpha fruticosa*	IA	IA
art.alb	*Artemisia alba*	N	
ber.vul	*Berberis vulgaris*	N	
bud.dav	*Buddleja davidii*	IA	IA
car.bet	*Carpinus betulus*	N	
cle.vit	*Clematis vitalba*	N	
con.sep	*Convolvulus sepium*	N	
cor.mas	*Cornus mas*	N	
cor.san	*Cornus sanguinea*	N	
cor.ave	*Corylus avellana*	N	
cot.hor	*Cotoneaster horizontalis*	IA	CA
cra.mon	*Crataegus monogyna*	N	
eri.car	*Erica carnea*	N	
euo.eur	*Euonymus europaeus*	N	
fag.syl	*Fagus sylvatica*	N	
fic.car	*Ficus carica*	N	
fra.aln	*Frangula alnus*	N	
fra.exc	*Fraxinus excelsior*	N	
fra.orn	*Fraxinus ornus*	N	
hed.hel	*Hedera helix*	N	
hip.flu	*Hippophaë fluviatilis*	N	
jug.reg	*Juglans regia*	C	NA
jun.com	*Juniperus communis*	N	
lig.luc	*Ligustrum lucidum*	IA	NA
lig.sin	*Ligustrum sinense*	IA	NA
lig.vul	*Ligustrum vulgare*	N	
lon.cap	*Lonicera caprifolium*	N	
lon.jap	*Lonicera japonica*	IA	IA
lon.xyl	*Lonicera xylosteum*	N	
ost.car	*Ostrya carpinifolia*	N	
par.qui	*Parthenocissus quinquefolia*	IA	NA
pin.nig	*Pinus nigra*	N	
pin.syl	*Pinus sylvestris*	N	
pla.his	*Platanus hispanica*	IA	NA
pop.nig	*Populus nigra*	N	
pop.tre	*Populus tremula*	N	
que.cer	*Quercus cerris*	N	
que.ile	*Quercus ilex*	N	

que.pub	*Quercus pubescens*	N	
que.rob	*Quercus robur*	N	
rha.cat	*Rhamnus cathartica*	N	
rob.pse	*Robinia pseudoacacia*	IA	IA
rub.cae	*Rubus caesius*	N	
rub.ulm	*Rubus ulmifolius*	N	
sal.alb	*Salix alba*	N	
sal.ele	*Salix eleagnos*	N	
sal.pur	*Salix purpurea*	N	
sal.tri	*Salix triandra*	N	
tax.bac	*Taxus baccata*	N	
til.cor	*Tilia cordata*	N	
ulm.min	*Ulmus minor*	N	
vib.lan	*Viburnum lantana*	N	
vib.opa	*Viburnum opalus*	N	

N: native, C: cryptogenic, IA: invasive alien, NA: naturalized alien, CA: casual alien.

Among the alien species, nine out of ten are considered IAS at the national level, only *J. regia* is considered cryptogenic. On the other hand, at the regional level, four are considered IAS, five are considered NAS, and just one is considered CAS.

Regarding the total number of species surveyed, a significant proportion were found in the herb layer, and more than half of them were found in the shrub layer (Table 8). Since more native than alien species were found, their proportion was certainly higher in the three layers.

Table 8.

Number and percentage of species found per strata.

Strata	Native	%	Alien	%	Total	%
H	44	77.19	9	15.79	53	92.98
S	28	49.12	6	10.53	34	59.65
T	18	31.58	3	3.51	21	36.84

A similar pattern was found regarding the mean number of species (Table 9). Native species showed a higher number at the plot level and per strata, especially on the herb layer, contrary to the tree layer in which the mean was notably low for both native and alien species.

Table 9.

Mean number of species per strata and per plot.

Per strata	Native	Alien	Total
H	4.7	0.5	4.2
S	1.9	0.3	1.6
T	0.4	0.0	0.4
Per plot	5.3	0.6	4.6

The mean number of native species at the cross-section level was particularly high for the lower cross-sections of both sub-reaches, as was the case for CR-3 and FL-3, but also, for FL-2 (Table 10). A similar trend was present for alien species. However, the mean number of alien species in FL-3 was significantly higher and was twice as much as its equivalent cross-section in Cornino. Thus, the mean number of species, total, and for native and alien species at the sub-reach level was higher for Flagogna.

Table 10.

Mean number of species per cross-section and sub-reach.

	Native	Alien	Total
CR-1	3.3	0.2	3.1
CR-2	3.3	0.5	2.8
CR-3	5.8	0.7	5.2
CR	4.1	0.4	3.7
FL-1	2.3	0.0	2.3
FL-2	7.5	0.9	6.6
FL-3	8.7	1.4	7.3
FL	6.8	0.9	5.9

4.2.3. Tree layer and tree dimension

Of the 291 plots surveyed, only 43 plots harbored woody species. In total, 138 individuals belonging to 21 different species were found in the field surveys. Three was the mean number of individuals per plot in a range that went from a minimum of one woody species to 17 per plot found in CR-3. The species with the highest numbers of individuals were *P. nigra* (34), *S. eleagnos* (24), *C. avellana* (19), *and F. excelsior* (10).

Eight diameter classes were defined, comprising individuals with a DBH from > 5 to 40 cm (Table 11). The majority of the individuals were in the two first diameter classes with 47.10% of the individuals with a DBH > 5 cm, and 34.06% of the individuals with a DBH until 10 cm. The species with the highest values for the mean DBH were *P. sylvestris* (28.17 cm), *A. glutinosa* (16 cm), *O. carpinifolia*, (14.50 cm), and *A. incana* (13.42 cm). The alien species found were *R. pseudoacacia* with five individuals and a mean DBH of 4.50 cm and *P. hispanica* was found just once with a DBH of 5 cm.

Table 11.
Distribution of tree diameter classes.

No. class	Diameter class (cm)	No. individuals
1	< 5.0	65
2	5.0 - 10.0	47
3	10.1 - 15.0	13
4	15.1 - 20.0	3
5	20.1 - 25.0	6
6	25.1 - 30.0	2
7	30.1 - 35.0	1
8	35.1 - 40.0	1
Total		138

4.2.4. Differences between sub-reaches

The NMDS and PERMANOVA analyses on species composition showed significant variability within sub-reaches in the herb (Figure 8) and shrub (Figure 9) layers separately, and in total (herb, shrub, and tree layers together) (Figure 10). For the case of the tree layer, the number of observations was insufficient to conduct the analyses. In addition, due to the presence of an outlier species (*E. carnea*) in the herb layer and consequently, in the total, the analyses were performed with and without it to evaluate how the patterns would change. However, the subsequent Betadisper and ANOVA analyses indicated significant differences in the dispersion of woody species composition, only when evaluating the total (Annex 2).

