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DISTRIBUTION PATTERNS OF RIPARIAN PLANT SPECIES ACROSS RIVER OF SARDINIA AND TUSCANY

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To Mum and Dad
Because is thanks to them if I am, here, this way, now.

Alla Mamma e al Babbo
Perché è grazie a loro se sono, qui, così, ora.

"In every respect, the valley rules the stream."

H.B.N. Hynes (1975)

"We were curious. Our curiosity was not limited, but was as wide and horizonless as that of Darwin of Agassiz or Linnaeus or Pliny. We wanted to see everything our eyes would accommodate, to think what we could, and, out of our seeing and thinking, to build some kind of structure in modeled imitation of the observed reality."

J. Steinbeck and E. Ricketts, Sea of Cortez (1941)

Contents

INTRODUCTION

1. PATTERNS OF REGIONAL AND LOCAL RIPARIAN FLORA: TESTING THE ROLE OF BIOGEOGRAPHY IN MEDITERRANEAN RIVERS

2. ENDEMIC AND ALIEN PLANT SPECIES DISTRIBUTION ALONG TWO MEDITERRANEAN RIVERS

3. INFLUENCE OF BEDROCK-ALLUVIAL TRANSITION ON PLANT SPECIES DISTRIBUTION ALONG A MEDITERRANEAN RIVER CORRIDOR

4. USING MULTIVARIATE ANALYSES TO ASSESS EFFECTS OF FLUVIAL TYPE ON PLANT SPECIES DISTRIBUTION IN A MEDITERRANEAN RIVER

5. MORPHOLOGICAL AND LAND-USE CLASSIFICATIONS FOR RIPARIAN VEGETATION: ARE THERE CONCORDANT ACROSS RIVERS AND PREDICTIVE OF PLANT DISTRIBUTION?

SUMMARY

This research project aims to analyze riparian vascular flora of four Mediterranean rivers belonging to two different regions (Sardinia and Tuscany). It focuses on the analysis of floristic differences, on distributional trends of functional and ecological groups, alien and endemic species, and also on the application of landscape classifications to be used as surrogate in conservation planning. The main goal is to evaluate similarities and differences among these rivers in the frame of a regional scale approach of study, thus contributing to improve the knowledge about their internal dynamics and their linkages with the main environmental factors, useful information for conservation management of these threatened habitats.

The first part of the work focuses on distributional patterns of species and examines floristic differences at regional (between regions) as well as at local level (between rivers belonging to the same region), in order to elucidate the main gradients of riverbed floras and to investigate the role played by biogeography in driving riparian plant species distribution. Despite many floristic similarities between the two areas, always emerges the high floristic heterogeneity and the regional differentiation as the main variable affecting the distribution of our riverbed floras, thus confirming the primary role of geography in driving riparian plant species distribution at regional scale. At local level, longitudinal gradient results to strongly affect riverbed flora patterns in our rivers, while lateral gradient has a weak effect at regional scale and a relevant effect only in Tuscany.

On the basis of the previous results, the second part was devoted to analyze more consistently endemic and alien flora of Sardinian rivers. This was done using a method to rapidly assess conservation priorities by comparing distribution models of these species along the fluvial corridors. The distributional trend of endemic and alien species resulted in general to follow the decreasing naturalness/increasing human impact gradient going toward the sea, but the study evidenced the presence of different degree of naturalness between the two rivers in general, nevertheless the presence of protected areas in both of them. The most critical areas resulted to be the middle course of the rivers, where endemic species coexist with alien species and overall with high human impact in the surroundings. These resulted to be the areas where should concentrate further conservation efforts.

In the third part is tested the variation of riparian plant species composition along a Sardinian river according to lithological features. The analyses were based on field data recorded along Santa Lucia river, where the morphology is influenced by the bedrock-alluvial transition. The results underline that lithological types are the primary drivers in the organization of the riparian plant communities, followed by geomorphology and altitude. Moreover, the change bedrock-alluvial marks the highest species turnover, linked also to a different degree of human disturbance. The results indicate that the degree of bedrock/alluvial influence is an integral component to the patch structure and strongly influences riparian plant distribution patterns in a Mediterranean environment.

Starting from the previous findings, and going towards the definition of a morphological classification of rivers, in the fourth part is proposed (and applied in one river as a preliminary test) a method to assess the distribution of plant assemblages along rivers delimiting homogeneous fluvial types using morphological features, quantified with aerial photos and geographic information system software. This method identifies four fluvial types, characterized by well-defined indicator species, functional and ecological groups. Based on the ordination results, dividing fluvial types according to morphological features is justified by environmental and floristic differences, although plant species variability is only partially described. This results illustrate that the fluvial type classification created using this methodology is consistent with natural plant species distribution patterns, and can thus consider as a potential surrogate for riparian plant assemblages in a Mediterranean river with low human impact.

Incorporating many landscape classifications in biodiversity surrogate schemes should increase concordance with biotic groups. Following this idea, in the last part is examined the strength of a morphology-based and a land-use based classification in accounting for riparian plant species and functional groups distribution in the four rivers, by applying a measure of classification strength. Moreover, is tested the hypothesis that a cross classification between morphology and land use would be more successful at explaining plant species variation than either of the separate approaches. Despite none of the classifications accounted for a large degree of variation in riparian plant assemblages, some of them performed better than others, suggesting that some factors at landscape scale could contribute to predict differences in biological characteristics at local scales, and that classifications created putting together many environmental variables would result in better performaces.

These findings will be useful for better understand distributional trends of riparian flora and above all for prioritizing conservation actions in these areas, considering the threats to which rivers have currently subjected to.

RIASSUNTO

Il presente lavoro di ricerca analizza la flora vascolare ripariale di 4 fiumi mediterranei di 2 regioni diverse (Sardegna e Toscana), al fine di approfondirne le conoscenze riguardo le differenze floristiche, i trend di distribuzione di gruppi funzionali ed ecologici, di specie endemiche e aliene; infine, vengono applicate diverse classificazioni di paesaggio e ne viene testato l'utilizzo come potenziali surrogati per la pianificazione della conservazione. L'obiettivo principale è valutare similarità e differenze tra questi fiumi nell'ottica di un approccio di analisi a scala regionale, per contribuire al miglioramento della conoscenza sulle loro dinamiche interne e i loro legami con i principali fattori ambientali, fornendo utili informazioni per la gestione della conservazione di questi habitat fortemente minacciati.

La prima parte del lavoro è incentrata sullo studio dei pattern di distribuzione delle specie ed è volta ad esaminare differenze floristiche a scala regionale (tra regioni) e a scala locale (differenze tra fiumi della stessa regione), per chiarificare quali siano i principali gradienti della flora ripariale e quanto e come la biogeografia influenzi la distribuzione di specie vegetali lungo questi fiumi. Nonostante le molte similarità floristiche tra le due aree, in tutte le analisi condotte è sempre emersa un'elevata eterogeneità floristica. Inoltre, l'appartenenza a differenti regioni si configura come la principale variabile che influenza la flora di questi fiumi, confermando il ruolo prominente della geografia nel guidare la distribuzione delle specie vegetali a scala regionale. A scala locale, è invece il gradiente longitudinale che risulta avere il maggior peso in tutti i fiumi indagati. Il gradiente laterale risulta avere un effetto rilevante solo in Toscana.

Sulla base dei precedenti risultati, nella seconda parte del lavoro vengono analizzati in maniera più approfondita il contingente di specie endemiche ed esotiche dei fumi sardi. Il metodo qui utilizzato permette di stabilire in maniera rapida priorità di conservazione comparando modelli di distribuzione di queste specie lungo il corridoio fluviale. I trend di distribuzione di queste specie risultano seguire in generale il gradiente di decrescente naturalità/ crescente impatto antropico verso il mare, ma lo studio evidenzia la presenza di differenti gradi di naturalità tra i due fiumi in generale, nonostante la presenza di aree protette in entrambi. Le aree più critiche sono state individuate nel medio corso dei fiumi, dove le endemiche coesistono con le aliene e soprattutto con un elevato impatto antropico nelle aree circostanti, e dove dovrebbero essere concentrati i futuri piani di conservazione.

Nella terza parte viene testata la variazione della flora ripariale in funzione delle caratteristiche litologiche del fiume. Le analisi hanno riguardato il Rio Santa Lucia (Sardegna), dove la morfologia è influenzata una netta transizione tra roccia affiorante e piana alluvionale. I risultati sottolineano come i tipi litologici siano i principali responsabili dell'organizzazione floristica delle comunità ripariali, seguiti da geomorfologia e altitudine. Inoltre in corrispondenza della transizione tra i due tipi litologici è stato riscontrato il più alto turnover di specie, in funzione anche del differente grado di disturbo antropico tra le due parti. I risultati sottolineano come che l'influenza della transizione roccia affiorante/depositi

alluviali sia una parte integrante della struttura di un’area e influenzi fortemente la distribuzione di specie ripariali in ambiente mediterraneo.

Partendo dai precedenti risultati, e andando verso la definizione di una classificazione morfologica dei fiumi, nella quarta parte del lavoro viene proposta (e applicata in uno dei fiumi come test preliminare) un metodo per stabilire la distribuzione di gruppi di specie ripariali lungo i fiumi delimitando tipi fluviali omogenei dal punto di vista delle caratteristiche morfologiche, quantificate con foto aeree e software di analisi GIS. Questo metodo ha permesso di identificare 4 tipi fluviali, tutti caratterizzati da ben definite specie indicatrici, gruppi funzionali ed ecologici. Sulla base dei risultati degli ordinamenti, la divisione in tipi fluviali secondo parametri morfologici riflette reali differenze ambientali e floristiche, anche se le variabilità specifica è solo parzialmente descritta. Questo lavoro dimostra che la classificazione creata secondo questa metodologia è consistente con reali pattern di distribuzione di specie ripariali e può essere considerata un potenziale surrogato per la distribuzione della vegetazione ripariale nei fiumi mediterranei a basso impatto antropico.

Unire più classificazioni del paesaggio negli schemi di classificazione da usare come surrogati di biodiversità dovrebbe incrementare la concordanza con questi e i gruppi biotici. Seguendo questa idea, nell’ultima parte del lavoro viene esaminata la forza di una classificazione morfologica e di una classificazione basata sull’uso del suolo nel determinare la distribuzione di gruppi funzionali e specie ripariali nei 4 fiumi oggetto di studio. Viene inoltre testata l’ipotesi che una classificazione incrociata tra morfologia e uso del suolo possa essere più idonea per spiegare la variazione floristica piuttosto che i due approcci separati. Nonostante nessuna delle classificazioni applicate abbia dimostrato di spiegare un’ampia frazione di variazione nella distribuzione della flora ripariale, alcune di queste hanno dimostrato di funzionare meglio di altre, suggerendo così che fattori misurabili a scala di paesaggio possono contribuire a predire differenze nelle caratteristiche delle comunità biologiche a scala locale. Inoltre, le classificazioni create unendo più fattori ambientali hanno avuto, come da previsione, le migliori *performances*.

I risultati ottenuti da questa ricerca potranno fornire utili informazioni per migliorare la comprensione dei trend di distribuzione della flora ripariale nei fiumi indagati e soprattutto per stabilire priorità di conservazione, considerando le minacce alle quali i fiumi sono attualmente soggetti.

INTRODUCTION

> “*The riparian landscape is unique among environments because it is a terrestrial habitat strongly affecting and affected by aquatic environments; it has a particular spatial configuration; it has use values derived from these features; and, like mountain or desert habitats, is diverse in its structure and function among regions while responding to the same primary factors*.”
>
> G.P.Malanson (1993)

Riparian zones are the interface between aquatic and terrestrial ecosystems. They are affected by fluvial processes such as flooding and deposition of alluvial soil, and typically support a distinctive flora that differs in structure and function from adjacent terrestrial vegetation (Gregory et al., 1991; Naiman et al., 1993; 2005; Tang and Montgomery, 1995; Prach et al., 1996; Naiman and Décamps, 1997). Riparian vegetation influences various important ecological functions in relation to aquatic habitats, including the provision of food, moderation of stream water temperature via evapotranspiration and shading, providing a buffer zone that filters sediments and controls nutrients, and stabilization of stream banks (Barling and Moore, 1994; Hood and Naiman, 2000). It also provides a corridor for the movement of biota (Naiman and Décamps, 1997) and serves many important roles for humans (Kemper, 2001). Ewel et al. (2001) coined the term ‘critical transition zones’ for ecosystems such as riparian zones that serve as conduits for substantial fluxes of materials and energy from one adjacent, clearly defined ecosystem to another. Such ecosystems, usually forming small parts of the landscape, are often the focus of intensive human activity, and present numerous challenges for managers.

Defining and delineating riparian zones

Riparius is a Latin word meaning "of or belonging to the bank of a river". The term riparian refers to biotic communities living on the shores of streams, rivers, ponds, lakes, and some wetlands (Naiman and Décamps, 1997). Due to their interaction with the aquatic system, riparian areas have peculiar ecological features; thus, their boundaries can be delineated by changes in soil conditions, vegetation, and other factors that reflect this aquatic-terrestrial interaction (Naiman and Décamps, 1997).

The spatial extent of the riparian zone may be difficult to delineate precisely because its physical heterogeneity is expressed in an array of plant life history strategies and successional patterns, while the functional attributes depend not only on community composition but also on the environmental setting.

The wider used definition of riparian zone is the area that encompasses the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water (Naiman et al., 1993; Naiman and Décamps, 1997). The width of the riparian zone, the level of control that the streambed vegetation has on the stream environment, and the diversity of functional attributes are related to the size of the stream, the position of the stream within the drainage network, the hydrologic regime, and the local geomorphology (Salo and Cundy, 1987; Naiman and Décamps, 1990; Décamps, 1996; Rot et al., 2000).

The term "riparian vegetation" refers to floodplain vegetation or vegetation directly adjacent to rivers and streams (Naiman and Décamps, 1997). Vegetation outside the zone that is not directly influenced by hydrologic conditions may be considered part of riparian zones, since contribute to the river dynamics by providing organic matter (e.g. leaves, wood, dissolved materials) to the floodplain or channel, or influencing the physical regime of the floodplain or channel by shading (Gregory et al., 1991; Brosofske et al., 1997).

Physical and ecological functions of riparian zones

Plants influence many properties of riparian ecosystems (Tabacchi et al., 2000). Through the process of evapotranspiration, riparian plants affect stream flow rates, ground water levels, and local climates. Riparian forests reduce solar heating of stream water by shading, especially in low order streams (Brown and Krygier, 1970), thus controlling microclimate. Rates of evapotranspiration and of groundwater use vary widely between plant species depending on factors such as rooting depth, leaf area, and ability to regulate stomatal conductance (Scott et al., 2000; Dahm et al., 2002).

With respect to stream geomorphology, plants influence rates of sedimentation (depending in part on the amount of biomass present in low strata) and resistance of soils to erosion during flood events (depending in part on root density). Increased friction with the soil surface can cause reduced velocity and consequent sedimentation of particulates (Tabacchi et al., 1998). This process modifies sediment transport either by physically entrapping materials, which appears to be most important in relatively low gradient environments, or by altering channel hydraulics. Alteration of channel hydraulics is accomplished either by roots or by large woody debris in the channel. All provide physical structure that slows water, decreases stream power, and holds materials in place. Plants also influence the vertical patterns of moisture throughout the soil profile, with root architecture being one of the factors that influences zones of water uptake and patterns of 'hydraulic redistribution' of soil water (Burgess et al., 2001; Hultine et al., 2004).

Riparian zones, as networks distributed over large areas, are key landscape components in maintaining biological connections along extended and dynamic environmental gradients (Naiman et al., 1993). The riparian corridor can be viewed as a major vector propagating matter, energy and organisms longitudinally (Tabacchi et al., 1990; Saunders and Hobbs, 1991). Ecological investigations of riparian corridors have demonstrated them to be a crucial landscape feature with important regulatory controls on environmental vitality (Naiman et al., 1992).

Plants influence many properties of soils, such as salinity, organic matter, and C:N ratios, depending on their rate of litter production and on the chemical composition of the litter, and directly and indirectly mediate many nutrient cycling processes, as reducing levels of nitrogen and other minerals from stream or ground water (Schade et al., 2001). Organic matter from riparian vegetation become also a source of nourishment for aquatic organisms (Hynes, 1963).

One of the most important role played by riparian vegetation is the control and the movement reduction of nonpoint sources of pollution by sediment and nutrients in agricultural watersheds, particularly inorganic nitrogen and phosphorus (Lowrance et al., 1986), with a short-term accumulation of nutrients in nonwoody biomass and a long-term accumulation in woody biomass (Groffman et al., 1992). Further, due to nitrogen saturation, phosphorus may become the limiting factor for tree growth, particularly in wetlands (Taylor et al., 1990), making vegetation an effective phosphorus sink. The ability of riparian vegetation to control and recycle allochthonous inputs from the upland drainage basin and the river itself is a fundamental aspect of river ecology (Schlosser and Karr, 1981).

Riparian forests are one of the bioshpere’s most complex ecological systems but also one of the most important for maintaining the vitality of landscape and its rivers (Naiman and Décamps, 1990;1997). In fact, as interfaces between terrestrial and aquatic systems, they encompass sharp gradients in environmental and community processes (Naiman et al., 1993; Naiman and Décamps, 1997), and are an unusually diverse mosaic of landforms, communities and environments within the larger landscape. Moreover, their natural disturbances (such as floods) are responsible for structuring spatial heterogeneity (Ward et al., 2002), generating a complex shifting mosaic (Naiman et al., 1993), created and destroyed on different spatio-temporal scales (Malanson, 1993). Consequently, plant species richness varies considerably in space and time along stream margins. According to Naiman et al. (1993), the reasons for the high diversity of vascular plants are related to: (1) the intensity and frequency of floods, (2) the small scale variation in topography and soils as a result of lateral migration of river channel, (3) variation in climate following the altitudinal gradient, and (4) disturbance regime created by upland environment. Also the migration capacity of plants along the riparian corridor is an important factor explaining this high biodiversity. Moreover, the presence of a mosaic of habitats in a state of non-equilibrium allows the overlap of different niches (Ward et al., 2002) and thus the co-existence of a wide variety of species (Naiman et al., 1993).

Riparian zones exhibit high diversity of wildlife species because of habitat they provide for obligate riparian species, species seeking edge habitat, and species associated with early successional plant communities. They sustain high trophic levels and provide sources of food for granivores and herbivorous/detrital insects, birds, and mammals. Riparian zones covered with a variety of woody vegetation (from shrubs to trees) are extremely important as refuges for small mammals, offering nesting and perching sites for birds, acting also as corridors for migration and dispersal (Brinson et al., 1981).

Threaths

Nearly all major rivers in the Northern Hemisphere have been altered for navigation, agriculture, power generation, or flood control (Dynesius and Nilsson, 1994; Vitousek et al., 1997). Along European rivers, human-induced alterations include neolithic deforestation and land-clearing during Gallo-Roman and medieval periods (Pautou et al., 1992). Civil engineering works in the nineteenth century and hydroelectric developments in the twentieth century accelerated these alterations (Petts et al., 1989).

Conventional river engineering operations often produce major anthropogenic impacts on the fluvial ecosystem (Brookes, 1988). Channelization generally reduces the physical heterogeneity of riverbeds and banks, accelerates erosional processes, changes flow and sediment load patterns, and consequently, at ecosystem level, the river system experiences a reduction of habitat heterogeneity, niche potential, and frequently ecological diversity as well (Jongman, 1992; Petersen et al., 1992; Higler, 1993). As a consequence, plant cover and species richness were lower in the regulated river.