Figure 8.

NMDS plot of the species composition in the herb layer with and without E. carnea.

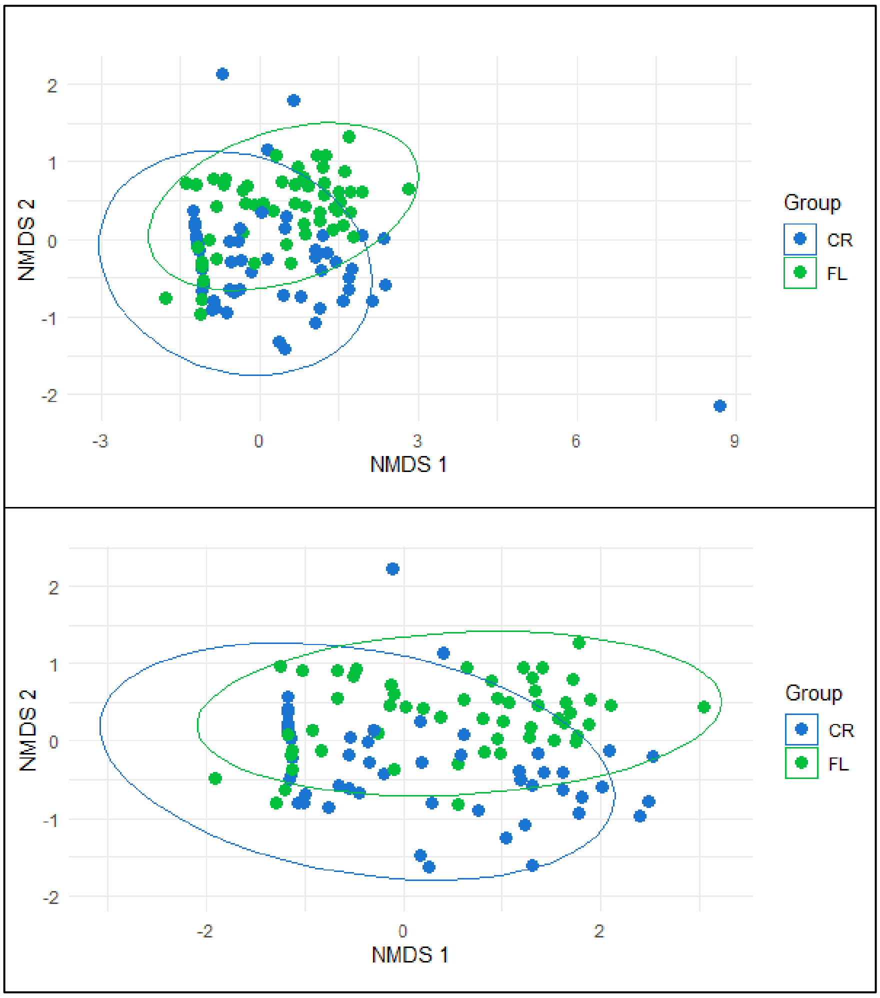


Figure 9.

NMDS plot of the species composition in the shrub layer.

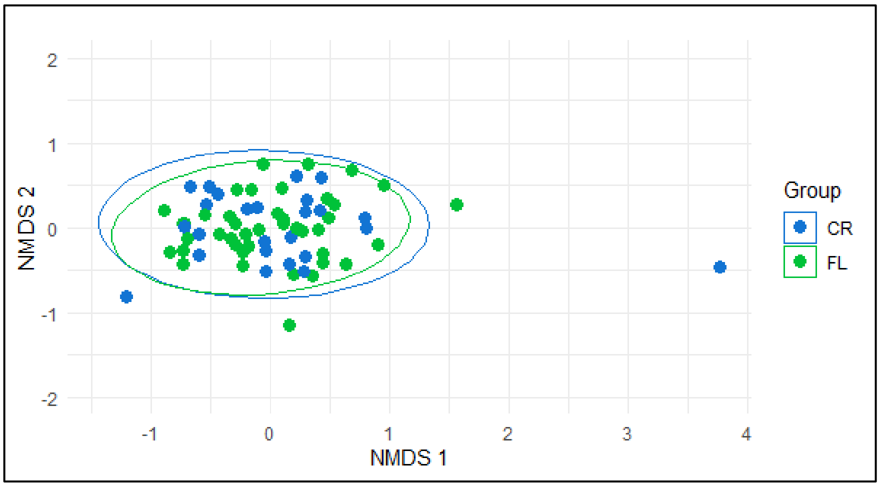
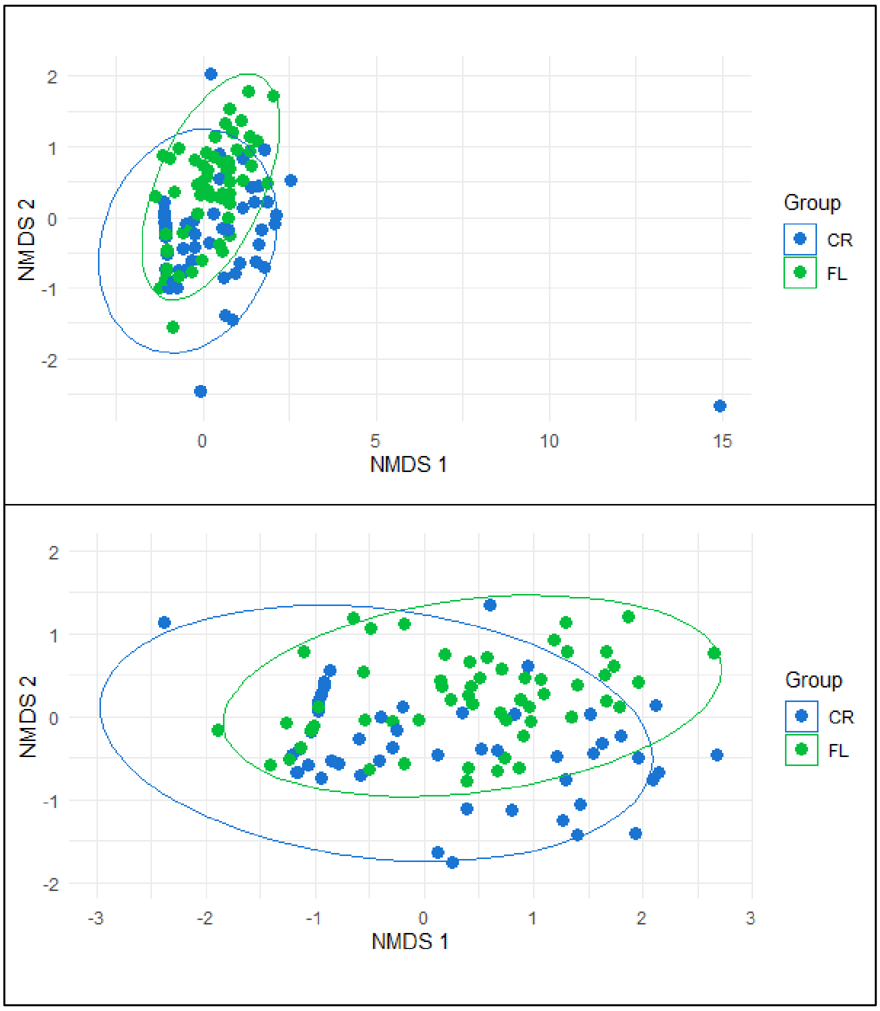