Regulation and fragmentation by dams belongs to the most widespread deliberate impacts of humans on the world's rivers, especially in the Northern Hemisphere (Jansson et al., 2000), and are the most obvious direct modifiers of river flow, capturing both low and high flows for flood control, electrical power generation, irrigation and municipal water needs, modifying daily and seasonal flows, blocking the movement of organisms, and preventing the downstream flow of mineral sediment and organic material (Ward and Stanford, 1983; Poff et al., 1997). Dams capture all but the finest sediment moving down a river, with severe downstream consequences for many aquatic species living in or using interstitial spaces among finest sediment. Also species with life stages sensitive to sedimentation, such as the eggs and larvae of many invertebrates and fish, can suffering high mortality rates. Dams have the potential to affect hydrochory in a number of ways, through modifying the hydrologic regime, influencing how far seeds travel and where they are deposited along channel margins (Merritt and Wohl, 2002) and the availability and suitability of streamside habitat for seed germination and seedling establishment. Moreover, they serve as a physical barrier to the downstream movement of plant propagules, trapping and storing seeds in reservoirs and resulting in retention and high rates of seed mortality.

For many rivers, land use activities, including timber harvest, livestock grazing, agriculture and urbanization are the primary causes of altered riparian areas. Human activities within fluvial corridors and surrounding landscapes have persistently stressed riparian ecosystems. Particulaly, river systems in mediterranean-climate regions often have relatively pristine upper catchments, but have been heavily transformed by anthropogenic activities in the lower reaches of the river (Meek et al., 2010). These are seasonally water-stressed environments, with the climatic harshness and the flashflow hydrological regime (Angiolini and Bacchetta, 2003; Ferreira and Aguiar, 2006), and at the same time are higly affected by human interferences in the flow regime, particularly water abstraction. Riparian corridors appear in fact to be one of the most threatened habitats in agricultural environments of

Mediterranean areas, as a result of the intense competition between humans and nature for limited supplies of fresh water (Corbacho et al., 2003).

Converting forest or prairie lands to agricultural lands generally decreases soil infiltration and result in increased overland flow, channel incision, floodplain isolation (Prestegaard, 1988). This reduces retention of water in watersheds and, instead, routes it quickly downstream, increasing the size and frequency of floods and reducing baseflow levels during dry periods. Similarly, urbanization creates impermeable surfaces that directs water away from subsurface pathways to overland flow. Consequently, floods increase in frequency and intensity (Beven, 1986), bank erode, and baseflow declines during dry periods.

River ecosystems are highly prone to invasion by alien plants, largely because of their dynamic hydrology and because rivers act as conduits for the efficient dispersal of propagule (Planty-Tabacchi et al., 1996; Johansson et al., 1996). The same factors supporting high plant species richness in riparian habitats may also increase susceptibility to invasion by exotic species (Pysek and Prach, 1994). Disturbance is thought to facilitate successful invasions by exotic species for some of the same reasons that it maintains native species diversity (di Castri, 1991; Hood and Naiman, 2000). Relations between invasion and disturbance are complex and depend on the type and frequency of disturbance, the environmental constraints and the biology of the particular species concerned (Lépart and Debussche, 1991).

Although common in nature, biological invasions have been accelerated through human activities (Lodge, 1993), leading to an increase of diversity and abundance of alien plants in riparian zones throughout the world (Richardson et al., 2007). For this reason, riparian areas are known to be highly vulnerable to invasion by exotic species, especially when subjected to human-induced disturbances (Hood and Naiman, 2000; Aguiar et al., 2001).

Considering the critical importance of riparian areas for their ecological functions, there is no doubt that the problem of conservation and adequate management of rivers is of worthwhile importance, and addressing it is urgent because their threats are growing daily, and their impacts are increasingly severe.

Landscape classification as potential surrogates for riparian conservation planning

Although riparian ecosystems have been heavily modified for centuries (Décamps et al., 1988; Washitani, 2001), generalized frameworks for their management are scarce. Giving the high rate of loss and conversion of floodplains worldwide, combined with usually inadequate information on their biological attributes (Hawkins and Norris, 2000), rapid assessments of plant species diversity and distribution along rivers become important (Stohlgren et al., 1997), and has resulted in a widespread reliance on environment-based approaches to classification in aquatic settings (Van Sickle and Hughes, 2000; Snelder and Biggs, 2002; Snelder et al., 2007).

Landscape classifications have recently been suggested as potential surrogates for river's conservation planning (Olivier et al., 2004). Classification is essential for scientific and managerial activities, such as developing inventories, interpreting data, extrapolating information from specific sites to larger or to other areas, setting strategic objectives or standards. By necessity, they are now commonly used for conservation planning, since provide a preliminary approach where resources are limited, even if the strength of these classifications is often weak (Hawkins et al., 2000; Van Sickle and Hughes, 2000; Olivier et al., 2004). They provide a necessary framework for research and development of management strategies and monitoring programs, and also a way to simplify complex information (Naiman et al., 2005).

Classifications partition naturally occurring variation among sites, describe biophysical attributes in a brief and effective form, and involve the selection of variables that are the most appropriate to the classification, and the application of methodology for grouping those variables in an understandable typology. Early approaches to this generally aimed to identify geographic or landscape units with relatively homogenous environmental conditions (e.g. Wiken and Ironside, 1977; Bailey, 1996). An ideal classification should include the controlling factors (e.g. geomorphology and climate) that influence the fitness of individuals, shape the characteristics of communities (e.g. species composition), and determine ecosystem function (e.g. nutrient cycling).

Geomorphological models are often used as first stage of classification for rivers (Richardson et al., 2007), and are among the most popular approaches (Naiman et al., 2005). In fact, perhaps more than any other ecosystem, rivers are intimately connected to and interact with their surrounding landforms (*sensu* Hynes, 1975). Bedrock geology and related geomorphic features (e.g. surface landforms such as erosional features and deposits) are among the major physical factors of river catchments that influence the development of riparian corridors (Tabacchi et al., 1998). In Mediterranean areas, Tabacchi et al. (1998) assumed that since every type of river system has its own geomorphological structure, the reciprocal control between hydrology and vegetation may be analyzed overall from a geomorphological template. Many studies have been addressing this topic, as reported in the important reviews of Steiger et al. (2005) and Corenblit et al. (2007), where landforms and physical processes resulted to drive the dynamics of biological communities.

Most classifications underscore the importance of the surrounding catchment in determining the structure and dynamics of streams (Frissell et al., 1986). Many human activities along a river and its valley, including agriculture, urbanization, surface mining, water abstraction, flow regulation and grazing are known to influence riparian vegetation (Malanson, 1993; Kondolf et al., 1996; Ferreira et al., 2005). As riparian zones are the focus of concentrated human activities, riparian vegetation is very often shaped by human-mediated disturbance (Holmes et al., 2005). Furthermore, linkages between landscape dynamics and fluvial ecological processes are especially interwoven (Gregory et al., 1991) and human interferences often disrupt these ecological bonds and interactions (Jungwirth et al., 2002). Many studies found that species composition along riparian zones is strongly affected by land use in the surrounding landscape (Meek et al., 2010). Morphological models of riparian areas adjusted following various land usage have been already developed in Italy (see Rinaldi, 2003; Surian and Rinaldi, 2003).

Many stream classification systems have been developed to assist in conceptualizing the various features of rivers (Rosgen, 1994). However, streams are notoriously heterogeneous both biologically and physically, especially over the large geographic areas. As a consequence, it can be especially difficult to develop classifications that work well for assessing impairment of stream ecosystems. As a result, there is no universally accepted riparian classification system, but there are several channel classification schemes that encompass riparian areas. Each of the many classifications in common use has advantages and disadvantages in geological, engineering and ecological applications, and no single classification can satisfy all possible purposes. Classification in fact merely provides one of many tools that can be applied to particular problems (Naiman et al., 2005). Nevertheless, the need for a river typology in natural resources management is widely accepted (European Commission, 2000), and several authors have made recommendations for general improvement of classification systems (e.g., Goodwin, 1999; Montgomery and Mc Donald, 2002), fundamental for designing new approaches for resource management.

Aims of the study

Starting form two different Mediterranean regions (Sardinia and Tuscany), this study investigates the riparian vegetation of four among the main rivercourses of the regions, owning the hydrological features of Mediterranean rivers, but belonging to two different geographical areas.

Particularly, this research is focused on:

- determining floristic patterns (taxonomic groups, life and chorological forms) along the four rivers investigated, both at regional and local scale, to find the main gradients, and to quantify the relative contributions of biogeography in significantly differentiating the flora of these riverbeds;

- deepening the distributional trends of endemic and exotic plant species along Sardinian rivers, were these species are an important part of the island's flora, thus deserving a stand-alone and more specific analysis;

- testing the effect of the dominant geology and in particular of the transition between bedrock-controlled and alluvial-controlled river segments on riparian flora;

- analyzing more deeply the role played by river morphology, in order to understand if exists and how strong is the relation between riparian plant species distribution and morphology, and thus if it could provide reliable classifications of streams;

- testing the concordance and strength of morphological and land use classifications in detecting real floristic differences in the four rivers, in order evaluate their efficiency, improvements and limitations, and finally to assess their utility as surrogate in conservation planning.

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CHAPTER 1:

DETERMINANTS OF REGIONAL AND LOCAL PATTERNS OF RIPARIAN FLORAS IN WESTERN MEDITERRANEAN RIVERS

ABSTRACT

We studied species distributional patterns of riparian flora in four Mediterranean rivers of two Italian regions and examined floristic differences between regions as well as between rivers belonging to the same region, in order to elucidate the main floristic gradients and to investigate the role played by biogeography in driving riparian plant species distribution. Differences in life forms, chorological groups and plant assemblages similarities were investigated. Floristic data were ordinated using DCA and partial DCA to find the main gradients driving plant distribution with or besides geographical position of rivers. Moreover, plant species data of the two regions were analyzed separately, with the aim of determining the local gradients. Variance partitioning was performed to quantify the relative contributions of variable subsets (biogeography, longitudinal and lateral gradient) at explaining floristic variation, and to test whether and how much the influence of biogeography could be disjointed from the effects of the other environment variables in determining the composition of riverbed plant assemblages. Despite many floristic similarities between the two areas, always emerged the high floristic heterogeneity and the regional differentiation as the main variable affecting the distribution of our riverbed floras, thus confirming the primary role of geography in driving riparian plant species distribution at regional scale in the study areas. After removing the “river effect”, the main gradient at regional level was found to be the structural transition from mountain woody to herbaceous lowland areas, following the longitudinal gradient of the river course and the parallel human disturbance increasing gradient. At local level, longitudinal and lateral gradients confirmed to be the most important for riparian vegetation. Despite the high value of unexplained variance, variance partitioning revealed longitudinal gradient to strongly affect riverbed flora patterns in these Mediterranean rivers, followed by biogeography, while lateral gradient, previously detected as an important floristic determinant at local scale in a region, had a weak effect at regional scale. Our study showed how biogeographical differences influenced riparian plant species variation, nourished also by the evidence of the scarce truly aquatic and hygrophilous (azonal) vegetation found in the study area.

Keywords: biogeography, chorological forms, gradient analysis, life forms, Italy, plant distribution

1.1 INTRODUCTION

Understanding mechanisms and processes that drive species diversity and distribution is a synthetic goal of ecology (Rosenzweig, 1995). Reaching this understanding is however not simple, because the processes that determine patterns of diversity are varied (Rey Benayas and Schneier, 2002). Particularly, disentangling the joint influence of environmental factors on vegetation (Ehrenfeld et al., 1997) and discerning gradients of regional importance when plant communities vary locally to a great extent (Huston, 1999; Hillebrand 2005) constitutes a major research need (Lalanne et al., 2010). Biogeographers and phytosociologists have long recognized the role of environmental and historical factors in regional- to continental-scale patterns of plant community composition, but current knowledge remains general and qualitative (Ohmann and Spies, 1998). Regional effects are often unmeasured, in spite of their widely appreciated potential importance in shaping biodiversity patterns at broad extents (Hortal et al., 2008), and factors associated with local patterns of community composition often are well known, but differ among localities (Ohmann and Spies, 1998). This is more true when studying riparian habitats, since they encompass diverse array of environmental gradients, landforms, habitats and communities within the larger landscape (Naiman et al., 1987; Nilsson et al., 1989; Tabacchi et al., 1990, Malanson 1993). All these features are specially present in Mediterranean-type environments (Corbacho et al., 2003).

Generally, riparian vegetation is considered azonal, seeming to be less sensitive to climate change than zonal communities, since the major limiting factors are non-climatic in character (Kienast et al., 1998; Gentili et al., 2010). But, even if it has a similar structure and composition in all European rivers (Pedrotti and Gafta, 1996; Ellenberg 1998), the riparian flora shows instead some important distinctive features in Mediterranean bioclimatic and biogeographic region (Alcaraz et al., 1997; Rivas Martínez, 2007). Despite owning this peculiarity, nowadays our knowledge is still mostly focused on the differences between Mediterranean and Eurosiberian/Continental regions, while the influence of biogeography on riparian floristic assemblages at different (higher) scales (Bulgarini et al., 2006; Blasi et al., 2011), remains still unknown. Most plant ecologists agree that, among the main determinants of community composition, environmental conditions are the most important factors at intermediate scales (i.e. local and regional scales; van der Valk, 1981; Keddy, 1992), whereas biotic interactions and chance biogeographical events are determinant at either the smallest (patch) scale or the largest (i.e. continental) scale (Zobel, 1992; Huston,1999; Mittelbach et al., 2001). On the other hand, lateral and longitudinal gradients are considered as the main driving of vegetation in riparian landscapes (Ferreira and Moreira, 1999; Lite et al., 2005; Sieben et al., 2009), and are considered composite gradients since they represent change in a number of important environmental variables (van Coller et al., 2000).

Elevation affect the riparian vegetation along the longitudinal gradient, directly influencing the erosive power of the flow in the upper and lower river reaches, and changes in habitat composition, adjacent land-use, and the resulting zonal vegetation (Campbell, 1983). Also climate, an expression of broad-scale temperature and moisture environment, and one of the primary associate of regional-scale patterns of community composition, varies along longitudinal dimension. Climatic factors, such as rainfall and temperature, are thought to influence communities directly (Gentili et al., 2010), through physiological effects on organisms and by limiting populations, and indirectly, by modifying or regulating the importance of local-scale factors and by favoring certain life forms and chorological groups. Several studies have demonstrated that lateral gradients can also have a great importance in structuring riparian vegetation (Angiolini et al., 1998; van Coller et al., 2000; Aguiar et al., 2001; Lite et al., 2005; Sieben et al., 2009). Height above and lateral distance away from the channel across the floodplain represent zones of different inundation frequency and flood disturbance, that typically diminish with increasing distance from (and above) the active channel, with paralleling increase in floodplain elevation that results from sediment aggradation and channel incision processes. Over the length of the river (longitudinal gradient), flood disturbance and water availability vary along this lateral (transversal) gradients (Lite et al., 2005).

In order to address the long-standing questions about factors controlling the distribution of species in riparian areas, in this study we aimed to identify and quantify floristic differences and gradients of riparian plant assemblages considering a broad region and large data set. To unravel these patterns, we investigated differences in composition and distribution of riverbed floras between and within two different regions/areas (Sardinia and Tuscany, Italy) owning paleogeographical and geographical differences (such as the insularity and continental conditions), but also comparable climatic, bioclimatic and biogeographic features, and examined main riparian gradient contributions in plant species variation at two spatial scales, namely regional- (rivers of different regions) and local-scale (rivers belonging to the same region). In fact, few studies have assessed the relative importance of environmental factors and biogeography and their interactions at different spatial scales, despite considered factors contributing to affect riparian plant community composition (Honnay et al., 2001).

Our specific objectives were: (1) to determine floristic patterns (taxonomic groups, life and chorological forms) in four Mediterranean rivers both at regional and local scale; (2) to find the main gradients affecting riparian flora at regional scale, and try to understand if they are the same operating at local scale; (3) to quantify the relative contributions of biogeography (considered at province level of classification) vs longitudinal and lateral gradients in significantly differentiating the flora of these Mediterranean riverbeds.

1.2 STUDY AREA

We selected four rivers from two different Mediterranean regions: S. Lucia and Leni in Sardinia, Albegna and Fiora in Tuscany (Fig.1). These are among the main rivercourses of the regions and own the hydrological features common also to many other Mediterranean rivers, with lower and wider parts that dry up almost totally during summer, while in autumn and spring they are affected by flood events (Angiolini and Bacchetta, 2003; Bacchetta, 2006; Landi and Angiolini, 2007; Angius and Bacchetta, 2009). The altitudinal ranges of the studied rivers were all about 600 meters a.s.l. The floodplain in the mountain part of all rivers is mainly made up of volcanic rocks and sandstones, while in the lower part of alluvial sands and clays. Agro-pastoral system is the prevalent land-use in the upper and most natural part, while in the valleys there are intensive agricultural landscapes, industries and human settlements. The principal features of the studied rivers are summarized in Tab 1.

Santa Lucia and Leni rivers are located in the south-western part of Sardinia. More than 2/3 of the Leni riverbed flow in Campidano valley, the most important graben of the whole island, while Santa Lucia river is almost equally distributed between the two geological substrates of siliceous rocks and sediments. In the mountain part the woodlands are dominated by holm oak (*Quercus ilex*) or cork oak (*Q. suber*). Riparian forests are made up of *Alnus glutinosa*, especially in the mountain part, while in the valley area *Salix* sp. pl., *Populus* sp. pl. and above all *Nerium oleander* subsp. *oleander* are dominant (Bacchetta et al., 2005; Angius and Bacchetta, 2009). In the middle part of the rivers there are fluvial terraces with garigues (dominated by *Helichrysum microphyllum* subsp. *tyrrhenicum* and *Teucrium marum*) and macchia type vegetation (Biondi et al., 1995; Angiolini and Bacchetta, 2003). The mountain parts of both rivers are located into protected areas, respectively Site of Community Importance "*Foresta di Monte Arcosu*" (ITB041105) for Santa Lucia river, and "*Monte Linas - Marganai*" (ITB041111) for Leni. Before directly flowing into the sea, Santa Lucia and Leni rivers flow into two wetlands, respectively Capoterra's pond and Santa Gilla lagoon, both included in the Site of Community Importance "*Stagno di Cagliari, Saline di Macchiareddu e Laguna di S. Gilla*" (ITB040023).

Albegna river is located in the south of Tuscany, while Fiora river is partly located in the southern Tuscany, partly in the northern Latium. Despite this last river flows across two regions, in order to make the results and discussions easier to understand, from here on we will refer to both these rivers as "Tuscan rivers". The slopes of the mountain parts are mostly covered by woods of *Carpinus betulus* and by deciduous forests of *Quercus cerris*, while the alluvial lower part is dominated by grassland and sheep-grazing, with a marginal part dedicated to cereal crops. The riparian forests of mountain areas are made up of *Alnus glutinosa*, while in the valley *Salix alba* and *Populus nigra* are dominant (Scoppola and Angiolini, 1997). The fluvial terraces located in the middle part of the rivers are covered by shrublands and chamaephytic vegetation (garigues dominated by *Santolina etrusca* and *Helichrysum italicum* subsp. *italicum*) and by the macchia type vegetation (Angiolini et al., 2008). The Tuscan part of Fiora river and the mountain part of Albegna river are located into protected areas (respectively Site of Community Importance "*Alto corso del Fiume Fiora*", IT5190019, and "*Monte Labbro e alta valle dell'Albegna*", IT5190018).

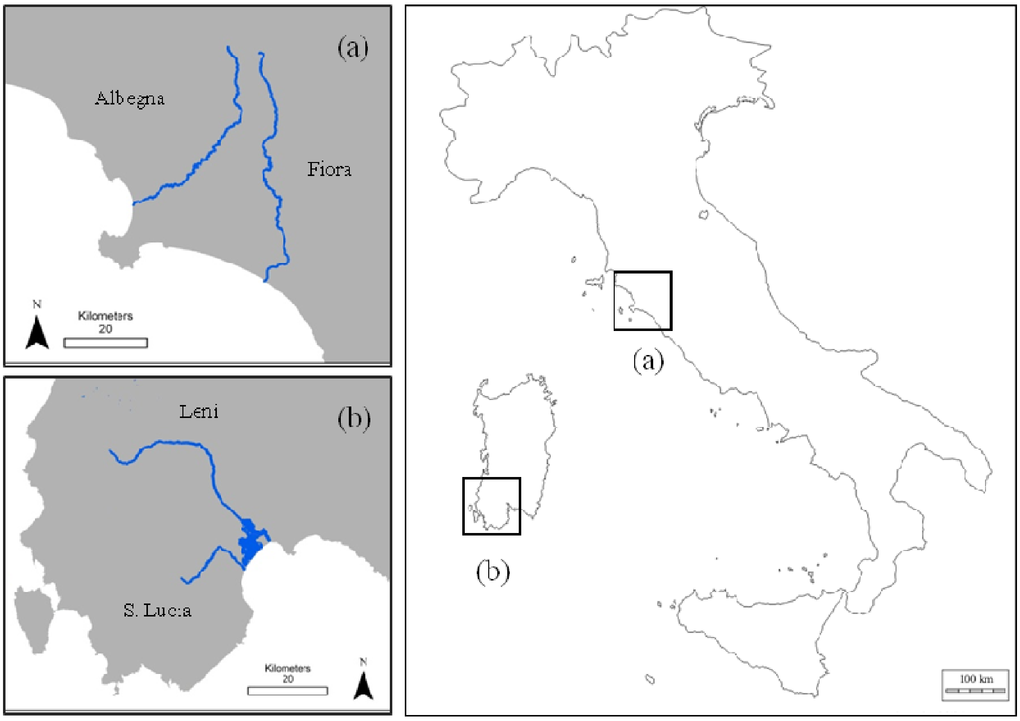


Fig. 1 Study areas and location of the rivers in Tuscany (a) and Sardinia (b).

Tab. 1 Main features of the four rivers. The number of plot (n) for each river is indicated in brackets.

Features	**Sardinia**		**Tuscany**	
	S. Lucia (n=25)	**Leni (n=48)**	**Albegna (n=48)**	**Fiora (n=68)**
Physical characteristics				
Basin (km^2)	110	130	750	820
Lenght (km)	25	50	50	70
Climatic features				
Bioclimate	Mediterranean Pluviseasonal Oceanic	Mediterranean Pluviseasonal Oceanic	Mediterranean Pluviseasonal Oceanic /Temperate Oceanic-Semicontinental	Mediterranean Pluviseasonal Oceanic /Temperate Oceanic-Semicontinental
Ombrotypes	Dry/Subhumid	Dry/Subhumid	Subhumid/Humid	Subhumid/Humid
Termotypes	Thermomediterranean /Mesomediterranean	Thermomediterranean /Mesomediterranean	Mesomediterranean/ Mesotemperate	Mesomediterranean/ Mesotemperate/ Supratemperate
Biogeographic characterization				
Region	Mediterranean	Mediterranean	Mediterranean	Mediterranean
Subregion	West Mediterranean	West Mediterranean	West Mediterranean	West Mediterranean
Superprovince	Italo-Thyrrenean	Italo-Thyrrenean	Italo-Thyrrenean	Italo-Thyrrenean
Province	Sardo-Corsican	Sardo-Corsican	Thyrrenean	Thyrrenean

1.3 MATERIALS AND METHODS

1.3.1 Sampling design and floristic data

In order to avoid the possibility to have grouped plots and with the aim to represent variations in species assemblages and environmental features, we used a stratified random sampling design, dividing the river, perpendicularly to direction flow (and excluding the area occupied by dams and lagoons), into sections of 2 km of lenght. In each section we randomly placed 2 plots of 10×10m, for a total of 189 plot sampled (see Tab. 1). Plots dimension was found to be adequate to detect the vegetational mosaic of the floodplain, because it made possible to explain the relationships between species richness and environmental features both in forests (Schuster and Diekmann, 2005) and in grasslands (Gross et al., 2000). Since one of the goal of this study was the analysis of riparian plant species, sampling was carried out considering only floodplain. To identify the floodplain, we used geological and land cover layers with GIS software (ArcMap 9.3, ESRI), first selecting the area with alluvial lithology, then removing the cultivated lands near the river.

For each plot we recorded from April until July 2007-2009 all vascular plants species (as presence/absence data), as suggested by Tamàs et al. (2001), since the presence/absence scale is proved to be particularly suitable for the floristic approach in which interest is focused on species list for landscape units or sample plot.

Plant families nomenclature followed the APGIII proposal (Chase and Reveal, 2009) and Peruzzi (2010), while taxonomic nomenclature Conti et al. (2005; 2007) and secondarily Greuter et al. (1984 - 2008).

1.3.2 Species and plot attributes

Studied variables can be classified into two groups: the group of species-related variables (life forms and chorological groups) and the group of environmental variables (altitude, temperature and rainfall used together as climate, distance from and height above the channel). For life forms we followed those proposed by Raunkiaer (1934) and Pignatti (1982), cosidering: chamaephytes (Ch), geophytes (G), hemicryptophytes (H), hydrophytes (Hy), nanophanerophytes (NP), phanerophytes (P) and therophytes (T).

In addition to the consulted floras, chorological forms referred to the classification proposed by Brullo et al. (1996). For chorological classification of the endemics, the nomenclature proposed by Arrigoni and Di Tommaso (1991) and modified by Bacchetta and Pontecorvo (2005) was followed. The phytogeographical elements analyzed were: Circum-Mediterranean (CIRC), Euro-Mediterranean (EUROM), Eurasiatic (EURAS), Boreal and Circumboreal (BOR), Atlantic (ATL), Wide distribution (WID), Endemic (END), Alien (ALI).

The plot attributes used in this study were altitude (m a.s.l.), mean annual temperatures (°C), mean annual rainfall (mm), distance from and height above running water (m). Altitude was derived for each plot using the Digital Elevation Model (DEM 75 m x 75 m). Climatic data of meteorological stations closest to the sampling sites were obtained from regional databases, respectively ARSIA (Servizio Agrometeorologico della Regione Toscana) for Tuscany, and ARPAS (Agenzia Regionale Protezione Ambiente Sardegna, Dipartimento Idrometeoclimatico) for Sardinia. Distance from and height above running water were measured in the field.

1.3.3 Biogeographic characterization

According to Takhtajan (1986) and Arrigoni (1980), all the studied areas belong to the Mediterranean Region (Tab. 1), nevertheless Rivas-Martínez et al. (2001) placed Sardinia and the Tyrrhenian coasts into the Mediterranean region, while the mountain part of Tuscany into Eurosiberian region. Even if in the biogeographic classification of the Mediterranean region proposed by Rivas-Martínez et al. (2002) the Italo-Tyrrhenian province is composed by Sardinian subprovince, Corsican subprovince and Tuscano-Calabrian subprovince, we preferred to use the division proposed by Ladero Alvarez et al. (1987) on the basis of many similarities (not only in the floristic aspects), identifying an Italo-Tyrrhenian superprovince extended to all over the western coast of the Italian Peninsula, from Tuscany up to Calabria, in turn subdivided into a Tyrrhenean province (where both the Tuscan rivers are located) and a Sardo-Corsican province (where the Sardinian rivers are located) (see Tab. 1).

1.3.4 Statistical analyses

At both regional and local scale, we applied: i) Sørensen’s index (Sørensen, 1948) in order to evaluate the similarities of floristic composition; ii) *t-tests* to assess the significant differences in percentage of life forms and chorological groups. Pearson’s correlations coefficient was used to explore the correlation among percentage of life and chorological forms between rivers belonging to the same region. Variables strongly correlated ($r > 0.85$) were excluded in order to eliminate problems of multi-collinearity (Kline, 2005). Floristic data were analyzed by the mean of a series of Detrended Correspondence Analysis (DCA), with subsequent introduction of environmental features (altitude, temperature, rainfall, distance from and heigth above running water), life forms and chorological groups as passive variables, to allow direct comparison of the ordination axes with these variables. Rare species were downweighted and the scaling was set to focus on inter-species distances and Hill’s scaling (ter Braak and Šmilauer, 2002). First, data of all sites were ordinated to calculate the length of the main gradient (SD) and to describe the general patterns in species distribution along the gradients (Lepš and Šmilauer, 2003). Secondly, partial ordination with rivers designated as covariables was performed to find the main gradients driving plant distribution besides differences in geographical location, regardless of any differences among rivers. Thirdly, floristic data were analyzed separately for the two regions, in order to determine local floristic gradients. Spearman rank correlation test was performed to examine relationships between DCAs axis 1 and 2 sample scores of regional and local ordinations and environmental variables, respectively.

We performed variance partitioning (ter Braak, 1988; Borcard et al., 1992; Økland and Eilertsen, 1994) to quantify the relative contributions of biogeography (at province level), longitudinal (temperature, rainfall and altitude variables) and lateral (distance from and height above the channel) gradients to explained variation, and to test whether and how much their effects in determining the composition of riverbed plant assemblages can be separated. Because the length of the main DCA gradient was 4.008 SD, we assumed that the use of a unimodal method would be appropriate (Lepš and Šmilauer, 2003). Partial CCAs with the procedure described by Anderson and Gribble (1998) were performed.

To ensure normality, species and plot attributes data were log transformed prior to statistical analyses. STATISTICA 6.0 (StatSoft Inc., 1995) was used for univariate analyses, while Canoco 4.5 (ter Braak and Šmilauer, 2002) for ordination analyses.

1.4 RESULTS

1.4.1 Floristic patterns at different levels

The flora encountered in Tuscan rivers was f 493 *taxa* while of 428 in Sardinian rivers, for a total flora of the whole study area of 745 *taxa*. Among these, 252 *taxa* (33.8% of the total flora) were exclusive of Sardinia, 317 (more than 42.6%) of Tuscany and 176 (23.6%) were in common. Apart from 2 families belonging to *Gymnospermae* (1 in Sardinia and 2 in Tuscany) and 7 families of *Pteridophytes* (7 in Sardinia, 3 in Tuscany), all the remaining 86 were *Angiospermae*. The first eight families reported in Tab. 2 comprised more than 50% of the total plant species. *Poaceae* and *Asteraceae* were the families more represented in the total flora, followed by *Fabaceae*. The main differences between the two regions concerned *Lamiaceae, Fabaceae* and *Rosaceae*, more frequent in Tuscany, and *Rubiaceae* and *Apiaceae*, more represented in Sardinia, together with *Cyperaceae* and *Juncaceae*.

Tab. 2 Number of species (in percentage) of the 20 families more represented on the total of species sampled, wiht their difference between the regions.

Families	Sardinia	Tuscany	Difference
Poaceae	9.36	9.82	0.46
Asteraceae	8.37	8.98	0.60
Fabaceae	5.75	7.15	1.41
Lamiaceae	2.30	5.47	3.17
Apiaceae	3.28	2.10	1.18
Caryophyllaceae	2.13	1.82	0.31
Plantaginaceae	2.13	1.68	0.45
Ranunculaceae	1.81	1.82	0.02
Rubiaceae	2.46	0.98	1.48
Rosaceae	0.82	2.24	1.42
Polygonaceae	1.31	1.54	0.23
Brassicaceae	1.48	1.26	0.22
Euphorbiaceae	1.48	1.26	0.22
Cyperaceae	1.64	0.98	0.66
Juncaceae	1.64	0.84	0.80
Amaranthaceae	1.15	0.98	0.17
Boraginaceae	0.99	0.84	0.14
Salicaceae	0.99	0.84	0.14
Caprifoliaceae	0.66	0.98	0.32
Geraniaceae	1.15	0.42	0.73

The most common species in all rivers was *Avena fatua* (percentage of occurrence of 89%) followed by *Rubus* gr. *ulmifolius* (88.8%), while in Tuscany *Clematis vitalba* and *Dactylis glomerata* and in Sardinia *Avena fatua, Sonchus oleraceus, Galactites tomentosa* and *Rubus* gr. *ulmifolius* (Tab. 3). Among the first 15 most frequent species in all rivers, there were above all herbaceous species typical of habitats frequently disturbed, such as *Anagallis arvensis, Foeniculum vulgare, Dittrichia viscosa* and *Lolium rigidum.* We found for Tuscany two main groups of plants: nemoral species (such as *Brachypodium sylvaticum* and *Hedera* *helix*) and species typical of open riverbeds (i.e. *Clematis vitalba* and *Dactylis glomerata* ssp. *glomerata*), while in Sardinia most of the species were sinantropic and typical of less developed substrates (i.e. *Avena fatua, Foeniculum vulgare, Dittrichia viscosa*). Among woody species, in Tuscany resulted to be more frequent species such as *Populus nigra, Acer campestre, Fraxinus ornus, Crataegus monogyna, Cornus sanguinea, Quercus cerris, Ulmus minor,* while in Sardinia *Nerium oleander* ssp. *oleander, Quercus ilex* ssp. *ilex, Phillyrea latifolia.*

Tab. 3 List of species with frequency of occurrence >20% on the total flora. Their frequency of occurrence (%) on the total number of plots in the two regions was reported.

Species	**Sardinia %**	**Tuscany %**
Avena fatua	49.3	39.7
Rubus gr. *ulmifolius*	46.6	42.2
Anagallis arvensis	30.1	43.1
Phragmites australis	41.1	31.9
Foeniculum vulgare	32.9	31.9
Brachypodium sylvaticum	19.2	38.8
Clematis vitalba	5.5	50.9
Rubia peregrina s.l.	21.9	33.6
Dittrichia viscosa	31.5	22.4
Hedera helix ssp. *helix*	11	39.7
Dactylis glomerata ssp. *glomerata*	0	50
Sonchus oleraceus	46.6	2.6
Lolium rigidum	27.4	20.7
Galactites tomentosa	46.6	0.9
Asparagus acutifolius	27.4	16.4
Calystegia sepium	21.9	21.6
Tamus communis	19.2	24.1
Salix purpurea	23.3	19
Anthemis arvensis	24.7	14.7
Populus nigra	2.7	36.2
Trifolium campestre	23.3	13.8
Oxalis pes-caprae	37	0
Rumex crispus	34.2	1.7
Daucus carota	26	9.5
Salix alba	13.7	19.8
Bromus sterilis	4.1	29.3
Chrysantemum coronarium	32.9	0
Sinapis alba	13.7	19
Cynosurus echinatus	24.7	7.8
Piptatherummiliaceum s.l.	26	6
Geranium purpureum	30.1	0
Nerium oleander ssp. *oleander*	30.1	0
Arundo donax	28.8	0.9
Acer campestre	0	29.3
Artemisia vulgaris	0	29.3
Papaver rhoeas	13.7	15.5
Quercus ilex ssp. *ilex*	19.2	9.5
Silene alba	11	17.2
(continued)	**Sardinia %**	**Tuscany %**
Bromus hordeaceus	23.3	4.3
Fraxinus ornus	0	27.6
Rumex bucephalophorus	27.4	0
Osyris alba	5.5	21.6
Sherardia arvensis	20.5	6
Briza maxima	24.7	1.7
Crataegus monogyna	0	25.9
Xanthium italicum	0	25.9
Coleostephus myconis	16.4	8.6
Rubus canescens	0	25
Phillyrea latifolia	20.5	4.3
Allium subhirsutum	24.7	0
Arum italicum ssp. *italicum*	24.7	0
Stellaria media ssp. *media*	21.9	2.6
Plantago lanceolata	9.6	14.7
Alnus glutinosa	16.4	7.8
Lagurus ovatus	23.3	0.9
Allium triquetrum	23.3	0
Nasturtium officinale	23.3	0
Saponaria officinalis	0	23.3
Smilax aspera	20.5	2.6
Parietaria officinalis	15.1	7.8
Urospermum dalechampii	9.6	12.9
Santolina etrusca	0	22.4
Urtica dioica	6.8	15.5
Catapodium rigidum	13.7	8.6
Hypochaeris achyrophorus	21.9	0
Oenanthe crocata	21.9	0
Silene gallica	21.9	0
Cornus sanguinea	0	21.6
Mentha aquatica	13.7	7.8
Carduus pycnocephalus	20.5	0.9
Trifolium angustifolium	12.3	8.6
Quercus cerris	0	20.7
Ulmus minor	0	20.7
Cyperus badius	20.5	0
Mentha insularis	20.5	0
Smirnium olusatrum	20.5	0
Juncus acutus	19.2	0.9

According to the previous results, the similarity between the two regions resulted to be low (Sørensen index value= 0.37), underlying high floristic heterogeneity. On the contrary, inside the same region, the value of the index raised (Tuscan rivers=0.62; Sardinian rivers=0.78).

The two main life forms of both the regions resulted to be hemicryptophytes and therophytes (Tab. 4). However, Tuscan rivers had higher percentages of hemicryptophytes, while conversely for Sardinian rivers the most important group was therophytes. *T-test* at regional level revealed highly significant differences in the percentage of geophytes, phanerophytes, nanophanerophytes, therophytes and hydrophytes. All chorological group percentages were highly significantly different at regional level, except for Wide distribution species (Tab. 4). Sardinian riverbeds were dominated by Wide distribution and Circum-Mediterranean species. Wide distribution instead resulted to be the most important chorological group of Tuscany, followed by Euro-Mediterranean, Eurasiatic and Boreal, showing higher values in Tuscany, while Atlantic, Endemic and Alien reached instead the higher values in Sardinia.

Tab. 4 Mean percentage (± SD) of life and chorological forms in the riverbeds of the two regions. *P-values* stand for significant differences (*t-test*) at regional level (df=187, n.s. = not significant).

Attributes		**Sardinia**	**Tuscany**	***p-values***
Life forms				
	Phanerophytes	11.3 ± 11.1	22.3 ± 16.2	**<0.001**
	Therophytes	36.4 ± 15.5	26.9 ± 15.8	**<0.001**
	Chamaephytes	3 ± 3.8	3.8 ±5.2	n.s.
	Geophytes	14.8 ± 8.5	8.1 ± 6.2	**<0.001**
	Hemichryptophytes	30.2 ± 11.5	33.1 ± 12.7	n.s.
	Hydrophytes	0.2 ± 0.9	0.0 ± 0.3	**<0.05**
	Nanophanerophytes	4.1 ± 4.8	5.7 ± 4.5	**<0.001**
Chorological forms				
	Alien	3.7 ± 3.7	1.6 ± 2.5	**<0.001**
	Atlantic	4.4 ± 3.8	2.3 ± 2.6	**<0.001**
	Boreal and Circumboreal	2.2 ± 3.6	6.5 ± 5.3	**<0.001**
	Circum-Mediterranean	29.6 ± 11.6	11.8 ± 6.9	**<0.001**
	Wide distribution	30 ± 11	27.8 ± 9.6	n.s.
	Endemic	3.9 ± 4.4	1.2 ± 2	**<0.001**
	Eurasiatic	6.5 ± 4.6	23.9 ± 10.2	**<0.001**
	Euro-Mediterranean	19.7 ± 7.6	24.9 ± 9.7	**<0.002**

Looking at the local differences, *t-test* (Tab. 5) revealed a quite homogeneous life form distribution, even if all rivers belonging to the same region significantly differed about percentage of phanerophytes and nanophanerophytes, but in addition in Sardinia also about the percentage of hemichryptophytes. Chorological forms between Tuscan rivers resulted to be strongly different, particularly about Atlantic, Boreal, Eurasiatic, Circum-Mediterranean and Euro-Mediterranean, while Sardinian rivers resulted instead to be quite similar, being marginally different only about Wide distribution.