Figure 10.
NMDS plot of the species composition in total with and without E. carnea.



Similarly, some indicator species were found in the herb and shrub layers, and the total. This information may be interpreted as a complement to the occurrence of the species obtained for both sub-reaches (Annex 1). For instance, in the case of Cornino, *S. purpurea* is the species with the highest occurrence and is also an indicator species for this sub-reach in the herb layer (Table 12). However, the analysis showed some additional species that can be identified specifically in the sub-reach such as *F. ornus,* an indicator species in both the herb and shrub layers (Tables 12 and 13). In the case of Flagogna, likewise, *P. nigra*, the most occurring species in the sub-reach was identified as indicator species in the shrub layer (Table 13). It is noteworthy to observe the pattern in Flagogna, in which it is clear that the sub-reach harbors more vegetation and different species than Cornino (Table 14).

Table 12.
Indicator species in the herb layer in the two sub-reaches.

	CR			FL	
Species	**stat**	**p**	**Species**	**stat**	**p**
sal.pur	0.712	0.001 ***	rub.cae	0.721	0.001 ***
fra.orn	0.458	0.003 **	hed.hel	0.677	0.001 ***
vib.lan	0.362	0.019 *	cor.mas	0.633	0.001 ***
			amo.fru	0.609	0.003 **
			fra.exc	0.551	0.001 ***
			car.bet	0.487	0.019 *
			ace.cam	0.296	0.013 *
			lon.xyl	0.295	0.014 *
			ace.pse	0.264	0.032 *

Table 13.
Indicator species in the shrub layer in the two sub-reaches.

	CR			FL	
Species	**stat**	**p**	**Species**	**stat**	**p**
fra.orn	0.650	0.001 ***	pop.nig	0.569	0.044 *
jun.com	0.439	0.009 **			

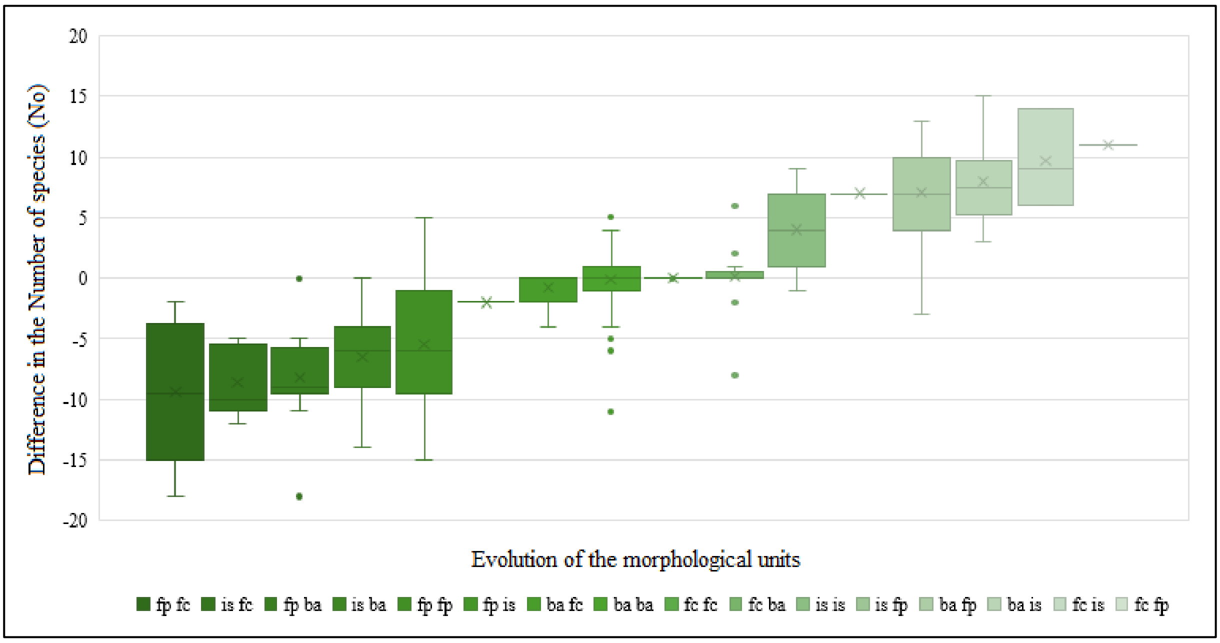
Table 14.
Indicator species in total in the two sub-reaches.