Tab. 5 Mean percentage (± SD) of biological and chorological forms in the four rivers. *P* values stands for significant differences at local level tested with *t-test* (df=71 for Sardinia, 114 for Tuscany; n.s. = not significant).

Attributes	**Sardinia**			**Tuscany**		
	Santa Lucia	Leni	***p-value***	Fiora	Albegna	***p-value***
Life forms						
Chamaephytes	3.9 ± 4.7	2.4 ± 3.2	n.s.	3.1 ± 4.4	5 ± 5.9	n.s.
Geophytes	12.3 ± 5.7	16.1 ± 9.5	n.s.	7.3 ± 5.4	9.3 ± 7.1	n.s.
Hemichryptophytes	24.5 ± 10.3	33.2 ± 11.1	**<0.002**	32.3 ± 10.7	34.4 ± 15.2	n.s.
Hydrophytes	0.3 ±0.9	0.2 ± 0.8	n.s.	0.0 ± 0.4	0	n.s.
Nanophanerophytes	6.4 ± 4.9	3.0 ± 4.4	**<0.01**	6.5 ± 4.6	4.5 ± 4	**<0.01**
Phanerophytes	17.6 ± 12.2	8.0 ± 9.1	**<0.002**	24.5 ± 15	19.2 ± 17.4	**<0.01**
Therophytes	35.0 ± 15.6	37.2 ± 15.9	n.s.	26.4 ± 16.3	27.8 ± 15.1	n.s.
Chorological forms						
Alien	2.8 ± 3.7	4.1 ± 3.7	n.s.	1.9 ± 2.7	1.2 ± 2.3	n.s.
Atlantic	4.1 ± 2.7	4.6 ± 4.2	n.s.	2.6 ± 2.5	1.8 ± 2.8	**<0.5**
Boreal and Circumboreal	1.9 ± 2.4	2.3 ± 4.1	n.s.	7.5 ± 5.4	5.1 ± 4.7	**<0.5**
Circum-Mediterranean	33.4 ± 13.5	27.7 ± 10.1	n.s.	9.6 ± 6.2	14.9 ± 6.9	**<0.001**
Wide distribution	26.0 ± 9.2	32.1 ± 11.5	**<0.05**	27.9 ± 9.9	27.6 ± 9.3	n.s.
Endemic	4.3 ± 4.1	3.7 ± 4.5	n.s.	1.1 ± 1.8	1.3 ± 2.3	n.s.
Eurasiatic	6.1 ± 2.9	6.8 ± 5.3	n.s.	26.2 ± 8.8	20.8 ± 11.3	**<0.001**
Euro-Mediterranean	21.4 ± 6.7	18.8± 7.9	n.s.	23.3 ± 10	27.3 ± 8.7	**<0.5**

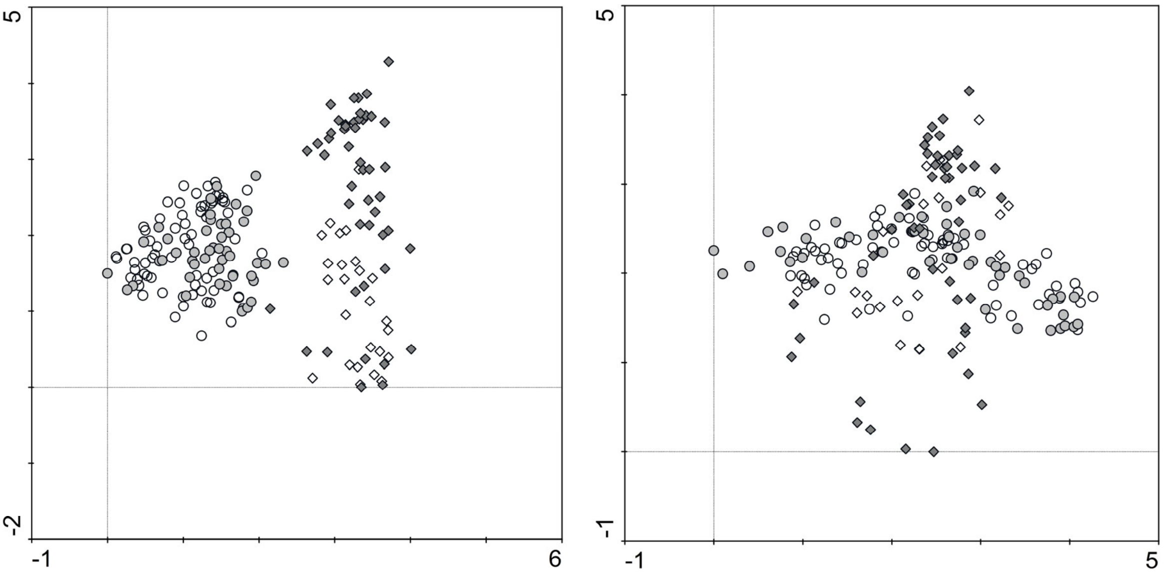
Two separate Pearson's correlation matrices for Sardinian and Tuscan plots were performed. Looking at the higher significant correlation values (|0.40|< r <|0.53|) among chorological groups and life forms (Tab. 6), we can observe that phanerophytes and nanophanerophytes were positively correlated with Endemic and negatively with Wide distribution in Sardinia, while positively with Eurasiatic and Atlantic (only phanerophytes) in Tuscany. Therophytes resulted to be positively correlated with Circum-Mediterranean in Sardinia, while positively with Euro-Mediterranean and negatively with Atlantic in Tuscany. Chamaephytes had the same positive correlation with Endemic species in rivers of both regions, thus showing in Sardinia high significant positive correlation with Atlantic, and negative with Alien and Wide distribution. Among chorological forms, in Sardinian rivers we can observe a negative correlation between Wide distribution and Endemic, Euro-Mediterranean and Circum-Mediterranean from one hand, and a positive correlation with Alien from the other. Correlations among life forms showed instead similar trends in both regions, where hemicryptophytes and therophytes were negatively correlated with phanerophytes and nanophanerophytes.

Tab. 6 Pearson’s correlation matrix for variables measured in Sardinian (values above the diagonal) and in Tuscan (numbers below the diagonal) rivers. Bold numbers stand for p<0.05.

	ALI	ATL	BOR	CIRC	WID	END	EURAS	EUROM	CH	G	H	I	NP	P	T
ALI	*	**-0.23**	0.08	**-0.37**	**0.46**	-0.15	0.04	**-0.4**	**-0.41**	**0.23**	**0.36**	0.12	**-0.3**	-0.1	-0.21
ATL	-0.02	*	-0.07	-0.11	**-0.36**	**0.24**	0.2	0	**0.4**	-0.19	**-0.25**	-0.01	**0.37**	0.22	-0.07
BOR	0.15	0.08	*	**-0.28**	**0.27**	-0.11	-0.18	-0.16	0.12	0.12	0.02	0.22	**-0.26**	-0.09	0
CIRC	**-0.27**	**-0.22**	**-0.35**	*	**-0.53**	0.11	-0.13	0.01	0.16	-0.1	-0.12	**-0.31**	0.1	0.09	**0.41**
WID	**0.21**	**-0.28**	0.03	**-0.2**	*	**-0.45**	-0.11	**-0.42**	**-0.42**	**0.28**	**0.42**	**0.29**	**-0.45**	**-0.4**	-0.14
END	**-0.29**	-0.13	0.06	0.06	**-0.3**	*	0	0.13	**0.42**	-0.01	**-0.28**	0.01	**0.49**	**0.43**	-0.07
EURAS	0.04	**0.24**	0.08	**-0.37**	**-0.35**	0.1	*	-0.05	-0.02	**-0.24**	0.14	-0.04	-0.21	-0.05	0.14
EUROM	**-0.32**	**-0.31**	**-0.39**	**0.34**	**-0.27**	0.17	**-0.36**	*	0.07	**-0.41**	-0.17	-0.01	0.15	0.03	**0.25**
CH	**-0.21**	0.15	-0.01	0	**-0.22**	**0.45**	0.02	**0.2**	*	-0.13	**-0.41**	0.08	**0.43**	**0.25**	0.01
G	-0.01	0.15	**0.2**	-0.08	0.04	-0.18	-0.12	-0.1	-0.11	*	0.02	-0.06	-0.03	0	**-0.44**
H	-0.09	**-0.31**	0.03	-0.14	**0.2**	0.12	-0.02	0.09	0.03	-0.17	*	0.09	**-0.59**	**-0.39**	-0.01
I	0.09	0.06	0.12	-0.14	0.03	-0.06	0.08	-0.18	-0.1	0.09	0.01	*	-0.11	-0.12	0.11
NP	-0.16	**0.22**	-0.06	0.02	**-0.36**	**0.31**	**0.41**	-0.08	0.16	-0.04	**-0.41**	-0.02	*	**0.63**	**-0.3**
P	0.14	**0.48**	0.12	**-0.19**	**-0.27**	**-0.21**	**0.53**	**-0.39**	-0.11	**0.18**	**-0.52**	0.05	**0.38**	*	**-0.45**
T	0.12	**-0.46**	-0.09	0.13	**0.36**	-0.05	**-0.38**	**0.4**	-0.06	**-0.23**	0.09	0	**-0.29**	**-0.52**	*

1.4.2 Floristic and ecological gradients

All correlations between life forms and chorological groups showed r-values <0.65 (Tab. 6), indicating no multicollinearity; all variables investigated have been thus used in ordination analyses (Kline, 2005). In all ordinations (first two axes significant at p=0.002) the length of the main gradient underlined a high floristic heterogeneity (Tab. 7a). On the basis of dissimilarities in their species composition, plots of Tuscan and Sardinian rivers were well separated within the space of the DCA on the first ordination axis (Fig. 2a). This stand for a climatic and geographic gradient as emerged by strong correlations with climatic variables (negative correlation with Rainfall and positive correlation with Temperature) and chorological forms (negative correlation with Eurasiatic and Boreal, positive correlation with Circum-Mediterranean) (Tab. 7b). The second axis separated Sardinian rivers (Leni and Santa Lucia rivers in Fig. 2a) and represented a longitudinal gradient (negative correlation with altitude) and overall a gradient of human disturbance, as suggested by chorological forms (positive correlation with Alien and Wide distribution) (Tab. 7b).



(a) (b)

Fig. 2 DCA (a) and Partial DCA with “rivers” as covariable (b). Circles = Tuscan rivers (Fiora river in white and Albegna river in light gray); diamonds = Sardinian rivers (Santa Lucia river in white and Leni river in dark gray).

In order to determine the main gradients common to all rivers after removing the “river effect”, partial DCA (Fig. 2b) was performed. Tuscan rivers were distributed along the first axis, while Sardinian ones were stretched along the second one. In contrast with the previous ordination, the main axis of partial DCA showed to be highly negatively correlated with phanerophytes and positively with hemicryptophytes and therophytes, while the second axis had the highest positive correlations with Wide distribution and Alien species, negative with Altitude and Rainfall. Separate ordinations (graphics not showed) with only Tuscan and Sardinian plots respectively were performed in order to detect the main local gradient inside rivers of the same region and their correlations with the environmental variables examined (Tab. 7b). The longest gradient of DCA performed with Sardinian rivers was shorter than that of Tuscan ones. In Sardinia the main axis was strongly negatively correlated with Altitude, Rainfall, nanophanerophytes and phanerophytes, while positively correlated with Temperature, hemicryptophytes and Wide distribution. In Tuscany, the first axis was strongly negatively correlated with phanerophytes, Atlantic and Rainfall, and highly positively with hemicryptophytes and Euro-Mediterranean, while the second axis highly negatively with Altitude and highly positively with Temperature, Wide distribution species and therophytes.

Tab. 7 Summary of axis 1 and 2 of: ordination with all plots (DCA); partial ordination (pDCA) with all plots; DCA with only Sardinian plots (Sardinia); DCA with only Tuscan plots (Tuscany) (a). Spearman rank correlations between life forms, chorological groups, environmental variables and ordination axes are reported (b). Significant differences (p<0.05) are marked with numbers in bold.

	DCA		pDCA		DCA Sardinia		DCA Tuscany	
(a)	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Summary of ordination								
Eigenvalues	11.007		10.143		7.058		8.095	
Longest gradient length (SD)	4.008		4.259		4.01		4.35	
Cumulative percentage of variance (%)	5.3	9.1	4.3	7.6	8.6	13.1	6.5	10.1

(b)	DCA Axis 1	DCA Axis 2	pDCA Axis 1	pDCA Axis 2	DCA Sardinia Axis 1	DCA Sardinia Axis 2	DCA Tuscany Axis 1	DCA Tuscany Axis 2
Life forms								
Chamaephytes	-0.05	**-0.45**	0.03	**-0.39**	**-0.49**	0.03	0.14	**-0.45**
Geophytes	**0.28**	**0.25**	**-0.29**	**0.38**	**0.40**	**-0.46**	**-0.27**	-0.07
Hemichryptophytes	0.01	**0.22**	**0.54**	0.05	**0.64**	0.21	**0.58**	-0.11
Hydrophytes	0.09	0.14	0.02	**0.14**	0.08	0.11	-0.12	-0.12
Nanophanerophytes	**-0.29**	**-0.55**	**-0.43**	**-0.43**	**-0.82**	**-0.24**	**-0.36**	**-0.35**
Phanerophytes	**-0.55**	**-0.36**	**-0.75**	**-0.16**	**-0.73**	**-0.51**	**-0.83**	**-0.29**
Therophytes	**0.53**	**0.28**	**0.50**	0.04	0.10	**0.62**	**0.49**	**0.62**
Chorological forms								
Alien	**0.15**	**0.41**	-0.09	**0.46**	**0.42**	-0.27	-0.19	0.18
Atlantic	0.14	**-0.15**	**-0.42**	-0.11	**-0.34**	-0.02	**-0.61**	**-0.30**
Boreal	**-0.49**	**0.18**	-0.07	**0.24**	0.25	-0.12	-0.21	0.01
Circum-Mediterranean	**0.74**	-0.09	0.06	-0.11	**-0.49**	0.04	**0.30**	0.08
Wide distribution	0.13	**0.62**	**0.15**	**0.58**	**0.65**	-0.04	0.05	**0.62**
Endemic	**0.36**	**-0.32**	0.08	**-0.26**	**-0.45**	**-0.31**	**0.36**	**-0.42**
Eurasiatic	**-0.79**	-0.08	**-0.16**	-0.11	0.19	0.03	**-0.47**	**-0.48**
Euro-Mediterranean	-0.02	**-0.31**	**0.41**	**-0.47**	-0.29	**0.42**	**0.53**	-0.10
Environmental variables								
Temperature (°C)	**0.75**	**0.39**	0.13	**0.36**	**0.51**	0.07	0.17	**0.67**
Rainfall (mm/y)	**-0.50**	**-0.41**	**-0.40**	**-0.43**	**-0.77**	-0.08	**-0.45**	**-0.38**
Altitude (m a.s.l.)	**-0.30**	**-0.61**	**-0.37**	**-0.53**	**-0.82**	-0.16	**-0.28**	**-0.71**
Distance from running water (m)	**0.74**	-0.12	0.06	-0.11	**-0.49**	0.04	**0.30**	0.08
Height from running water (m)	**-0.51**	**0.17**	-0.07	**0.24**	**0.25**	-0.12	**-0.21**	0.01

1.4.3 Variance partitioning

Total variance explained by the three predictors was low (12%). Longitudinal gradient alone was the most important variable influencing the floras of the four rivers, accounting for more than 40% the total variance explained. Biogeography (at province level, see Tab. 1) explained about 20% of total variance, followed by the Lateral gradient, that explained less data variation, almost 18% of the total. The Venn diagram in Fig. 3 showed that an high percentage of variation (more than 17% on the total explained) resulted to be shared between the factors Longitudinal gradient and Biogeography, while the amount of variance shared by Lateral gradient with the other two factors was marginal. The amount of shared variation among all variables resulted to be very low.

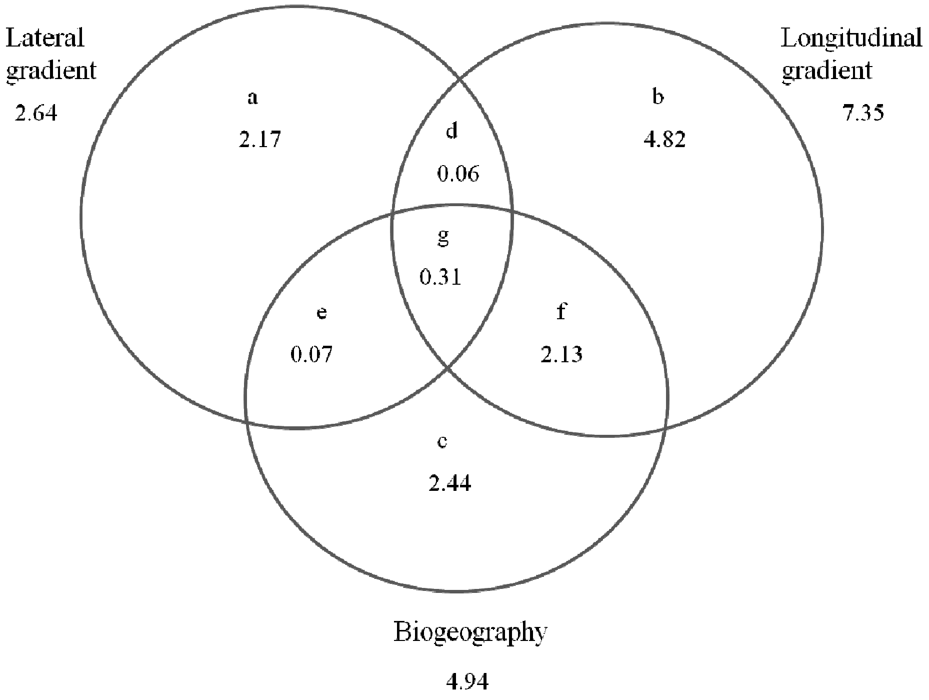


Fig. 3 Partitioning variation in species composition data represented as a Venn diagram indicating three groups of variables (Biogeography, Longitudinal and Lateral gradient) with their percentage value of variance explained. Various sets of partial constrained correspondence analysis (CCA) were compared. All CCA analyses had F-ratios < 0.01 in a Monte Carlo test; a, b and c were the unique effects respectively of Lateral gradient, Longitudinal gradient and Biogeography, while d, e, f and g were fractions indicating their joint effects. Numbers outside the circles stand for the total variance explained by each variable (included all joint effects).

1.5 DISCUSSION

1.5.1 Floristic patterns of riverbed flora

The high number of families and vascular plants species found at both regional and local scale confirmed that riparian areas had a high floristic biodiversity. This result, according to many other authors (Naiman and Décamps, 1997; Pollock et al., 1998; Naiman et al., 2005), underlined the importance of riparian landscapes for biodiversity conservation, particularly in Mediterranean areas (Corbacho et al., 2003).

Some general features of riparian flora resulted to be similar in both regions: i) the dominant families, *Poaceae*, *Asteraceae* and *Fabaceae,* are the dominant families of in Italian flora in general (Podda et al., 2011); ii) the most frequent species, linked to human impacted habitats, showing that probably riparian areas with the higher similarity between Sardinia and Tuscany were those highly disturbed, since the alterations of the internal structure of Mediterranean riparian corridors determine the proliferation of terrestrial opportunistic or nitrophylous species (Ferreira and Aguiar, 2006) and also the simplification of the structural heterogeneity (Corbacho et al., 2003); iii) the presence of hygrophylous trees (es. *Salix* sp.pl., *Tamarix* sp.pl., *Populus* sp.pl.), found mainly downstream (Landi and Angiolini, 2007), with species (azonal) shared in general among all rivers (see Naiman et al., 2005); iv) the trend of life forms, with negative correlations between herbaceous (perennials and annuals) and woody plants, a pattern already observed by Lite et al. (2005) in riparian habitats of semi-arid zones. At the same time the high frequency of hemichryptophytes in all rivers indicated that this life form is adapted to areas with continuous modifications and transformations due to fluvial dynamics and to the wood's edges (Bacchetta et al., 2005). Therophytes and Wide distribution species were ephemeral plant species generally linked to the presence of Mediterranean climatic conditions, characterized by climatic dryness, intermittent flows and semiarid riverbeds (Ferreira et al., 2004; Ferreira and Aguiar, 2006), but in Mediterranean biogeographical region also to the presence of anthropic disturbance (Pignatti et al., 2002; Bacchetta, 2006).

Our results, however, indicated a high floristic heterogeneity between the two regions (low value of Sørensen index, low number of species shared, differences about the most frequent species, long DCA axis 1 gradient), probably due in part to the variation in environmental features that have different importance within different regions (Neilson et al., 1992), but also to historical-biogeographical factors such as: i) different geological origin and paleographic history of Tuscany and Sardinia, that consequently affected the available species pools of each area (Whittaker et al., 2001), determined by evolutionary and historical processes and proved to be important for understanding community composition (Nilsson et al., 1989, 1994; Danvind and Nilsson, 1997; Partel and Zobel, 1998); ii) the insularity of Sardinia, due to its prolonged Tertiary isolation, together with high geological diversity and wide range of habitats, that contributed to the differentiation of neo-endemics that are specific to each area (Médail and Quézel, 1997). At the same time, we found different distribution patterns of taxonomic groups, life forms and chorological groups at regional level. The major differences about families can be related to different land use management, that in Tuscan riverbeds led to higher percentages of *Fabaceae, Lamiaceae* and *Rosaceae*, with species typical of shrubby formations, as a consequence of the abandonment of traditional management and subsequent expansion of woody vegetation (as largely observed in central Italy, see Rocchini et al., 2006). This general succession trend from pastures to woody vegetation explained the presence in Tuscan rivers of nemoral species among the most frequent plants. In Sardinia, higher percentage of *Rubiaceae* and *Apiaceae* were a consequence of the presence of ecotonal areas of woodlands and maquies edges, probably related to a pattern of recolonization of abandoned agricoltural lands similar of that described above for Tuscany. Besides, species such as *Avena fatua*, *Sonchus oleraceus* and *Galactites tomentosa* suggested the presence of cultivated and, in general, more degraded areas, especially in level lands. On the other hand, the presence of wetlands in the lowland areas of both Sardinian rivers could explain the higher percentage of *Cyperaceae* and *Juncaceae,* families rich in hygrophilous species (Desfayes, 2008).

The diversity between the two regions was also confirmed by the different distribution trends among almost all life forms (particularly P, NP, G, T) and chorological groups (all except Wide distribution). Deeply linked to the Mediterranean-type climate resulted to be geophytes (Fenu and Bacchetta, 2008), favored by the traditional field management systems of Sardinia, with dead grasses that are burnt off, a practice that had been proved also to stimulate the occurrences of herbaceous annuals and conversely constrain those of woody species (Ishida et al., 2008). Woodlands resulted to have a different floristic composition between the two regions, since Sardinian hardwoods were dominated by sclerophyllous while Tuscan ones by deciduous species, due to regional climatic differences (Alcaraz et al., 1997). Along small streams with relatively steep banks (as in the case of the upper stretches of all rivers studied) the up slope forest may extend to the stream bank; in this way, riparian vegetation gains the features of the surrounding vegetation (Richardson et al., 2007). For this reason, species of hardwooded zones increased both with the increase in distance from the watercourse and with the greater altitude of the floodplain, as highlighted and measured in other studies on riparian areas, while softwooded zones (hygrophilous forests) were more likely to be found downstream (e.g. Kozlowski, 1997; Ferreira and Aguiar, 2006; Landi and Angiolini, 2007). Besides this, alien plants presence resulted to be stronger in Sardinian rivers, where they were particularly spread in lowlands, in correspondence of agricultural lands and human settlements, a phenomenon that can be related to the higher vulnerability of Mediterranean insular ecosystems to biological invasions (DAISIE, 2009; Podda et al., 2010). An interesting finding was that, despite riparian communities have been described as highly susceptible to invasion by alien species (Deferrari and Naiman, 1994; Stromberg and Chew, 1997; Hood and Naiman, 2000), in the present study alien precentage was substantially lower than in other Mediterranean rivers (Tabacchi et al., 1996; Aguiar et al., 2000; Ferreira et al., 2002), probably because native competitors are well adapted to the area’s torrential hydrological regimes (Tabacchi et al., 1996).

At regional level, the differences in Sørensen’s index on life forms and chorological groups revealed a high intra basin similarity already detected in other Mediterranean rivers (Ferreira et al., 2002), and as generally expected for neighboring areas. At local level, the differences between rivers of the same region were due to the dynamic nature or riparian areas (Gregory et al., 1991), but also to factors that do not vary in the same way inside a region (Neilson et al., 1992). Tuscan rivers revealed to have the higher floristic heterogeneity and many differences concerning chorological forms, a feature that could be referred to their major course length, that clearly led to high floristic heterogeneity, since many environmental features of riverbeds (such as geology and morphology, van Coller et al., 2000; human disturbance, Aguiar and Ferrerira, 2005; land use, Meek et al., 2010), not investigated in this study, changed along the longitudinal gradient.

1.5.2 Regional and local gradients

Previous studies on Mediterranean rivers have already regarded the primary role of longitudinal, lateral (e.g. Tabacchi et al., 1990, 1998; Landi and Angiolini, 2007; Salinas and Casas, 2007) and, sometimes, also geographical gradients (Sieben et al., 2009) in controlling riparian vegetation patterns. In our study the first axis of DCA ordination, that clearly detected the separation of Tuscan and Sardinian plots, underlined that climatic and morphological variables were the most important environmental factors in explaining plots distribution pattern along the main gradient that, according to the findings of Sieben et al. (2009), corresponded to a geographic differentiation. However, this result was probably due in part to the high species turnover between Sardinia and Tuscany discussed above and can be considered a specific outcome of these regions. Regardless geographical differences among rivers, the principal gradients affecting riverbed floras operated along the longitudinal dimension (highest negative correlation between axis 2 and altitude), as found by Tabacchi et al. (1998) and Salinas and Casas (2007), that overlaps with a gradient of naturalness/human disturbance on riparian habitats (high positive correlation with Wide distribution species). In fact, according to Corbacho et al. (2003), in upper sections of Mediterranean streams generally low land-use intensity schemes (forests, shrublands, extensive agriculture) took place, while in the lower sections with flat landscapes, intensive agricultural production methods and livestock farming) were dominant, driving also a lot of herbaceous generalist species.

After removing the “river effect” by partial DCA, the main gradient of the riparian flora at regional level resulted to be structural. This gradient can be partly explained by the presence of zones with different inundation frequency linked to the transversal dimension, nevertheless it failed to significantly emerge. In fact the lateral gradient resulted to be deeply linked to the regional differentiation (as evidenced by the high correlation values with the first axis of DCA), and for this reason once removing “river effect”, also its effect disappeared. The second axis resulted to be linked to the altitudinal-longitudinal gradient, that confirmed in this way to be one of the most important gradient for riparian vegetation also in Mediterranean areas (see Tabacchi et al., 1998; Lite et al., 2005; Salinas and Casas, 2007).

The main gradients at local scale resulted to be the same (longitudinal and lateral). In the first ordination axis of Sardinian and Tuscan rivers, longitudinal and lateral gradients occurred together, even if with different relative importance, confirming to be partially nested environmental gradients (Sieben et al., 2009). In fact, the transition from upland woody to lowland herbaceous areas occurred along the river followed the decreasing gradient of flow intensity and the related increasing gradient riverbed amplitude. The change in fluvial bed width that occurs at low altitudes causes a decrease in both the depth and speed of the water, consequently increasing the sedimentation, that is necessary for the establishment and maintenance of pioneer riparian communities of shrubby (nanophanerophytes) and herbaceous species (Landi and Angiolini, 2007). Going towards the mouth, the high temperature as well as human pressure tend to increase dryness, condition that favours herbaceous species, in particular the most ruderal and rain-dependent xeric-annuals (Tabacchi et al., 1998; Bagstad et al., 2005; Lite et al., 2005). In Sardinia, however, rivers seemed less affected by the lateral gradient than in Tuscany, because here floodplains were not as wide as Tuscan ones, and subsequently the vegetation patterns developed in the prevalent (longitudinal) gradient, while the lateral riparian zonation was not present (Sieben et al., 2009). Here the correlations of second axis, suggested a high environmental heterogeneity and patchiness, probably underlining a structural differentiation that occurred beside any longitudinal and lateral gradient, but potentially linked instead to the presence of local disturbance. In fact, where some kind of disturbance (as flooding, rocky soils, dryness) is present, it did not allow the establishment of perennial plant species, thus favoring annual herbaceous; river stretches with more stable conditions, are instead covered by woods (Angius and Bacchetta, 2009). In Tuscany instead the lateral gradient seemed to be the principal gradient of the areas, as noted also by van Coller et al. (2000) in other semi-arid rivers, thanks to particular morphological characteristics of these riverbeds (as found by Landi and Angiolini, 2007), and to more natural conditions of the medium/lower reaches of the rivers, where riparian zonation was more distinct (Sieben et al., 2009). Moreover, the second axis stand for an autonomous altitudinal/naturalness gradient, because riparian width varied along the upstream-downstream gradient in a different spatial pattern with respect to Sardinian rivers, since the wider riparian formation were located at middle course (Angiolini et al., 2011).

1.5.3 Relative contribution of longitudinal gradient, lateral gradient and biogeography to riparian floras patterns

The partial ordination analysis quantified the relative contributions of Biogeography (considered at province level of classification) with respect to Longitudinal and Lateral gradients in influencing riparian floras patterns of these Mediterranean riverbeds. The variables considered differed strongly in their ability to explain the floristic variation. Longitudinal gradient resulted to be the most important predictor in riparian plant species distribution. In fact, in addition of being the major vector propagating matter, energy and organisms from source to mouth (Tabacchi et al., 1998), the longitudinal gradient of riparian corridors was linked to changes in many environmental factors (such as climate and microclimate, topography, erosion, land use) (Campbell, 1983; Sieben et al., 2009; Gentili et al., 2010). Besides this, altitude and climate are considered as the most important factors affecting riparian composition at regional level both in human disturbed Portuguese rivers (Aguiar and Ferreira, 2005) and in the near-natural Tagliamento River (north-east Italy) (Karrenberg et al., 2003). These similar results in contrasting landscapes, between the highly-disturbed corridors of the Tagus basin and the morphologically intact Tagliamento River, suggested that broad geographical variables linked with stream hydrodynamics are essential for understanding riparian ecosystems and functional features in riparian corridors.

As already indicated by DCA, also biogeographical differences resulted to strongly affect riverbed flora patterns at regional level in these rivers. Quantifying the role of historic-paleogeographic factors alone allowed us to confirm our former assumption that biogeographical differences do not only account for variation in zonal vegetation, but also for variation within azonal vegetation, like riparian corridors. This is true both at macroscale (e.g. Mediterranean vs Eurasiatic) (Whittaker et al., 2001; O’Brien, 2006) and at regional scale (Sieben et al., 2009), as found in our study area, since the four rivers are located all inside the Mediterranean region (from the bioclimatic and biogeographic point of view), but belong to different biogeographic units, and above all they have two different paleogeographic backgrounds. However, it should be pointed out that, even if dealing with rivers and riparian vegetation, truly aquatic and hygrophilous (azonal) vegetation resulted to be scarce in the whole study area compared to what found in other fluvial systems (Naiman et al., 1993), due to human interferences in the flow regime (particularly water abstraction) and to the hydrological intermittency of the rivers. The climatic harshness conditions, typical of the southern basins of Mediterranean rivers (Ferreira et al., 2004), tend to favor the colonization of riverbanks by species with scarce soil moisture needs (Ferreira and Moreira, 1999), derived from adjacent land use near the rivers, thus becoming the prevalent part of riverbed flora (Ferreira and Aguiar, 2006), that for this reason is affected by climatic differences between and along the rivers, as any other zonal vegetation.

The high percentage of variance shared between Biogeography and Longitudinal gradient underlined strong linkages between the two variables. As reported before, this result was a consequence of the fact that Longitudinal gradient was the principal gradient in Sardinian rivers, while not in Tuscan ones, and probably because of this reason it followed (and probably matched) at regional level the geographic/biogeographic differentiation. Lateral gradient resulted to be almost completely independent from the other two variables. As emerged also by the previous analyses, Lateral gradient was evident in the Tuscan rivers, where riparian zonation is more distinct than in Sardinian ones (as noted by other authors, see Angiolini et al., 1998; Bacchetta et al., 2005; Landi and Angiolini, 2007), and it doesn’t follow the longitudinal gradient (see Angiolini et al., 2011). As a consequence, the variance explained by Lateral resulted to be disjoined by the Longitudinal gradient and moreover was toned down because of the marginal contribution of Sardinian rivers.

In conclusion, it should be underlined that the percentage of variance explained by the different factors was, as expected, relatively low, because many other gradients (not subjected by this study) may potentially account for a substantial proportion of unexplained biotic variation (Salinas and Casas, 2007), as for instance the difference of land use between the two regions and between rivers of the same regions. Moreover, local scale factors, strongly affecting riparian plant composition and environmental variability, generally fail to be captured by broad-scale variables (Pyne et al., 2007). Anyway, it has been demonstrated that large fractions of unexplained variance may arise from the inherent spatial autocorrelation in river networks, the subtlety of the gradients investigated (Demars and Harper, 2005), the existence of large fractions of random compositional variance in the data (Gentili et al., 2010), but also for purely statistical reasons (Økland, 1999).

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CHAPTER 2:

ENDEMIC AND ALIEN PLANT SPECIES DISTRIBUTION ALONG TWO MEDITERRANEAN RIVERS

ABSTRACT

In this paper is proposed a method to rapidly assess conservation priorities using plant species information recorded by random sampling and univariate/multivariate statistics. We applied the method in two Mediterranean rivers in order to determine floristic variability along the longitudinal gradient and to compare the distribution models of alien and endemic species along the fluvial corridors. The results highlighted the high number of endemic species in all the study area, while a low alien species richness. The distributional trends of endemic and alien species resulted in general to follow the naturalness gradient of increasing human impact going toward the sea, but the study evidenced the presence of different degree of naturalness between the two rivers in general, nevertheless the presence of protected areas in both of them. The most critical areas resulted to be the middle course of the rivers, where endemic species coexist with alien species and overall with high human impact in the surroundings. These resulted to be the areas where should concentrate further conservation efforts. The method proposed allowed us to obtain general information about the main ecological features of rivers, to be used as starting point for following ecological studies of conservation planning of the area.

Keywords: conservation priorities, Generalized Additive Models (GAM), functional groups, ordinations, Sardinia, vascular flora.

2.1 INTRODUCTION

Ephemeral streams are common features of landscapes around the world, and are the predominant fluvial environment in arid zones (Nanson et al., 2002; Shaw and Cooper, 2008) such as in Mediterranean areas. Current understanding of dryland riparian ecology is derived primarily from perennial stream environments, and since watercourses in arid and semiarid areas differ considerably from the conceptual models of streamwaters in more mesic regions (Malanson, 1993), little is known about the factors controlling vegetation along ephemeral streams (e.g. Zimmerman, 1969; Stromberg, 1998; Zimmerman et al., 1999). Moreover, rivers generally display a pronounced spatial variability in species richness, composition and density from headwaters to lowlands (Ward and Stanford, 1995, Tabacchi et al., 1996). Linking diversity in plant species composition and distribution to environmental gradients and general landscape features can be an important guide in the development of conservation and restoration strategies (Aguiar et al., 2007). Such an approach is particularly needed in areas where high levels of biodiversity coexist with high human impact and landscape transformation, such as in Mediterranean basin (di Castri, 1991; Gasith and Resh, 1999; Aguiar and Ferreira, 2005). Myers et al. (2000) ranked this basin third of the list of leading hotspots for endemic plant species in the world, due to the exceptional rate of plant endemism and the extent of habitat loss, with only 4.7% of primary vegetation remaining. Sardinia island, at the center of Mediterranean sea, is particularly rich in endemic *taxa* (Bacchetta and Pontecorvo, 2005) due to its ecologic isolation and insularity, and is considered an hot spot area together with Corsica and Sicily (Medail and Quézel,1997; Fenu et al., 2010). But Mediterranean basin and thus Sardinia island have a long history of human presence, deeply linked to the water for survivor (as in other semi-arid basins, Nilsson et al., 1993; Salinas et al., 2000). The historical and present human-made disturbance is omnipresent, condition that led to degradation and physical modification in the riparian landscape (Baatrup-Pedersen et al., 2005), even with higher speed and magnitude. At present, they are undergoing increasing competing demands of superficial water and groundwater for irrigation of intensive crops and for tourism activities in coastal areas (Corbacho et al., 2003). Given the high speed of loss and conversion of floodplains, as well as the threats to remaining areas, we urgently need to improve our understanding of their internal dynamics and floristic features in order to best conserve the remnants. For these reasons, rapid assessments of plant species diversity and distribution along rivers become important (Stohlgren et al., 1997). Particularly, since resources are limited, extensive field surveys over large geographical areas to determine the spatial variability of plant species along rivers are not a reliable approach, because costly in terms of practical limitations, time and – above all - money. In many riparian areas of Europe one of the widely used approach for relating vegetation patterns to environmental conditions is combining plant species data and statistical techniques. Nilsson et al. (1989) studied bank vegetation along two rivers in north Sweden in order to test for pattern in species richness and natural/ruderal species using regression and correlation analyses. The floristic diversity and composition of river Meuse in Belgium was analysed by Van Looy et al. (2006) in order to test their contribution to the biodiversity of the floodplain by the use of dissimilarity index and ordination. Ferreira et al. (2002) used river plant assemblages as indicators of ecological quality in a southern Iberian basin, and applied the multivariate approach to derive group of sites with similar compositional properties. In southwest France, Tabacchi and Planty-

Tabacchi (2001) analysed the spatial pattern of plant species changes, richness and functional groups along the Adour river by the means of correlation analyses. Aguiar and Ferreira (2005) used univariate methods and indirect ordination techniques to assess the overall spatial patterns of riparian formations on the Tagus river floodplain in Portugal in order to help improve environmental management strategies in riparian corridors in this region. In Italy there is instead a substantially lack of this kind of approach. Moreover, studies on dominance shifts between native and alien species rarely include the endemic species and are more common on a small scale (as in experimental patches of vegetation, see Woitke and Dietz, 2002; Thomson, 2005; Angiolini et al., 2011), even if the importance of landscape perspective approaches for the study of native/endemic alien species interactions have been emphasized for the quantification of the threats from aliens and the establishment of management (Higgins et al., 1999; Draper et al., 2003; Kühn et al., 2003). In fact, nevertheless the importance of Mediterranean basin as endemic richness area, and the high vulnerability to the invasion by exotic species, particularly in riparian habitats (Hood and Naiman, 2000; Aguair et al., 2001), few studies focused on the coexistence of alien and endemic flora (Aguiar et al., 2007), and of their distributional pattern along human impacted rivers.