	CR			FL	
Species	**stat**	**p**	**Species**	**stat**	**p**
sal.pur	0.682	0.003 **	pop.nig	0.764	0.002 **
fra.orn	0.458	0.002 **	rub.cae	0.714	0.001 ***
jun.com	0.313	0.036 *	hed.hel	0.671	0.001 ***
			amo.fru	0.641	0.001 ***
			cor.mas	0.619	0.001 ***
			fra.exc	0.552	0.001 ***
			car.bet	0.500	0.014 *
			ace.pse	0.322	0.006 **
			aln.inc	0.296	0.030 *
			ace.cam	0.294	0.013 *
			lon.xyl	0.293	0.014 *
			sal.alb	0.285	0.027 *

4.3. Combined analyses

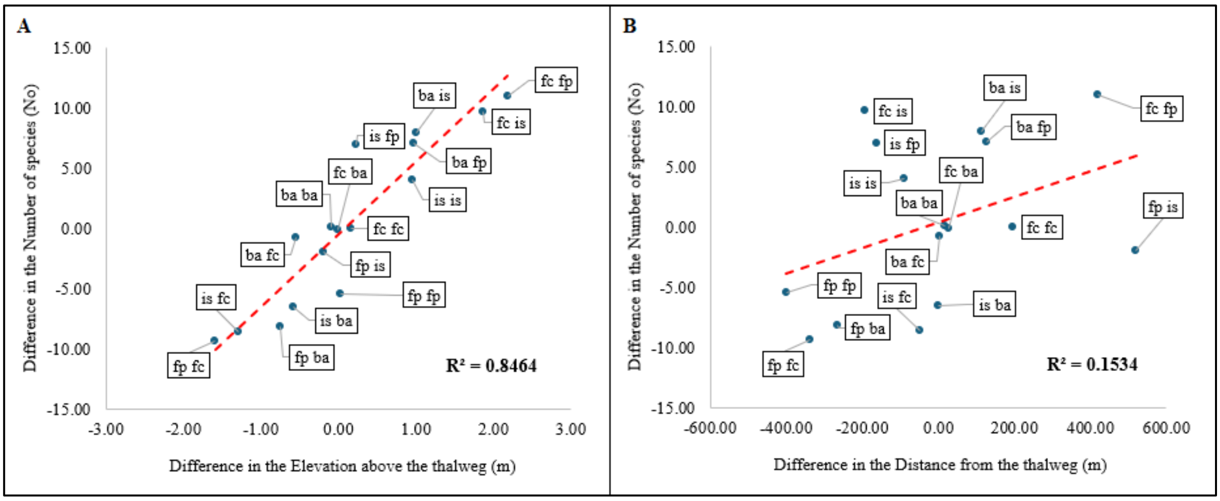
The evolution of the morphological units from 2010 to 2024 seems to have an impact on the difference in the number of species found per plot (Figure 11). According to the results, the transformation of flowing channels or bars into morphological units characterized by a higher presence of vegetation such as islands or floodplains, showed higher species richness values. For instance, the evolution of flowing channel into floodplain (fc fp) presented the highest mean with around 11 species, followed by flowing channel into island (fc is) and bar into island (ba is) with means of around 10 and 8 species, respectively. Conversely, the transformation in the opposite direction showed lower species richness values. The exact opposite, the evolution of floodplain into flowing channel (fp fc) presented the lowest mean with around -9 species, followed by island into flowing channel (is fc) and floodplain into bar (fp ba) with means of around -9 and -8 species, respectively. However, these results should be considered cautiously since the number of observations for each evolution type is variable, and in some cases, there is a limited number (e.g. fp is, is fp, fc fp).

Figure 11.
Impact of the evolution of the morphological units (between 2010 and 2024) on the number of species.



Regarding the relationship between the elevation above the thalweg and the number of species, there is a strong positive correlation. It suggests that the elevation above the thalweg, which is one of the several characteristics that may help to distinguish the morphological units, and the changes it undergoes through time have a relevant influence on the species richness. On the other hand, from the analysis of distance from the thalweg and the number of species, the linear relationship explains only a weak correlation between the variables.

Figure 12.
Correlation functions showing the relationship between A. the elevation above the thalweg and B. the distance from the thalweg with the number of species.



5. Discussion

Surian & Rinaldi (2003) compiled and analyzed several studies concerning the channel adjustments observed in Italian rivers in the last century. Bed incision, channel narrowing, and modifications in the channel patterns are among the most relevant morphological changes. In contrast, aggradation and widening are considered secondary changes. Among their findings, the average bed incision was found around 3-4 m reaching up to 10 m in some extreme cases. Rinaldi (2003) noted that some upper reaches of rivers in the northern part of Tuscany showed incisions of more than 2 m, whereas the largest incision levels recorded were in the middle and lower reaches of the Arno River, with 4-9 m. Conversely, for reaches in the southern part of the region, incision was moderate, which means not higher than 2 m. Even though main adjustments are generally expected, rivers often undergo secondary channel adjustments such as widening and aggradation after an initial phase of incision and widening (Surian & Rinaldi, 2003).

Ziliani & Surian (2016) studied the historical changes in the Tagliamento River, in a reach between Pinzano and San Vito al Tagliamento, located downstream from the present study area. According to the authors, the channel first underwent a first phase characterized by incision with values of 0.3-0.4 m at the end of 1960. Then, from 1960 to 1990, a second phase took place with an average incision of 1 m, in a range of values from 0.15-2 m. Finally, a third phase of widening with some aggradation occurred, in which, on average the channel width increased by 2 m/year, and the values for aggradation were 0.2 m. It is worth noting that the widening phase was not constant but intermittent, with peaks during the periods of 1997-2001 and 2007-2009 in which width increased by 7 and 14 m/year, respectively (Surian et al., 2009; Ziliani & Surian, 2012; Ziliani & Surian, 2016). Therefore, taking into account this information, the values obtained in this study for incision and aggradation in which none exceeded 0.5 m, are within the range of the historically recorded values. Concerning channel widening, in the two upper cross-sections in Cornino, the values for the lateral shift corresponded to 3.21 and 12.85 m/year, considering these changes have taken place for the last 14 years. Nevertheless, this general statement assumes the change has been constant and does not consider possible yearly variations in the river morphology. However, Surian et al. (2009) also reported that in the Tagliamento River, bank retreat may take place from tens of meters to more than 100 m even during a single flood event.

According to Surian & Rinaldi (2003), some of the changes rivers undergo in Italy may be closely related to anthropogenic disturbances that started mainly around 1950 and 1960 and are still causing an impact nowadays. Ziliani & Surian (2012) and Ziliani & Surian (2016) noted the effects of human interventions such as channelization and gravel mining. However, these activities have been considerably reduced in the last decades, especially since the enactment of a law in 1994 in which the regulations for mining activities at local and national levels were stated. The Tagliamento River is considered an exception to the generalization of rivers impacted by human activities, since no major changes in its hydrological and geomorphological processes have occurred, compared to other rivers (Surian et al., 2009). Moreover, the values obtained in this study for some of the channel adjustments discussed may validate the previous stance.

Regarding the grain size distribution, Surian et al. (2009) conducted a study in two different sub-reaches in the Tagliamento River, both located downstream from the present study area. The first sub-reach located between Pinzano and San Paolo with a braided configuration and average slope of 0.003 m m^{-1}, presented a sediment grain size of $D_{50} = 0.024$ m. On the other hand, the second sub-reach located between San Paolo and Latisana with a meandering configuration and average slope of 0.001 m m^{-1}, presented a sediment grain size of $D_{50} = 0.017$ m. Cornino and Flagogna located upstream with sediment grain sizes of $D_{50} = 0.030$ m and $D_{50} = 0.027$ m, respectively, altogether with the aforementioned information may serve as a demonstration of the decreasing grain size gradient changing from the source to the mouth of the river.

The complexity and variability of the dynamics of braided rivers can be observed in the changes of the morphological units from different reaches within the Tagliamento River, and their responses to flood events (Surian et al., 2009). For example, small floods corresponding to 20-50% of the bankfull discharge with recurrence intervals (RI) lower than a year proved to have a relevant impact on shaping and changing the main and secondary channels. During floods with RI close to the bankfull discharge (1.1 years), low bars were subjected to high activity, whereas high bars were just moderately active with partial grain remotion. For high bars and islands to undergo full activity, floods with RI of around 5 years are needed (Surian et al., 2009). In the present study, on average 63% of the bars, 33% of the floodplains, 26% of the flowing channels, and 17% of the islands persisted after 14 years. Conversely, Sitzia et al. (2016) reported that persistence was higher in floodplains, followed by bars and islands when evaluating aerial photographs in the period 1954-2010. According to Surian & Fontana (2017), vegetation turnover occurs rapidly in the Tagliamento River. After a comparison made by Surian et al.

(2015) on aerial photographs in the period 1954-2011, it was noted that around 50% of the vegetation usually persists for less than 6 years and just 10% persists for more than 18 years. Bertoldi et al. (2009) stated that the threshold at which floods may cause vegetation erosion is around 3 years. Nevertheless, Surian et al. (2015) argued that this threshold may be even lower, which means that floods with an RI between 1 and 2.5 years will certainly have an impact on vegetation. These previous considerations are essential to determine what can be expected under certain circumstances and to better understand how floods with diverse frequencies and magnitudes may affect fluvial landforms.

Surian et al. (2015) studied the vegetation turnover in two sub-reaches of the Tagliamento River, the upper one located between Osoppo and Cornino and the lower one located between Cornino and Pinzano. It is important to note that, the location of these study areas closely resembled those in the present study. Both sub-reaches followed similar trends regarding the river morphology, however, they showed some relevant differences in vegetation. In fact, vegetation dynamics may be comparable with Cornino and Flagogna, in which the latter exhibited a higher presence of islands and thus, a more complex and developed vegetation community. 45.25% of the plots in Cornino contained vegetation, compared to 51.79% in Flagogna, which at a glance may not seem a significant difference. Nonetheless, the vegetation cover in Flagogna was superior. More in detail, Surian et al (2015) mentioned that the lower sub-reach presented higher vegetation cover and higher variability in terms of the "vegetation area/active channel area" ratio over the years. Moreover, the rates of vegetation erosion and establishment were more dynamic in the upper sub-reach, while they were more stable in the lower sub-reach. Welber et al. (2012) studied the river planform configuration in the same sub-reaches as the present study. The authors mentioned that 21% of the total corridor area was covered by vegetation in Flagogna, in contrast with 4% in Cornino. A higher water table in the alluvial aquifer confers the area with an interesting water dynamic that highly controls moisture availability and thus, the vegetation colonization rates in Flagogna. For this reason, its annual growth rate tends to be two to three times higher than in Cornino (Bertoldi et al., 2011; Welber et al., 2012).

In the present study, 15 indicator species were found in total, four and ten indicator species for Cornino and Flagogna separately. Sitzia et al. (2016) reported 40 indicator species in the same study area. The most common species were *P. nigra, S. purpurea, R. caesius, A. fruticosa* and *S. eleagnos.* Interestingly, some of them were documented by Karrenberg et al. (2003) as well, more specifically: *P. nigra, A. incana, S. eleagnos, S. alba,* and *S. purpurea.* Moreover, the authors stated that *A. fruticosa* was found in the lower reaches of the Tagliamento and at that moment IAS were not widespread along the river. Contrary to the results obtained from this study in which *A. fruticosa* was the most common IAS, present in 38.85% of the plots.

According to Karrenberg et al. (2003), a peak of nine woody species per plot was recorded, and then species richness decreased in the reaches downstream with an average of four species per plot. From this study's results, 15 species in a plot in Flagogna was the maximum number of species reported per plot, with an average of five species per plot and cross-section. The average per sub-reach was four species for Cornino and seven for Flagogna.

Sitzia et al. (2016) cited that the spatial succession of the woody communities in the Tagliamento River follows a clear pattern in which pioneer communities, adapted to lower-elevation landforms characterized by frequent disturbances can be found close to the channels, while more developed tree communities in the floodplains. In the present study, *S. eleagnos, S. purpurea,* and *P. nigra* were commonly found in bars. *S. purpurea* was an indicator species in the herb layer for Cornino, whereas *P. nigra,* in the shrub layer for Flagogna. Sitzia et al. (2016) likely found these species, including *S. daphnoides* as indicator species for bars. Hupp & Bornette (2003) stated that species from the genera *Salix* and *Populus* survive in these landforms since they withstand inundation and considerable amounts of sediment deposition. In addition, their establishment and persistence are facilitated by their rapid root growth.

Regarding the species that can be found in the islands and the floodplain, many of the indicator species reported by Sitzia et al. (2016), were obtained as well in the present study. Species such as *P. nigra, R. caesius, H. helix, F. excelsior* among others for Flagogna, and *F. ornus* for Cornino. Nonetheless, some new species also appeared such as *C. mass, C. betulus, A.campestre,* and *A. pseudoplatanus* in Flagogna, and *J. comunis* and *V. lantana* in Cornino. Sitzia et al. (2016) recorded *R. pseudoacacia* and *A. fruticosa* from the IAS, whereas in the present study *R. pseudoacacia* different from *A. fruticosa*, was not considered an indicator species and was present only in 3.60% of the plots during the field surveys. Hupp & Bornette (2003) cited some genera typical from middle floodplain elevations like *Ulmus, Quercus* and *Fraxinus* and some others common from well-drained locations in upper elevations like *Pinus* and *Fagus*. Among the results, two species of *Pinus, P. sylvestris* and *P. nigra*, together with *A. glutinosa* and *A. incana* found in the floodplains were among the species with higher DBH. The lateral dynamics of the river system create an interesting mosaic of vegetation characterized by diverse structures, ages, and hydrological requirements. Thus, eventually, the species become indicators of the hydrogeomorphic conditions ruling the landform in which they have developed (Hupp & Bornette, 2003).