For these reasons, we aimed to study two Mediterranean insular river floodplains in order to determine floristic, alien and exotic species variability along the longitudinal gradient, considered the most important gradient for riparian plant species distribution (and here represented by the variables altitude and climate), using plant species information recorded by random sampling of the areas and analysed by the mean of univariate/multivariate statistics. Secondly, we want to compare the distribution models of alien and endemic species along this gradient, in order to detect their trends along the fluvial corridors. Finally, we want to assess if this method could be useful to rapidly obtain general information for conservation planning of the area.

2.2 STUDY AREA

Rio Leni and Rio Santa Lucia (Fig. 1) were selected for this study because they own the typical features of Mediterranean rivers, such as a flow regime subjected to erratic interannual fluctuations, with a gradually declining flow and subsequent drying during late spring and summer that lead to harsher habitat conditions, followed by high floods usually occurring in autumn or early winter (Bacchetta, 2006). The rivers originate from two of the higher reliefs of south Sardinia (Monte Lattias, 1086 m, and Monte Linas, 1234 m, respectively), and are among the most important rivers of the area. The catchment basin is respectively of 110 and 130 km^2, and the stretches investigated extended for almost 25 km in Santa Lucia riverside floodplain, and almost 50 km in Leni river. The altitudinal range is respectively of almost 500 m and 600 m.

Relief and climate gradients throughout the basins are relatively low. For both rivers the climate is substantially homogeneous and belong to the Mediterranean type. Following Rivas-Martínez et al. (2002), the study area was classified within the Mediterranean pluviseasonal oceanic bioclimate, with thermotypes ranging between the upper thermo- and the lower supramediterranean and ombrotypes between the upper dry and the lower humid (Bacchetta, 2006; Angius and Bacchetta, 2009).

From a biogeographical point of view, and according to Rivas-Martínez et al. (2001), the studied area belong to the Mediterranean Region, West Mediterranean Subregion, Italo-Tyrrhenian superprovince and Sardo-Corsican province. The Sardo-Corsican province, on its turn, can further be divided into a Sardinian and a Corsican subprovinces. Each subprovince is subdivided into several sectors. The mountain parts of both the rivers lay in the Sulcitano-Iglesiente sector (but in two different subsectors, see Fig. 1), while the valley part in the Campidanese sector, on the basis mainly of endemic *taxa* distribution (see Bacchetta and Pontecorvo, 2005, Bacchetta et al., 2007; Angius and Bacchetta 2009).

Most of the upper part of the basin is made up by outcrops of resistant rock, in the form of Palaeozoic granites and metamorphytes. Mountain areas are predominantly occupied by woodlands of holm oak (*Quercus ilex*) and cork oak (*Q. suber*). The mountain parts of both the rivers are located into protected areas, and respectively Site of Community Importance "*Foresta di Monte Arcosu*" (ITB041105) for Santa Lucia, and "*Monte Linas - Marganai*" (ITB041111) for Leni.

In correspondence of the transition from bedrock to the alluvial lithology, they wide over an alluvial conoid made up of cobblestones, sands and clays deposited by streams during the Quaternary sediment accumulation (see Bacchetta et al., 2003). More than 2/3 of the Leni riverbed flow in Campidano graben, the most important level land of the whole island, while Santa Lucia river is almost equally distributed between the two geological substrates of granites and sediments. Irrigation crops such as citrus orchards, artichokes, tomatoes occupy the rich alluvial soil of lowlands. Agricultural practices and livestock grazing are common at both rivers, although Leni is most impacted by cultivation and grazing. Human settlement are small and scattered, especially in Santa Lucia river. Industrial facilities are small and dotted throughout the basin and most are related to livestock (goats, sheep, pigs) and cork processing. Livestock grazing and water abstraction are the main impacts on the stream channel and adjacent riparian areas, while in the past decades there were also mining activities. Both the rivers flow into a wetland included into the protected area "*Stagno di Cagliari, Saline di Macchiareddu e Laguna di S. Gilla*" (ITB040023).

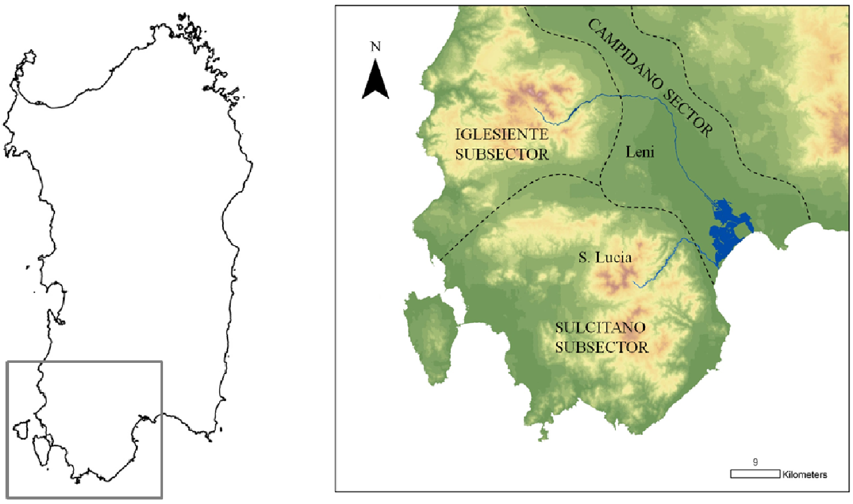


Fig. 1 Study area with division into biogeographical units. Iglesiente and Sulcitano Subsectors belong to the Sulcitano-Iglesiente Sector.

2.3 MATERIALS AND METHODS

2.3.1 Floristic data

For the analyses of plant composition and distribution along the rivers, we used a stratified random sampling design. Since one of the goal of this study was the analysis of riparian vascular plant species, sampling was carried out considering only floodplain. To identify the floodplain, we first selected the area with alluvial lithology, then we removed the cultivated land near the river. To avoid the possibility to have grouped plots and with the aim to represent variations in species assemblages and environmental features, the river was divided, perpendicularly to direction flow, into sections of 2 km of lenght; for each section we placed randomly 2 plots of 10×10m, for a total of 73 plots. This dimension was found to be adequate to detect the vegetational mosaic of the floodplain, because it made it possible to explain the relationships between species richness and environmental features both in forests (Schuster and Diekmann, 2005) and in grasslands (Gross et al., 2000). For each plot we recorded all vascular plants presence from April to July 2008 - 2010. The species nomenclature followed the recent checklist of Italian flora by Conti et al. (2005; 2007).

2.3.2 Species attributes and environmental data

For statistical analyses, studied variables can be classified into two groups: i) the group of species-related attributes (functional groups, alien and endemic species), and ii) the group of environmental variables (altitude, rainfall and temperature data).

To test whether functional groups of plants, defined as groups of species that share the same adaptive features in relation to a well-defined function (McIntyre et al., 1995), respond differently to the main (longitudinal) gradient of the area, species were classified into the following functional groups: a) woody species (phanerophytes and nanophanerophytes); b) perennial herbaceous species (geophytes, hemichryptophytes, chamephytes); d) annual species (therophytes); e) aquatic species. For the assessing of aliens we followed Bacchetta et al. (2009) and Podda et al. (2010; 2011), while for endemics we followed the classification (and the abbreviations) made by Bacchetta and Pontecorvo (2005), but grouping their categories into 3 main groups: Cyrno-Sardinian Endemics (SA-CO); Tyrrhenian-insular Endemics (ETI); Tyrrhenian Endemics (ET). For alien and endemic species we calculated the “Frequency of Occurrence”, as the quotient of the number of sites at which a given species was observed and the total number of sites surveyed (Aguiar et al., 2007).

Altitude was recorded for each plot using the Digital Elevation Model (DEM), while climatic data (higher and lower temperature and rainfall as annual/monthly medium of the nearest station) were provided by Angius and Bacchetta (2009).

2.3.3 Statistical analyses

Species data from all sites were ordinated using detrended correspondence analysis (DCA). This unconstrained ordination was applied also to find the axes with maximum variation in floristic composition and thus described the general pattern in species distribution along gradients (Lepš and Šmilauer, 2003). The options chosen for DCA were down-weighting rare species and inter-species distances by Hill's scaling (ter Braak and Šmilauer 2002); otherwise the default options were accepted. The DCA diagram was subsequently passively projected with the environmental variables (altitude, rainfall and temperature), functional groups, aliens and endemic species to show their variation across the main gradients. Variables correlation coefficients were studied to find the linkages between them and the main DCA axes. To test the significance of difference in the percentage of functional groups and endemic/alien species among the rivers, *t- test* was conducted.

Since from the DCA emerged a clear strong linkage on first axis with altitude and rainfall, we assumed that the longitudinal gradient in our study area was actually the altitudinal/longitudinal one. Generalised Additive Models (GAMs) were then used to construct species response curves along this altitudinal gradient (first axis of DCA) for endemic and alien species. GAMs are semi-parametric extensions of GLMs that assume no a priori responses of a species to an environmental gradient (Guisan et al., 2002). Options for frequency data (Poisson distribution and use of maximum value) were employed. We investigate the trends of endemic species with the higher frequency (>10%) in the study area, while due to their low number, all the exotic species were taken into account.

The Monte Carlo test (499 random permutations) was used to test the significance of ordination axes of unconstrained and constrained ordination. Canoco 4.5 for Windows (ter Braak and Šmilauer, 2002) was used for ordination analyses, while STATISTICA 6.0 (StatSoft Inc., 1995) for univariate analyses.

2.4 RESULTS

2.4.1 Floristic, alien and endemic species variability

On a total endemic flora of 22 species (6.3% of the total endemic flora of the island, see Bacchetta et al. 2005), half of the species were in common. The most frequent endemic species in the study area were *Mentha suaveolens* ssp. *insularis* and *Hypericum hyrcinum* ssp. *hyrcinum*. The endemic species exclusive of Santa Lucia were only three: *Salix arrigonii*, *Arum pictum* ssp. *pictum* and *Delphnium pictum.* In Leni river they were instead numerous: *Genista corsica*, *Stachys glutinosa, Eupatorium cannabinum* ssp. *corsicum*, *Apium crassipes, Torilis nemoralaris, Rumex scutatus* ssp. *glaucescens, Aristolochia navicularis, Crepis bursifolia* (Tab. 1). Tyrrhenian-insular (ETI) group resulted to be the most important group of endemics in Santa Lucia (76% FO), followed by Cyrno-Sardinian (SA-CO) (64 FO). The inverse pattern instead was found in Leni, where Cyrno-Sardinian was dominant (47.9 FO), followed by Tyrrhenian-insular (39.6 FO). Tyrrhenian (ET) group resulted to be important in Leni (25 FO), while in Santa Lucia was only marginally present (4 FO).

Tab.1 Endemic species of the two rivers with their group and their “Frequency of Occurrence” (FO).

Kind of endemism	**Species**	**S. Lucia**	**Leni**
Cyrno-Sardinian Endemic (SA-CO)	*Arum pictum* ssp. *pictum*	8.0	0.0
	Bryonia marmorata	4.0	2.1
	Carex microcarpa	8.0	2.1
	Genista corsica	0.0	6.3
	Hypericum hircinum ssp. *hircinum*	20.0	10.4
	Plagius flosculosus	4.0	14.6
	Polygonum scoparium	8.0	8.3
	Salix arrigonii	12.0	0.0
	Stachys glutinosa	0.0	4.2
Tyrrhenian-insular Endemic (ETI)	*Bellium bellidioides*	8.0	8.3
	Cymbalaria aequitriloba ssp. *aequitriloba*	8.0	2.1
	Delphinium pictum	12.0	0.0
	Helichrysum microphyllum ssp. *tyrrhenicum*	12.0	10.4
	Mentha suaveolens ssp. *insularis*	32.0	14.6
	Teucrium marum ssp. *marum*	4.0	2.1
	Torilis nemoralis	0.0	2.1
Tyrrhenian Endemic (ET)	*Apium crassipes*	0.0	2.1
	Aristolochia navicularis	0.0	10.4
	Crepis bursifolia	0.0	2.1
	Eupatorium cannabinum ssp. *corsicum*	0.0	2.1
	Euphorbia amygdaloides ssp. *arbuscula*	4.0	2.1
	Rumex scutatus ssp. *glaucescens*	0.0	6.3

Exotic species in the study area accounted for about 3% of the total flora. The most frequent aliens were *Eucalyptus camaldulensis* (particularly in Santa Lucia, 32% of plots) and *Oxalis pes-caprae* (particularly in Leni river, 47.9% of the plots) (Tab. 2). Only 7 exotic species were found in Santa Lucia, and apart from those reported above, were present with quite high frequency also *Acacia saligna* (12%), *Asclepias fructicosus* and *Arundo donax* (8%). Leni river instead resulted to have more alien species (10), also if many of them with very low frequencies (as *Avena sativa*, *Chenopodium ambrosioides* and *Xanthium spinosum*).

Tab. 2 Exotic species of the two rivers with their "Frequency of Occurrence" (FO).

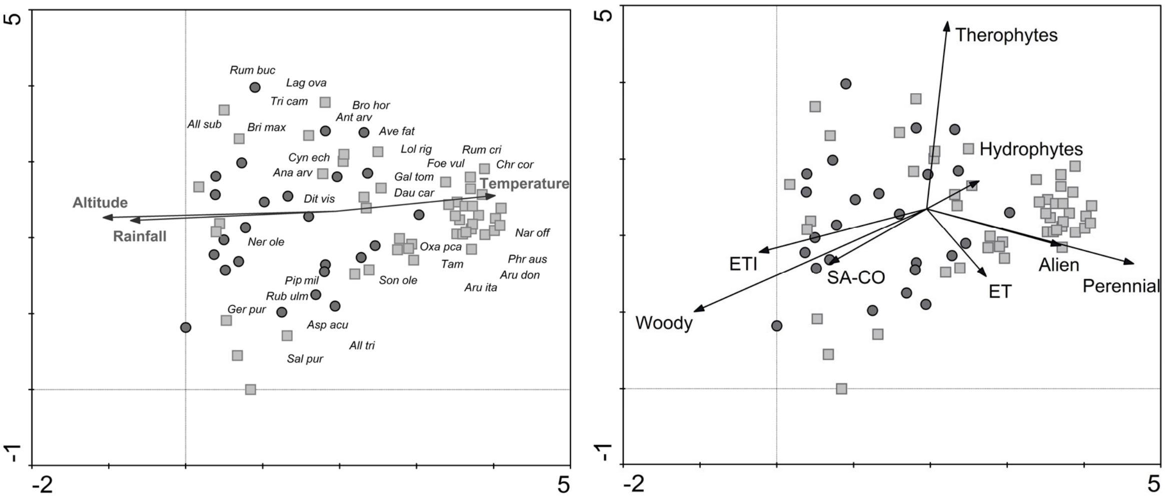
Alien species	**S. Lucia**	**Leni**
Acacia dealbata	0.0	8.3
Acacia saligna	12.0	0.0
Arundo donax	8.0	39.7
Asclepias fructicosus	8.0	0.0
Avena sativa	0.0	2.1
Brassica napus	0.0	6.3
Chenopodium ambrosioides	0.0	2.1
Erigeron bonariensis	0.0	8.3
Eucalyptus camaldulensis	32.0	12.5
Oxalis pes-caprae	16.0	47.9
Senegalia visco	4.0	0.0
Symphyotrichum squamatum	8.0	6.3
Xanthium spinosum	0.0	2.1
Xanthium strumarium	0.0	6.3

2.4.2 Floristic gradients

The longest gradient of DCA with all rivers' plots was 4.09 SD, underlying an high heterogeneity. The first axis, explaining 60.8% of the species data variability, represented the main gradient of the rivers. This was very high negatively correlated with altitude (-0.79), rain (-0.7) and positively with temperature (0.54). This gradient was linked also to the naturalness, since from one end (Fig. 2a, negative part) we can found species such as *Nerium oleander* ssp. *oleander*, a riparian woody species linked to natural or less disturbed areas, while at the other end (positive part) we found the aliens *Arundo donax* and *Oxalis pes-caprae*, species linked to high level of disturbance and to landscapes deeply modified by human activities. This finding was also confirmed by the contraposition, along the first axis, between endemic on the negative part and alien on the positive. Moreover, unconstrained ordination with functional groups passively projected (Fig. 2b) allowed to confirm that the first axes was also a structural transition from woody to herbaceous communities.

Tyrrhenian-insular and Cyrno-Sardinian endemic groups were related to the uppermost part of both the rivers, particularly of Santa Lucia, while on the contrary Tyrrhenian endemic group was linked to the lower part of Leni (Fig. 2b). The linkage of these groups with the altitudinal gradient was also confirmed by the high correlation values on the first axis (Tab. 3), while by low values on the second, underlying their independence to the second gradient.

The second axis explained 31.9% of floristic variability. It was linked to the arrow of therophytes (Fig. 2b), and detected a gradient from sites with pioneer vegetation (Fig. 2a), mostly made up by herbaceous annual species (as *Lagurus ovatus*, *Trifolium campestre*, *Briza* *maxima*), to those with more stable vegetation (as *Salix purpurea*, *Asparagus acutifolius*, *Rubus* gr. *ulmifolius*).



(a) (b)

Fig. 2 (a) DCA with environmental variables passively projected (Temperature, Altitude, Rainfall). Only species with fit range >45% are showed. Dark circles stand for Santa Lucia river plots, light squares for Leni. Legend for species abbreviation (letters in bold): ***All**ium* ***subh**irsutum*, ***All**ium* ***tri**quetrum*, ***Ana**gallis* ***arv**ensis*, ***Ant**hemis* ***arv**ensis*, ***Aru**ndo* ***don**ax*, ***Asp**aragus* ***acu**tifolius*, ***Aru**m* ***ita**licum*, ***Ave**na* ***fat**ua*, ***Bri**za* ***max**ima*, ***Bro**mus* ***hor**deaceus*, ***Chr**ysanthemum* ***cor**onarium*, ***Cyn**osurus* ***ech**inatus*, ***Dau**cus* ***car**ota*, ***Dit**trichia* ***vis**cosa*, ***Foe**niculum* ***vul**gare*, ***Gal**actites* ***tom**entosa*, ***Ger**anium* ***pur**pureum*, ***Lag**urus* ***ova**tus*, ***Lol**ium* ***rig**idum*, ***Nas**turtium* ***off**icinale* ssp. *officinale*, ***Ner**ium* ***ole**ander* ssp. *oleander*, ***Pip**tatherum* ***mil**iaceum* ssp. *miliaceum*, ***Oxa**lis* ***p**es-**ca**prae*, ***Phr**agmites* ***aus**tralis*, ***Rum**ex* ***buc**ephalophorus*, ***Rum**ex* ***cri**spus*, ***Rub**us* gr. ***ulm**ifolius*, ***Sal**ix* ***pur**purea*, ***Son**chus* ***ole**raceus*, ***Tam**arix* *sp.*, ***Tri**folium* ***cam**pestre*. (b) DCA with functional groups (Woody species, Perennial herbaceous species, Therophytes, Hydrophytes), Endemic groups (ETI = Tyrrhenian Insular endemic group; ET= Tyrrhenian endemic group; SA-CO= Cyrno-Sardinian endemic group) and Alien species passively projected.