Finally, from the correlation functions, it can be concluded that the elevation above the thalweg proved to be a determining factor for species richness. Sitzia et al. (2016) pointed out that this variable is correlated to the layer of fine sediment, the tree age, and the mean DBH. In this case, an emphasis on the suitability of the landforms can be made, recognizing that these two first variables are crucial to assure the development of tree communities. The most important variables controlling the moisture contents for vegetated patches within the active channel are the elevation above the thalweg and the grain size. These elements in conjunction provide a diversity of conditions that eventually influence the habitat diversity and species richness (Gilvear et al., 2008; Sitzia et al., 2016). Furthermore, this information offered some valuable insights regarding how the evolution of the morphological units over the years may affect the woody communities in the Tagliamento River.

6. Conclusions

The present work tried to convey the significance of conducting research on the geomorphological and vegetation changes in river systems in order to get a better understanding of their mutual interactions and possible impacts. For this purpose, it is fundamental to consider the different spatial and temporal scales to obtain a wider perspective under diverse geographical and climatic settings. In this regard, the future climate change scenarios and their effects on flood frequency and magnitude must be considered to predict future channel stability. This is crucial for implementing future effective measures to conduct adequate management and subsequent ecological restoration if needed.

The various changes in fluvial morphology indeed have an impact on the vegetation and vice versa. For this, it is important to comprehend that non-native species, in the same way as native species, have a role and an influence on the vegetation community within river systems. Thus, it is essential to determine the most appropriate management strategies focused on nature-based solutions to support the balanced and healthy functioning of river systems and their elements. Finally, it is suggested to conduct further research on non-native species, especially on the species *Amorpha fruticosa*, and to consider its possible spread in the future.

7. References

Aronson, M., Patel, M., O'Neill, K. & Ehrenfeld, J. (2017). Urban riparian systems function as corridors for both native and invasive plant species. *Biological Invasions, 19*, 3645-3657.

Baturina, N. (2019). Functional structure of river ecosystems: Retrospective of the development of contemporary concepts. *Inland Water Biology, 12*, 1-9.

Bendix, J. & Hupp, C. (2000). Hydrological and geomorphological impacts on riparian plant communities. *Hydrological processes, 14*(16-17), 2977-2990.

Bertoldi, W., Zanoni, L. & Tubino, M. (2010). Assessment of morphological changes induced by flow and flood pulses in a gravel bed braided river: The Tagliamento River (Italy). *Geomorphology, 114*(3), 348-360.

Bertoldi, W., Drake, N. & Gurnell, A. (2011). Interactions between river flows and colonizing vegetation on a braided river: Exploring spatial and temporal dynamics in riparian vegetation cover using satellite data. *Earth Surface Processes and Landforms, 36*(11), 1474-1486.

Castro, P. & Alonso, A. (2017). Effects of non-native riparian plants in riparian and fluvial ecosystems: A review for the Iberian Peninsula. *Limnetica, 36*(2), 525-541.

Corenblit, D., Tabacchi, E., Steiger, J. & Gurnell, A. (2007). Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: A review of complementary approaches. *Earth-Science Reviews, 84*(1-2), 56-86.

Corenblit, D., Steiger, J., Gurnell, A., Tabacchi, E. & Roques, L. (2009). Control of sediment dynamics by vegetation as a key function driving biogeomorphic succession within fluvial corridors. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group, 34*(13), 1790-1810.

De Cáceres, M. & Legendre, P. (2009). Associations between species and groups of sites: indices and statistical inference. *Ecology, 90*(12), 3566-3574.

Doretto, A., Piano, E. & Larson, C. (2020). The River Continuum Concept: lessons from the past and perspectives for the future. *Canadian Journal of Fisheries and Aquatic Sciences, 77*(11), 1853-1864.

Eaton, B., Moore, R. & MacKenzie, L. (2019). Percentile-based grain size distribution analysis tools (GSDtools) – estimating confidence limits and hypothesis tests for comparing two samples. *Earth Surface Dynamics, 7*(3), 789-806.

Flanagan, N., Richardson, C. & Ho, M. (2015). Connecting differential responses of native and invasive riparian plants to climate change and environmental alteration. *Ecological Applications, 25*(3), 753-767.

Folk, R. & Ward, W. (1957). Brazos River Bar: A study in the significance of grain size parameters. *Journal of sedimentary research, 27*(1), 3-26.

Gilvear, D., Francis, R., Willby, N. & Gurnell, A. (2008). Gravel bars: a key habitat of gravel-bed rivers for vegetation. *Developments in Earth Surface Processes, 11*, 677-700.

Gurnell, A. (2014). Plants as river system engineers. *Earth Surface Processes and Landforms, 39*(1), 4-25.

Gurnell, A. & Petts, G. (2006). Trees as riparian engineers: the Tagliamento River, Italy. *Earth Surface Processes and Landforms, 31*(12), 1558-1574.

Gurnell, A., Bertoldi, W. & Corenblit, D. (2012). Changing river channels: The roles of hydrological processes, plants and pioneer fluvial landforms in humid temperate, mixed load, gravel bed rivers. *Earth-Science Reviews, 111*(1-2), 129-141.

Gurnell, A. & Bertoldi, W. (2024). Plants and river morphodynamics: The emergence of fluvial biogeomorphology. River Research and Applications.

Hupp, C. & Bornette, G. (2003). Vegetation as a tool in the interpretation of fluvial geomorphic processes and landforms in humid temperate areas. *Tools in Fluvial Geomorphology*, 269-288.

Jones, C., Lawton, J. & Shachak, M. (1994). Organisms as ecosystem engineers. *Oikos, 69*(3), 373–386.

Junk, W., Bayley, P. & Sparks, R. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences, 106*(1), 110-127.

Karrenberg, S., Kollmann, J., Edwards, P., Gurnell, A. & Petts, G. (2003). Patterns in woody vegetation along the active zone of a near-natural Alpine river. *Basic and Applied Ecology, 4*(2), 157-166.

Kondolf, G. & Wolman, M. (1993). The sizes of salmonid spawning gravels. *Water Resources Research, 29*(7), 2275-2285.