Therophytes and perennial herbaceous species were the most important life form groups of the studied area. *T-test* underlined the presence of significant differences in the distribution of woody and perennial herbaceous (Tab. 3). Particularly, Santa Lucia river resulted to be significantly more wooded with respect to Leni. It should be stressed moreover that, while woody and perennial were strongly linked to the first axis, therophytes was the only life form highly correlated with the second axis (0.67), confirming what previously found in the ordination.

T- test about alien and endemic groups between the two rivers revealed significant differences in the distribution of Tyrrhenian endemic group (Tab. 3), significantly more frequent in Leni with respect to S. Lucia.

Tab. 3 Average percentage and standard deviation of functional groups, alien and endemic groups (ETI = Tyrrhenean Insular endemic group; ET= Tyrrhenian endemic group; SA-CO= Cyrno-Sardinian endemic group) in the two rivers. Significant differences (p<0.05, numbers in bold) were tested with a *T-test*. The last two columns reported the intra-set correlation of each group with the first two axes of DCA.

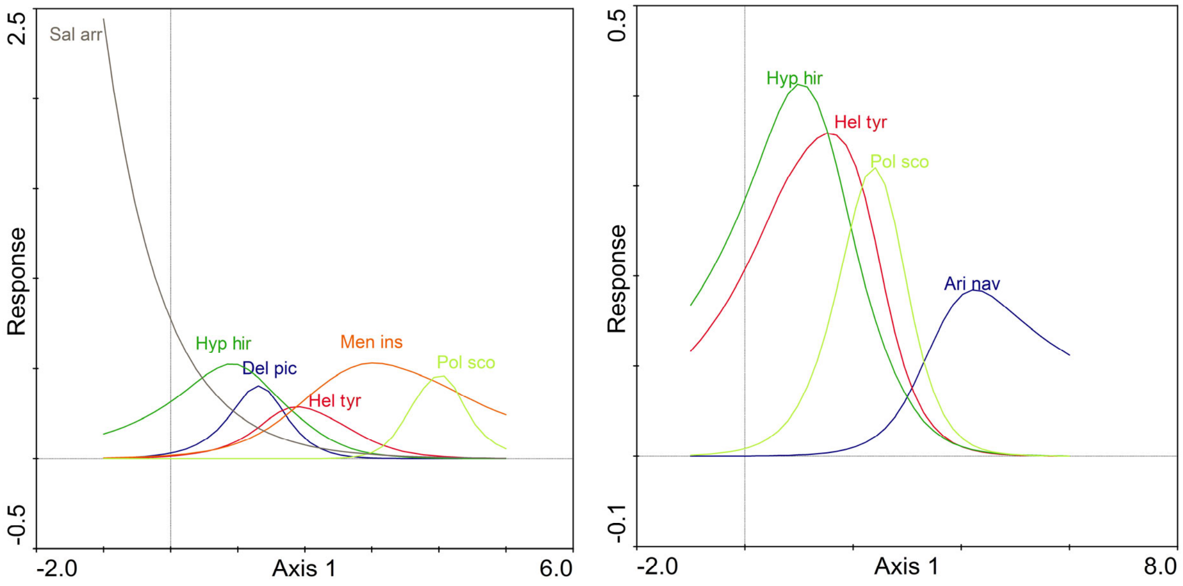
	SANTA LUCIA	LENI	Correlation Axis 1	Correlation Axis 2
Hydrophytes	0.3 ± 0.9	0.2 ± 0.8	0.17	0.1
Perennial herbs	**40.8 ± 13.8**	**51.7 ± 13.7**	0.67	-0.2
Therophytes	35 ± 15.6	37.2 ± 15.6	0.07	0.67
Woody	**24 ± 12.9**	**10.1 ± 12.9**	-0.75	-0.36
Alien	3.5 ± 4.2	4.4 ± 4	0.44	-0.13
ETI	2.3 ± 1.8	1.3 ± 2.3	-0.54	-0.15
ET	**0.2 ± 0.9**	**0.9 ± 1.7**	0.19	-0.24
SA-CO	1.9 ± 3	1.5 ± 2.5	-0.32	-0.19

2.4.3 Endemic and alien species distribution

In order to investigate how endemic and exotic species vary along the river corridor, species response curves along the first DCA axis were performed. Particularly, species response curves were created separately for the two rivers in order to understand if the endemic groups were distributed in the same manner in the two different human impacted areas.

Not all the endemic and alien species presented a significant response to the GAMs, and moreover there was not a similar pattern among the *taxa*. In Santa Lucia (Fig 4a) emerged clearly that *Salix arrigonii* was strictly linked to the upper part of the rivercourse, while all the other endemic species had unimodal response to the longitudinal gradient, and their maximum frequencies were expected at medium course, apart from *Mentha suaveolens* ssp. *insularis* and *Polygonum scoparium*, more linked to low altitude, also with the higher level of significance (Tab.5).

Endemic species of Leni had their maximum frequency in the upper an medium part of the river, with quite narrow curves; only *Aristolochia navicularis* showed to have the highest frequency of occurrence downstream. The distribution of the two major endemic species of this river, *Mentha suaveolens* ssp. *insularis* and *Plagius flosculosus*, resulted to have no preference for a specific altitude level.



(a) (b)

Fig. 4 Endemic species response curves to the first axis of DCA of (a) Santa Lucia and (b) Leni. Abbreviations stand for: Ari nav = *Aristolochia navicularis*, Del pic = *Delphinium pictum*; Hel tyr = *Helichrysum microphyllum* subsp. *tyrrhenicum*; Hyp hir = *Hypericum hircinum* ssp. *hircinum*; Men ins = *Mentha suaveolens* ssp. *insularis*; Pol sco = *Polygonum scoparium*, Sal arr = *Salix arrigonii*.

Tab. 5 Results of generalized additive models (GAM) developed for each statistically significant endemic species (*=p<0.05; **=p<0.01; ***=p<0.001).

	S. Lucia		**Leni**	
Species	F	*p*	F	*p*
Aristolochia navicularis			3.52	*
Delphinium pictum	15.94	***		
Helichrysum microphyllum ssp. *tyrrhenicum*	3.68	*	17.26	***
Hypericum hircinum ssp *hircinum*	9.18	***	11.97	***
Mentha suaveolens ssp. *insularis*	4.25	*		
Polygonum scoparium	15.02	***	21.17	***
Salix arrigonii	5.56	*		

The response curves of alien species in Santa Lucia evidenced primary that all these species were concentrated downstream. *Eucalyptus camaldulensis* was the species with the wider range of frequency; All the other species were instead more localized (*Senegalia visco* and *Acacia saligna* above all), while *Oxalis pes-caprae* and *Arundo donax* had the maximum of frequency in the last parts of the river.

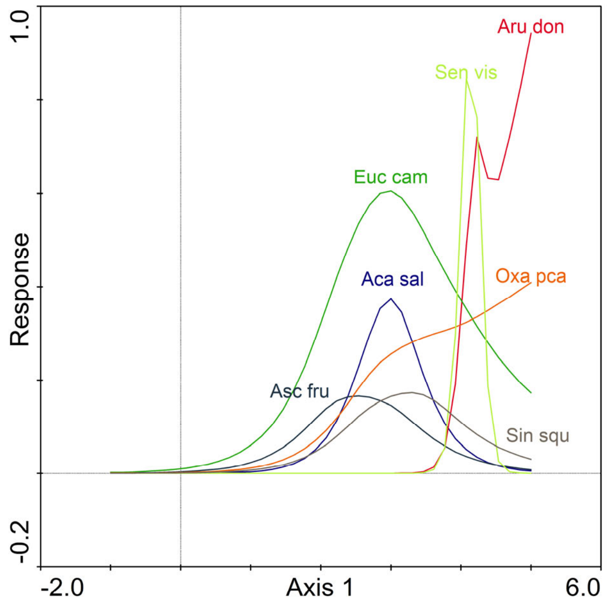
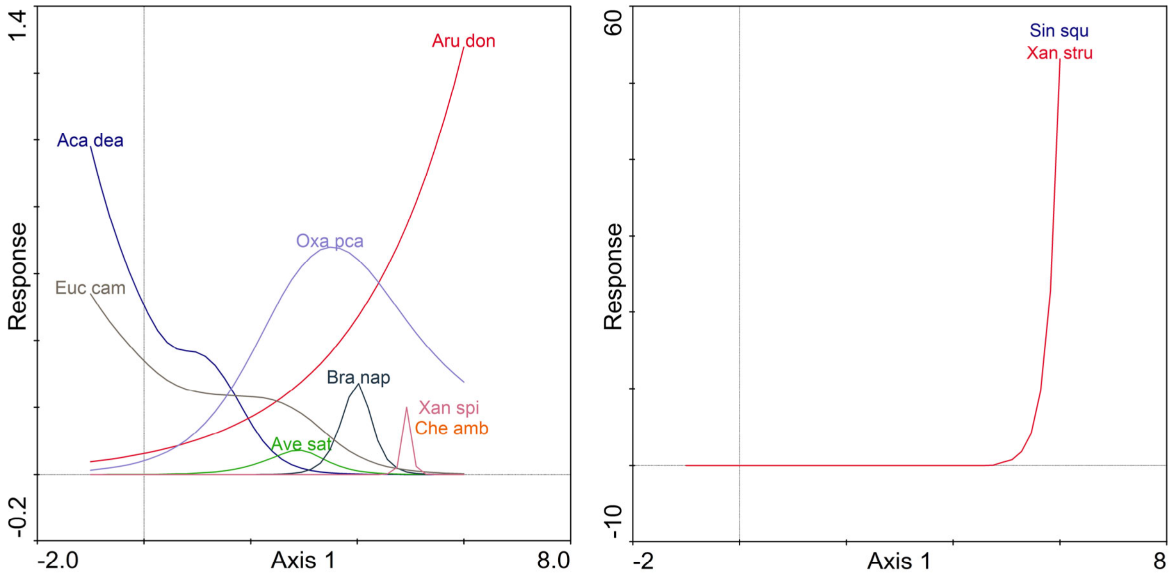


Fig. 4 Alien species response curves to the first axis of DCA of Santa Lucia. Abbreviations stand for: Asc fru = *Asclepias fructicosus*; Euc cam = *Eucalyptus camaldulensis*; Aca sal = *Acacia saligna*; Sen vis = *Senegalia visco*; Aru don = *Arundo donax*; Oxa pca = *Oxalis pes-caprae*; Sin squ = *Symphyotrichum squamatum*.

Alien species were distributed all along Leni river (Fig. 4a and b). In the upper and medium part, woody species such as *Acacia dealbata* and *Eucalyptus camaldulensis* had the maximum frequency, that decreased rapidly with decreasing altitude. On the contrary of what previously found, *Oxalis pes-caprae* was spread all along this river (with a highly significant model, see Tab. 6), while also here *Arundo donax* revealed an increasing frequency going towards the sea. Apart from *Avena sativa*, other species such as *Brassica napus*, *Chenopodium ambrosioides* and *Xanthium spinosum* showed very narrowed curves (Fig. 4a). *Symphyotrichum squamatum* and *Xanthium strumarium* revealed to be linked with the first axis, and a huge length of the second axis. Since the enormous difference about the length of this gradient between these two species and all the others would have flattened all the other species' curves, preventing us from visualize the trends, we separated them in another graph (Fig. 4b). From this analysis clearly emerged how they were strongly localized in the lowest stretches.



(a) (b)

Fig. 4 Alien species response curves to the first axis of DCA of Leni. Abbreviations stand for: (a) Ave sat = *Avena sativa*, Che amb = *Chenopodium ambrosioides*; Xan spi = *Xanthium spinosum*; Bra nap = *Brassica napus*; Aca dea = *Acacia dealbata*; Euc cam = *Eucalyptus camaldulensis*; Aru don = *Arundo donax*; Oxa pca = *Oxalis pes-caprae;* (b) Sin squ = *Symphyotrichum squamatum*; Xan str = *Xanthium strumarium*.

Tab. 6 Results of generalized additive models (GAM) developed for each statistically significant exotic species (*=p<0.05; **=p<0.01; ***=p<0.001).

	S. Lucia		Leni	
	F	*p*	F	*p*
Acacia dealbata			28.29	***
Acacia saligna	13.21	***		
Arundo donax	60.84	***	10.61	**
Asclepias fructicosus	2.13	n.s.		
Avena sativa			4.45	*
Brassica napus			23.15	***
Chenopodium ambrosioides			2.34	*
Conyza bonariensis			2.94	n.s.
Eucalyptus camaldulensis	8.65	**	5.34	**
Oxalis pes-caprae	3.89	*	9.53	***
Senegalia visco	103.75	***		
Symphyotrichum squamatum	2.46	n.s.	5.38	***
Xanthium spinosum			2.39	*
Xanthium strumarium			5.38	***

2.5 DISCUSSION

2.5.1 Floristic features of the rivers

The length of the main gradient of ordination, together with the fact that less than half of total species were shared, demonstrated the high floristic diversity of the study areas and confirmed the importance of riparian landscapes for biodiversity conservation (Nilsson et al., 1989; Pollock et al., 1998; Ward et al., 1999; Naiman et al., 1993), particularly in Mediterranean basin (Corbacho et al., 2003). Despite the deep human influence, alien richness was substantially low, as found in other Mediterranean rivers of Portugal and Spain (Aguiar et al., 2000; Ferreira et al., 2002; Tabacchi et al., 1996). Some authors suggested that the low number of aliens is related to the fact that native competitors are well adapted to the area's torrential hydrological regimes (Tabacchi et al., 1996), and also to the resilience of Mediterranean sclerophyllous vegetation (Traverset et al., 2008; Vilà et al., 2008). In our case, one of the most important alien species in both areas was *Eucalyptus camaldulensis,* planted in the last century in coastal areas in order to fight the *malaria*, a typical disease of Mediterranean marshy zones, and also employed in paper industries. This three, usually not invasive species, tend instead to become naturalized in rivers, invading their floodplains (Podda et al., 2010; 2011). *Oxalis pes-caprae* is an alien species considered the most invasive in Mediterranean (Vilà et al., 2006; Affre et al., 2010), intentionally introduced in Sardinia and afterwards quickly spread, because of its high reproductive rate and wide ecological range. Also *Arundo donax* resulted to be frequent in the lowlands of both the rivers, as a consequence of the deep human impact and high-nitrogen availability due mainly to agriculture (Salinas and Casas, 2007; Podda et al., 2010). Other alien species were found in our study area with low frequencies (as *Acacia saligna, Senegalia visco, Brassica napus, Chenopodium ambrosioides* and *Xanthium spinosum*) and were localized to single riverbed stretches, mostly near areas with specific kind of cultivations.

These rivers resulted to share only one half of the total endemic flora. The number of endemic species was high in all the study area, and in both rivers Sardo-Corsican and Tyrrhenean-insular endemics were dominant, confirming the biogeographical classification of the study area, according to Bacchetta and Pontecorvo (2005) and Bacchetta et al. (2007; 2009). Particularly, the different relative dominance of these groups in the two areas was due to the presence, in the lower section of Leni river, of carbonatic sediments (Angius and Bacchetta, 2009) that tend to favor Sardinian Subprovince endemics. The most frequent endemic species, *Mentha suaveolens* ssp. *insularis* and *Hypericum hircinum* ssp *hircinum,* were linked to *Hyperico hircini-Caricetum microcarpae* association (Bacchetta and Mossa, 2004), phytocoenoses dominated by *Carex microcarpa,* whose location in watercourses is limited by the presence of water during all the year, condition that in Sardinia is confined mostly in the headwater section of streams.

2.5.2 Floristic gradient

Ordination analysis clearly confirmed that the altitudinal/longitudinal was the main gradient driving the development of riparian flora in the area. Looking at the correlation coefficients of DCA first axis with altitude and at the distribution of functional groups along this gradient, we observed a longitudinal structural zonation from shrub and tree species of the mountain areas (woody species, left part of the axis) to herbaceous communities of lowlands (perennial herbaceous), a pattern deeply linked to the naturalness, as showed by the contraposition endemic vs. alien (positive correlation with alien, negative with Cyrno-Sardinian and Tyrrhenean Endemic). Thanks to the higher naturalness (Bacchetta et al., 2003), provided also by the presence of protected areas, and also to more suitable environmental conditions (higher moisture, lower temperature), woody species were related to this upper reaches of the streams and less accessible zones of the basins, where it is rarely convenient to carry out agricultural practices (cultivation, grazing) because of the steep slopes, to the advantage of natural vegetation. In the lowland areas, instead, there were the more suitable conditions for human activities, that as noted by Corbacho et al. (2003), bring to the alterations of the internal structure of the riparian corridor and the subsequent simplification of the structural heterogeneity, with a decrease on species diversity (e.g. Croonquist and Brooks, 1993; Keller et al., 1993; Montalvo and Herrera, 1993). This degradation was in fact the principal cause of the floristic similarities among the lower plots of Leni river. The reduction of riparian strips in the impacted areas strongly affect floristic composition, since led each plot to be more influenced by the surrounding matrix instead that by the natural gradients and dynamics of the river (Richardson et al., 2007). This feature should be regarded also as one of the main causes of plant species unexplained variability, even if it can result partly from chance and partly from the deterministic effects of historical factors that could not be included in the community analysis and that are unique for each community (Kodric-Brown and Brown, 1993; Belyea and Lancaster, 1999).

The analysis of more frequent species and of functional groups revealed that in Santa Lucia there were mostly woody species (such as *Nerium oleander* ssp. *oleander, Rubus* gr. *ulmifolius*) and endemics, while in Leni perennial (sinantropic such as *Avena fatua*) and alien species (as *Oxalis pes-caprae* and *Arundo donax*). These findings were a reflection of the dominant morphology of the area, since the 2/3 of Leni river flow in the main level land of the whole island (see Fig.1), with resulting higher human impact (intensive agricultural activities, towns, farms and generally a deep human modifications of riparian strips), conditions that didn’t allow the survivor of the natural riparian vegetation. Santa Lucia instead is much shorter and overall doesn’t flow between towns or agricultural lands, but from the mountain directly into the sea, thus preserving a more natural flora. Also the different percentage of woody and herbaceous species between the rivers should be referred to this. In Santa Lucia, since the alluvial part is shorter, the proportion of mountain riverbed with respect to valley riverbed is much higher than in Leni river. As a result, the environmental features that dominate in the course (such as the higher moisture) were suitable for woody species. On the contrary, in correspondence of lowlands, with high temperatures, low rainfall and high human pressure that tend to increase dryness, the environmental conditions that favour the growth of herbaceous xeric therophytes, likely to recover from disturbance more quickly than woody species, due to their shorter life-span and higher colonization rates, in particular the most ruderal and rain-dependent xeric-annuals (Tabacchi et al., 1998; Bagstad et al., 2005; Lite et al., 2005), and also of alien species (such as *Senegalia visco*).

Therophytes were one of the dominant life forms of the study area, since particularly linked to Mediterranean rivers environmental conditions (Ferreira and Moreira, 1999; Ferreira et al., 2004). They were also the group more linked to the positive part of the second axis of DCA, in contrast to woody species, linked to the negative side. Also in this case there was a structural differentiation between, from one hand, plots characterized by the presence of some kind of disturbance (as flooding, presence of rocky soils, dryness) that doesn't allow the establishment of perennial plant species (Mossa and Bacchetta, 1998; Bacchetta, 2006), and for this reason dominated by annual species (e.g. therophytes such as *Lagurus ovatus*, *Briza maxima*, *Trifolium campestre*, *Cynosurus echinatus*) and, from the other, plots of river stretches covered by woods (such as *Nerium oleander* ssp. *oleander*, see Fig. 2a). These environmental and vegetational features coexisted in the upper part of both the rivers.