Krumbein, W. (1936). Application of logarithmic moments to size-frequency distributions of sediments. *Journal of Sedimentary Research, 6*(1), 35-47.

Larsen, S., Bruno, M., Vaughan, I. & Zolezzi, G. (2019). Testing the River Continuum Concept with geostatistical stream-network models. *Ecological Complexity, 39*, 100773.

López, G. (2017). Grain size analysis. *Encyclopedia of Geoarchaeology*, 341-348.

Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Stevens, M., Oksanen, M., et al. (2007). *Vegan: Community Ecology Package*. Available online at: https://cran.r-project.org/web/packages/vegan/index.html (accessed September 30, 2024).

Osterkamp, W. & Hupp, C. (2010). Fluvial processes and vegetation - Glimpses of the past, the present, and perhaps the future. *Geomorphology, 116*(3-4), 274-285.

Pattison, Z., Minderman, J., Boon, P. & Willby, N. (2017). Twenty years of change in riverside vegetation: What role have invasive alien plants played?. *Applied Vegetation Science, 20*(3), 422-434.

Pattison, Z., Whytock, R., & Willby, N. (2018). Invasion legacy effects versus sediment deposition as drivers of riparian vegetation. *Biological invasions, 20*, 1189-1198.

Picco, L., Mao, L., Cavalli, M., Buzzi, E., Rainato, R. & Lenzi, M. (2013). Evaluating short-term morphological changes in a gravel-bed braided river using terrestrial laser scanner. *Geomorphology, 201*, 323-334.

R Core Team. (2013). R: A language and environment for statistical computing. *Foundation for Statistical Computing*, Vienna, Austria.

Ravazzolo, D., Mao, L., Picco, L. & Lenzi, M. (2015a). Tracking log displacement during floods in the Tagliamento River using RFID and GPS tracker devices. *Geomorphology, 228*, 226-233.

Ravazzolo, D., Mao, L., Picco, L., Sitzia, T. & Lenzi, M. (2015b). Geomorphic effects of wood quantity and characteristics in three Italian gravel-bed rivers. *Geomorphology, 246*, 79-89.

Richardson, D., Pyšek, P., Rejmanek, M., Barbour, M., Panetta, F. & West, C. (2000). Naturalization and invasion of alien plants: concepts and definitions. *Diversity and distributions, 6(*2), 93-107.

Richardson, D., Holmes, P., Esler, K., Galatowitsch, S., Stromberg, J., Kirkman, S., ... & Hobbs, R. (2007). Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Diversity and distributions, 13*(1), 126-139.

Rinaldi, M. (2003). Recent channel adjustments in alluvial rivers of Tuscany, Central Italy. *Earth Surface Processes and Landforms, 28*(6), 587-608.

Schnitzler, A., Hale, B. & Alsum, E. (2007). Examining native and exotic species diversity in European riparian forests. *Biological conservation, 138*(1-2), 146-156.

Sitzia, T., Picco, L., Ravazzolo, D., Comiti, F., Mao, L. & Lenzi, M. (2016). Relationships between woody vegetation and geomorphological patterns in three gravel-bed rivers with different intensities of anthropogenic disturbance. *Advances in Water Resources, 93*, 193-204.

Sitzia, T., Iacopino, S., Alterio, E., Comiti, F., Surian, N., Mao, L., ... & Picco, L. (2023). Revisiting vegetation gradient analysis and the Intermediate Disturbance Hypothesis for the interpretation of riverine geomorphic patterns. *Land, 12*(2), 378.

Surian, N. & Fontana, A. (2017). The Tagliamento River: the fluvial landscape and long-term evolution of a large alpine braided river. Landscapes and Landforms of Italy, 157-167.

Surian, N. & Rinaldi, M. (2003). Morphological response to river engineering and management in alluvial channels in Italy. *Geomorphology, 50*(4), 307-326.

Surian, N., Mao, L., Giacomin, M. & Ziliani, L. (2009). Morphological effects of different channel-forming discharges in a gravel-bed river. *Earth Surface Processes and Landforms, 34*(8), 1093-1107.

Surian, N., Barban, M., Ziliani, L., Monegato, G., Bertoldi, W. & Comiti, F. (2015). Vegetation turnover in a braided river: frequency and effectiveness of floods of different magnitude. *Earth Surface Processes and Landforms, 40*(4), 542-558.

Tockner, K., Ward, J., Arscott, D., Edwards, P., Kollmann, J., Gurnell, A., … & Maiolini, B. (2003). The Tagliamento River: a model ecosystem of European importance. *Aquatic Sciences, 65*, 239-253.

Vannote, R., Minshall, G., Cummins, K., Sedell, J. & Cushing, C. (1980). The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences, 37*(1), 130-137.

Welber, M., Bertoldi, W. & Tubino, M. (2012). The response of braided planform configuration to flow variations, bed reworking and vegetation: the case of the Tagliamento River, Italy. *Earth Surface Processes and Landforms, 37*(5), 572-582.

Wentworth, C. (1922). A scale of grade and class terms for clastic sediments. *The Journal of Geology, 30*(5), 377-392.

Ziliani, L. & Surian, N. (2012). Evolutionary trajectory of channel morphology and controlling factors in a large gravel-bed river. *Geomorphology, 173*, 104-117.

Ziliani, L., & Surian, N. (2016). Reconstructing temporal changes and prediction of channel evolution in a large Alpine river: the Tagliamento River, Italy. *Aquatic sciences, 78*, 83-94.

8. Annexes

Annex 1

Occurrence of the species in total and per sub-reach expressed in percentages.

TOTAL		Cornino		Flagogna	
Species	**Percentage**	**Species**	**Percentage**	**Species**	**Percentage**
Populus nigra	61.15	*Salix purpurea*	60.49	*Populus nigra*	74.14
Salix purpurea	46.76	*Populus nigra*	51.85	*Rubus caesius*	63.79
Rubus caesius	43.17	*Rubus caesius*	28.40	*Amorpha fruticosa*	56.90
Amorpha fruticosa	38.85	*Amorpha fruticosa*	25.93	*Hedera helix*	50.00
Salix eleagnos	29.50	*Ligustrum vulgare*	24.69	*Cornus mas*	43.10
Hedera helix	28.78	*Fraxinus ornus*	20.99	*Salix eleagnos*	41.38
Ligustrum vulgare	28.78	*Salix eleagnos*	20.99	*Fraxinus excelsior*	36.21
Carpinus betulus	23.02	*Carpinus betulus*	16.05	*Ligustrum vulgare*	34.48
Cornus mas	23.02	*Viburnum lantana*	14.81	*Carpinus betulus*	32.76
Fraxinus excelsior	18.71	*Hedera helix*	13.58	*Salix purpurea*	27.59
Crataegus monogyna	17.99	*Crataegus monogyna*	12.35	*Crataegus monogyna*	25.86
Cornus sanguinea	15.11	*Cornus sanguinea*	11.11	*Cornus sanguinea*	20.69
Corylus avellana	12.95	*Juniperus communis*	9.88	*Corylus avellana*	20.69
Fraxinus ornus	12.95	*Salix triandra*	9.88	*Acer pseudoplatanus*	10.34
Salix triandra	10.07	*Cornus mas*	8.64	*Alnus incana*	10.34
Viburnum lantana	9.35	*Lonicera japonica*	8.64	*Clematis vitalba*	10.34
Lonicera japonica	8.63	*Corylus avellana*	7.41	*Salix triandra*	10.34
Clematis vitalba	7.91	*Clematis vitalba*	6.17	*Acer campestre*	8.62
Frangula alnus	6.47	*Frangula alnus*	6.17	*Lonicera xylosteum*	8.62
Juniperus communis	6.47	*Fraxinus excelsior*	6.17	*Salix alba*	8.62

Alnus incana	5.76	*Pinus sylvestris*	4.94	*Lonicera japonica*	8.62
Acer pseudoplatanus	5.04	*Quercus robur*	4.94	*Frangula alnus*	6.90
Lonicera xylosteum	4.32	*Berberis vulgaris*	3.70	*Buddleja davidii*	6.90
Salix alba	4.32	*Erica carnea*	3.70	*Rubus ulmifolius*	5.17
Buddleja davidii	4.32	*Ulmus minor*	3.70	*Ligustrum sinense*	5.17
Acer campestre	3.60	*Alnus incana*	2.47	*Robinia pseudoacacia*	5.17
Pinus sylvestris	3.60	*Quercus cerris*	2.47	*Alnus glutinosa*	3.45
Quercus robur	3.60	*Rhamnus cathartica*	2.47	*Convolvulus sepium*	3.45
Robinia pseudoacacia	3.60	*Buddleja davidii*	2.47	*Fagus sylvatica*	3.45
Erica carnea	2.88	*Cotoneaster horizontalis*	2.47	*Quercus ilex*	3.45
Rubus ulmifolius	2.88	*Robinia pseudoacacia*	2.47	*Taxus baccata*	3.45
Ulmus minor	2.88	*Acer pseudoplatanus*	1.23	*Tilia cordata*	3.45
Berberis vulgaris	2.16	*Ficus carica*	1.23	*Ligustrum lucidum*	3.45
Ligustrum sinense	2.16	*Lonicera xylosteum*	1.23	*Parthenocissus quinquefolia*	3.45
Alnus glutinosa	1.44	*Ostrya carpinifolia*	1.23	*Artemisia alba*	1.72
Convolvulus sepium	1.44	*Pinus nigra*	1.23	*Erica carnea*	1.72
Fagus sylvatica	1.44	*Rubus ulmifolius*	1.23	*Euonymus europaeus*	1.72
Quercus cerris	1.44	*Salix alba*	1.23	*Fraxinus ornus*	1.72
Quercus ilex	1.44	*Viburnum opalus*	1.23	*Hippophaë fluviatilis*	1.72
Rhamnus cathartica	1.44	*Juglans regia*	1.23	*Juniperus communis*	1.72
Taxus baccata	1.44	*Acer campestre*	0.00	*Lonicera caprifolium*	1.72
Tilia cordata	1.44	*Alnus glutinosa*	0.00	*Pinus sylvestris*	1.72
Cotoneaster horizontalis	1.44	*Artemisia alba*	0.00	*Populus tremula*	1.72
Ligustrum lucidum	1.44	*Convolvulus sepium*	0.00	*Quercus pubescens*	1.72
Parthenocissus quinquefolia	1.44	*Euonymus europaeus*	0.00	*Quercus robur*	1.72

Artemisia alba	0.72	*Fagus sylvatica*	0.00	*Ulmus minor*	1.72
Euonymus europaeus	0.72	*Hippophaë fluviatilis*	0.00	*Viburnum lantana*	1.72
Ficus carica	0.72	*Lonicera caprifolium*	0.00	*Platanus hispanica*	1.72
Hippophaë fluviatilis	0.72	*Populus tremula*	0.00	*Berberis vulgaris*	0.00
Lonicera caprifolium	0.72	*Quercus ilex*	0.00	*Ficus carica*	0.00
Ostrya carpinifolia	0.72	*Quercus pubescens*	0.00	*Ostrya carpinifolia*	0.00
Pinus nigra	0.72	*Taxus baccata*	0.00	*Pinus nigra*	0.00
Populus tremula	0.72	*Tilia cordata*	0.00	*Quercus cerris*	0.00
Quercus pubescens	0.72	*Ligustrum lucidum*	0.00	*Rhamnus cathartica*	0.00
Viburnum opalus	0.72	*Ligustrum sinense*	0.00	*Viburnum opalus*	0.00
Juglans regia	0.72	*Parthenocissus quinquefolia*	0.00	*Cotoneaster horizontalis*	0.00
Platanus hispanica	0.72	*Platanus hispanica*	0.00	*Juglans regia*	0.00

Alien species are highlighted in red.

Annex 2

Parameters and results from the NMDS, PERMANOVA, and Betadisper analyses comparing sub-reaches.

Layer	NMDS			PERMANOVA			Betadisper		
	Distance	K (dimensions)	Stress	R^2	F	p	Mean Sq	F	p
Total	Bray-Curtis	2	0.12965	0.0455	6.5344	0.001 ***	0.032815	3.9465	0.0489 *
Total (no spp)	Bray-Curtis	2	0.14150	0.0460	6.5602	0.001 ***	0.028929	3.4636	0.0648 .
Shrub layer	Bray-Curtis	2	0.15807	0.0273	1.9085	0.031 *	0.009577	1.0702	0.3046
Herb layer	Bray-Curtis	2	0.12103	0.0464	6.6236	0.001 ***	0.014472	1.8615	0.1747
Herb layer (no spp)	Bray-Curtis	2	0.12721	0.0470	6.6627	0.001 ***	0.011937	1.5295	0.2183

spp = Erica carnea