Percentage of hydrophytes was low in the whole study area compared to what found in mesic fluvial systems (Naiman et al., 1993). According to Ferreira et al. (2004), this low richness can be attributed to the hydrological intermittency of the rivers, and to human interferences in the flow regime, particularly water abstraction. For this reason, the study area does not offer many ecological niches suitable for hydrophytes (Bacchetta and Pontecorvo, 2005; Angius and Bacchetta, 2009). The Mediterranean climatic conditions favored instead perennial herbaceous species, related also to rupestrian habitats of the upper parts of the two rivers (Bacchetta and Pontecorvo, 2005; Bacchetta, 2006).

2.5.3 Comparison among endemic and alien species distribution

Alien and endemic species resulted to respond differently to the longitudinal gradient of each river. As noted also in the previous analyses, Santa Lucia was richer in endemic species, and they were distributed all along the river corridor, even if with different frequencies, from headwater to mouth. This fact can be explained taking into account that endemic species are generally linked to the more natural and less disturbed areas that occur upstream in the headwater section (as *Salix arrigonii*, linked to the most natural riparian woodlands, see Brullo, 1993; Angius and Bacchetta, 2009), but at the same time, in Mediterranean basin, they are mainly stress-tolerant species, perfectly adapted to harsh habitats (Médail and Verlaque, 1997) occurring on the medium course (as *Hypericum hircinum* and *Mentha insularis*, linked to riparian scrublands dominated by *Nerium oleander* or *Salix purpurea*). As expected, all endemic species resulted to decrease at the final stretches of the rivers, probably due to the higher environmental stress (as salinity), but overall because of the presence of ruderal and human impacted areas where wide distribution and annual species were dominant (Bacchetta, 2006). Here we found species such as *Helichrysum microphyllum* ssp. *tyrrhenicum* and *Polygonum scoparium*, typical of garrigues of lowlands alluvial terraces (Angiolini and Bacchetta, 2003; Biondi et al., 1995). Since the level of naturalness was instead very low in Leni river, also the number of endemics was low (tuned down by the high human impact and landscape modification). All these species were distributed in the medium (e.g. *Hypericum hircinum* ssp. *hircinum*), low (e.g. *Helichrysum microphyllum* ssp. *tyrrhenicum*) and very low (e.g. *Aristolochia navicularis*) rivercourse. The most frequent endemic species, *Mentha suaveolens* ssp. *insularis*, showed no particular distributional pattern along the longitudinal gradient, and at the same time in Santa Lucia resulted to be linked to the longitudinal gradient with a wide curve, a result due to its wide ecological range, particularly to its ability to tolerate different ecological conditions and hydrological fluctuations that are typical of torrential streams (Valsecchi, 1993).

The distribution of alien species resulted to be inhomogeneous between the two rivers, since in Santa Lucia they were present only in the second half of the river, while in Leni they were spread everywhere along the course, a feature linked one more time to the higher degree and wider distributed human impact, here present also in the upper part (with dams, reforestation areas and mining activities in the past). As noted by Affre et al. (2010) for Mediterranean islands, alien species, even some of the worst invaders, are largely restricted to anthropogenic habitats where levels of native plant endemism are often low (Vilà and Muñoz, 1999). Moreover, most alien species introduced to Mediterranean basin tend not to be as tolerant as the native species to the xeric conditions typical of this habitat (Lambdon et al., 2008; Traveset et al., 2008; Vilà et al., 2008). This result is especially interesting in light of the fact that shrubby habitats form a large fraction of typical Mediterranean island vegetation, including the upper part of the studied rivers. Our results seemed to confirm this finding: *Oxalis pes-caprae*, one of the most spread alien species in the study area, and one of the most invasive species, resulted in fact to have the peak of frequency in the most disturbed areas, and particularly in the final half of Leni river, with the surrounding environmental matrix deeply modified by cultivations, since it spreads only in agricultural/disturbed habitats (Traveset et al., 2008). Exotic woody species (such as *Eucalyptus camaldulensis* and *Acacia* sp. pl.) seemed instead not to follow this pattern, being more frequent in the upper (Leni) and medium (S. Lucia) part of the rivers, and decreasing rapidly with decreasing altitude, since linked of the presence of reforestation areas, and because of the intense agricultural activities of the valley do not allow the survivor of woody species, either natural and exotic. Concerning the other alien species investigated in this study, we can see that in general the curves of Santa Lucia's aliens were quite wide, while those of Leni much more narrowed, identifying the localized presence of these species in different parts of the rivers. The strict presence of these species was a result of the lateral connections between the riparian and terrestrial ecosystems (Aguiar and Ferreira, 2005), that in this area were mostly occupied by a patchy mosaic pattern of nearby land-use, that provided a large and diverse pool of alien species (Aguiar et al., 2007). This was confirmed also by the fact that *Chenopodium ambrosioides*, *Xanthium* sp. pl., *Symphyotrichum squamatus*, *Avena sativa*, *Brassica napus* and *Asclepias fructicosus* were all alien species of "unintentional introduction" (Miller et al., 2006), introduced with cultivations. These species only rarely became dangerous for the native vegetation, but in riparian areas this is more likely to happen, as in the case of *Symphyotrichum* (Podda et al., 2010).

In correspondence of the middle course of Santa Lucia, endemic and alien species resulted to coexist. The higher frequencies of *Mentha insularis* and *Polygonum scoparium* were in fact found together with those of *Eucalyptus camaldulensis* and *Acacia saligna*. Other species, such as *Salix arrigonii*, *Hypericum hircinum* and *Delphinum pictum*, showed to have preferential area of distribution in the upper part of the river, probably because they require particular environmental conditions and resources, and for these reasons are highly sensitive to habitat disturbance and transformation (Aguiar et al., 2007). In Leni river the coexistence of the two groups of species resulted to be more difficult. Only *Aristolochia navicularis*, whose maximum frequency occurred in the lower sections of the river, resulted to share the habitat with *Brassica napus* and, above all, *Oxalis pes-caprae*. The other endemic species curves resulted instead to be shifted towards upstream. This was for instance the case of *Polygonum scoparium*, that in Santa Lucia had the higher frequency in the last sections of riverbed, while in Leni it was found at middle course, a result that can be linked to the severe disturbance of this area. Also *Helichrysum tyrrhenicum* and *Hypericum hircinum* resulted to have the maximum frequency in the upper sections, and this can be due respectively to the presence of alluvial terraces and incoherent soils and to ecological preference for riparian forest and scrublands. Affre et al. (2010) noted that, even where native habitats are colonized, patterns of alien abundance are highly variable, indicating that native species may be threatened in some localities but not in all their area of distribution. In fact, alien plant species are thought to be largely restricted to human dominated habitats of islands and their impact on native communities, and hence the threat to endemics, might be limited.

2.6 CONCLUSIONS

Improved understanding of plant distribution is critical for managing and conserving areas of biodiversity importance, especially given the continuing threats to biodiversity from human activity (Vogiatzakis and Griffiths, 2006). Worldwide, many regions of significant botanical interest remain poorly known given restricted resources for detailed botanical survey. It is therefore essential to develop and test techniques to determine vascular flora distribution, especially in the less studied areas. In the frame of this needs and limitations, an approach as that used in our study allowed us to have a quite defined idea of the ecological condition of both rivers. By our analyses, the distribution patterns of alien and endemic resulted to be strongly related to the naturalness conditions of the rivers stretches, such as, as expected, the upper part of both rivers. Nevertheless, clearly emerged the different degree of naturalness of these river stretches (even if both included into Protected Areas), a finding that should be carefully taken into account in every further management strategies for Leni river. The lower parts, being deeply human impacted, had the most severe modifications, and alien species resulted to have the wider spread of the whole area. In the intermediate part of the rivers, instead, alien and endemic species resulted to coexist. This is an important finding, since it underlined the presence of areas with important presence of endemic species, that at the same time are affected by the presence of exotic species due to the landscape modifications of the surroundings. This underscored the need to protect riparian vegetation, especially in transformed landscapes. In fact, weak or absent human pressure, fragmentation and land degradation, together with higher competition by autochthonous species in their natural habitats, tend to reduce alien species impact (Vilà and Weiner, 2004). For this reason, conservation strategies should keep on preserving the most natural areas that harbor habitats of endemic species (such as the mountain parts of both the rivers), but above all focus in reducing the human pressure all along the river corridors, reducing in turn the probability of alien invasion in other areas not jet subjected to conservation but where endemic are however present (Aguiar et al., 2007). Maintaining natural shrubby and woody riparian habitats may thus serve as a significant barrier to invasive species spread (Marvier et al., 2004), in addition of improving many other ecosystem fuctions (as resistance of soils to erosion during flood events frequently involving the area during autumn and spring, Bacchetta et al., 2003; Angius and Bacchetta 2009).

This study demonstrated that combining plant species information recorded by random sampling and multivariate statistics can be a reliable tool to rapidly assess broad and preliminary information about the distribution of important plant groups along rivers. Our analyses allowed to delineate general floristic features of the two rivers, such as also similarities and differences. In this way, we can obtain, in a rapid and cost-effective way, basic general information of areas where floristic datasets are poor or absent, to be used as starting point for further ecological studies about conservation planning strategies. Results pointed out the usefulness of the adopted method in order to plan cost-effective field surveys specifically devoted to the management of most endangered areas, since proposed a methodology able to provide information on more critical segments. In this way, it allows to better planning following studies, with also a reduction of the number of sampling sites, filling an important gap in the current lack of resources for extensive surveys.

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CHAPTER 3:

INFLUENCE OF BEDROCK-ALLUVIAL TRANSITION ON PLANT SPECIES DISTRIBUTION ALONG A MEDITERRANEAN RIVER CORRIDOR

ABSTRACT

The variation of riparian plant species composition along a river according to lithological features, forming more or less discrete plant assemblages, was tested using multivariate and univariate analyses, applying Sørensen index to examine similarity between geological and floristic groups and Wilson-Shmida index to investigate species turnover. The analyses were based on field data recorded along a Mediterranean river (Rio Santa Lucia, Sardinia, Italy), where the morphology is influenced to the bedrock-alluvial transition. The results obtained from the various analytical techniques applied were in close agreement and underlined that the lithological types exerted an important influence on the distribution and richness (peak in the medium and the upper river part) of riparian plants, but also in their life forms (woody species and hemicryptophytes). The distribution patterns of species along the river suggested that primary drivers in the organization of the riparian plant communities were lithological types, geomorphology and altitude. Moreover, the change bedrock-alluvial marked the highest species turnover, linked also to a different degree of human disturbance. The results of the present study indicate that the degree of bedrock/alluvial influence is an integral component of the patch structure and strongly influence riparian plant distribution patterns in a Mediterranean environment.

Keywords: β-turnover, floristic discontinuity, riparian plants, Sardinia, species richness, statistical techniques

3.1 INTRODUCTION

River corridors are recognized as linear landscapes in which water flows play a key role in connecting various landscape patches (Nilsson et al., 1989; Malanson, 1993; Ward, 1998). Due to their extremely high habitat heterogeneity and habitat connectivity, river corridors are among the most species rich ecosystems of temperate regions (Nilsson et al., 1989; Pollock et al., 1998; Corbacho et al., 2003).

Most understanding of vegetation environment relationships along riparian corridors has emerged predominantly from relationships established with gradients (Hughes, 1988; Bowman and McDonough, 1991; Glavac et al., 1992; van Coller et al., 1997). In fact, the environmental heterogeneity of riparian corridors is a function of the strong environmental gradients that extend vertically (height above the channel, Hupp and Osterkamp, 1985), laterally (lateral distance away from the channel, Decocq, 2002) and longitudinally (distance down river, Tabacchi et al., 1990). These are composite gradients (Austin and Smith, 1989; van Coller et al., 2000), as represent change in a number of important environmental variables, such as flooding, water availability, soil texture and nutrients, and are for this reason useful descriptors of plant species distribution, providing important insights into the possible processes that determine such distribution patterns (van Coller et al., 2000).

For many riparian systems, a simple gradient approach adequately characterizes riparian vegetation patterns and has resulted in an understanding of important influencing processes. However, for geomorphologically complex rivers, a gradient paradigm does not deal effectively with the complexity of the patch mosaic structure arising from dynamic fluvial processes. In fact, despite the distribution of plant species in riparian forests have repeatedly been shown to be closely associated with variation in topography (Xu et al., 2008) and landforms (Hupp and Rinaldi, 2007; Mollot et al., 2008), the influence of the complex geomorphological structure of riparian ecosystems (Gregory et al., 1991) on vegetation distribution patterns is often ignored.

The catchment geology combined with the hydrogeomorphic processes of rivers create a high heterogeneous landscape consisting of a mosaic of different morphological units (Gregory et al., 1991). This heterogeneity is an important factor controlling vegetation development (Kalliola and Puhakka, 1988; Amoros and Bornette, 2002; Baattrup-Pedersen et al., 2005). Patchiness in the geomorphology is further enhanced by the presence of bedrock (van Niekerk et al., 1995), a feature insufficiently dealt with in riparian vegetation studies. In fact, while most attention has been focused on rivers that are predominantly alluvial controlled, few studies have looked at systems where the morphology is influenced to a large degree by the underlying geology and bedrock lithologies (van Coller et al., 1997), resulting in variable sedimentation and erosion down the course of the river in response to variable channel gradients (van Niekerk et al., 1996). The presence of outcrop of bedrock tend to create a complex geomorphology, and thus a complex plant species distribution (van Niekerk et al., 1995; van Coller et al., 2000). The transition between different kind of geology generally lead also to topographic discontinuities, strongly influencing ecological processes that structure biological communities (Malanson, 1993; Steiger et al., 2005), generating high level of plant turnover and thus creating deep floristic discontinuities (Malanson 1993; van Coller 1997). This important feature of riparian landscapes is still now poorly and insufficiently studied (van Coller et al., 2000), and all previous researches do not quantify the influence of bedrock/alluvial transition on plant species distribution. Besides, distribution patterns of river plants are scarcely investigated in Mediterranean areas (Ferreira and Moreira, 1999; Hupp and Rinaldi, 2007; Salinas and Casas, 2007).

Here we present the results of a study carried out along a Mediterranean river, characterized by the upper stretch bedrock-controlled and lower part alluvial-controlled. The question of main interest is how much plant species composition vary along the river according to lithological types (bedrock/alluvial), forming more or less discrete plant coenosis. To test and measure the influence bedrock-alluvial transition on species distribution, life forms and richness we used different (both univariate and multivariate) statistical techniques, in order to determine if there was consistency in results using multiple procedures. This approach provided added assurance that the results by any one method were actually occurring (see Mollot et al., 2008). We used also the method of Borcard et al. (1992) to explore how lithological type and elevation are related to the compositional variation in a Mediterranean riparian area. To investigate the presence and location of meaningful discontinuities in riparian plant distribution and richness along the river corridor, we analyzed the degree of floristic continuity/discontinuity with Wilson and Shmida index, a beta turnover measure for species presence/absence data along environmental gradients (Wilson and Shmida, 1984).

3.2 STUDY AREA

The Santa Lucia river is located in the south-western part of Sardinia, between 39° 09’ 10’’ and 39° 06’ 56’’ N, 9° 01’ 17’’ and 8° 46’ 51’’ E (Figure 1). It represents the main river of the Sulcis region and the catchment basin is almost 110 km^2. The stretch investigated extends for almost 20 km riverside floodplain and flows in a prevalent NE direction in the upper part and SE in the lower. The altitudinal range is of almost 500 m and the river has not any tributary.

The climate belong to Mediterranean type and is substantially homogeneous in the study area, with total annual rainfall ranges from 546 mm to 1172 mm (monthly maximum mean of 193.5 mm in December and minimum mean of 3.3 mm in July) and mean temperature range from 13.1°C to 18.5°C (monthly maximum mean of 28.1°C in August and minimum mean of 6.7°C in January).

According to the climatic data available and in agreement with the bioclimatic classification by Rivas-Martínez (2002), the bioclimate of the studied area is Mediterranean Pluviseasonal Oceanic (MPO). Thermothypes vary from the upper thermomediterranean to the lower mesomediterranean belt with ombrotypes ranging to upper dry to lower humid (Bacchetta, 2006). During summer the river dries up almost totally, while in autumn and spring is affected by flood events.

Santa Lucia river flows in the upper part over outcrops of resistant rock (bedrock), in the form of Palaeozoic granites and metamorphytes, while in lowlands there was the Quaternary sediment accumulation (alluvial) with cobblestones, sands and clays deposited by streams (see Bacchetta et al., 2003; 2005; Bacchetta, 2006). The change bedrock-alluvial is underlined also by the change in geomorphology and elevation gradient of riverbed. In the mountain part the river flows into a narrow valley with V profile, while in correspondence of the transition from bedrock to the alluvial lithology, it wides over an alluvial conoid (Fig. 1). In the mountain part, located into a protected area (SCI - Site of Community Importance), the landscape is characterized by low-intensity agro-pastoral systems and by woodlands dominated by holm-oak (*Quercus ilex*) with cork-oak (*Q. suber*); in the lower part, there are industries, villages and extensive grazing areas. Phytosociological surveys of Angius and Bacchetta (2009) reported the class *Quercetea ilicis* for woodlands surrounding the river and the classes *Nerio-Tamaricetea* and *Salici purpureae-Populetea nigrae* for the riparian woods (for *syntaxa* nomenclature see Bacchetta et al. 2009). At the end of its course, the river flows into a wetland included in a protected area (SCI).

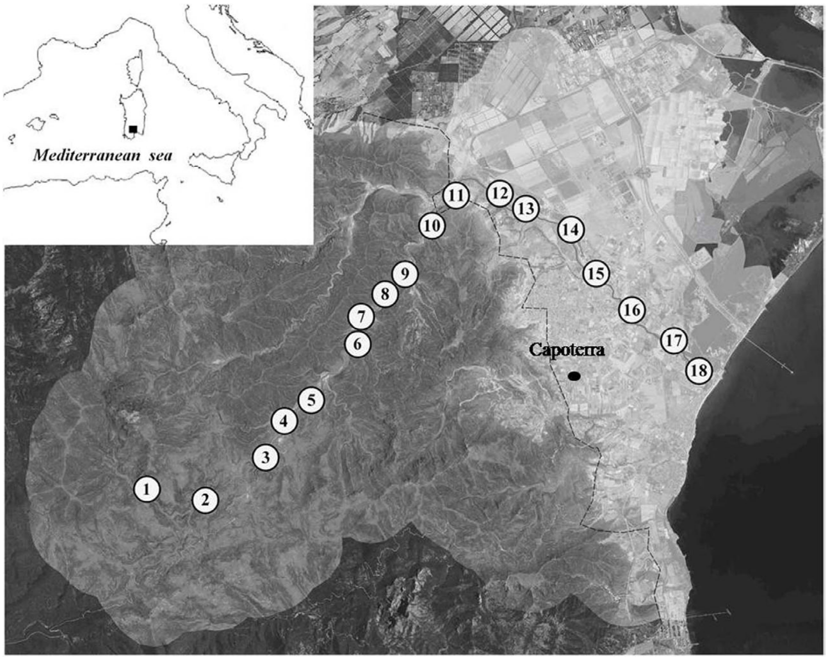

Fig. 1 Santa Lucia River basin (light grey) with plots signed as circles (and their respective number) and the geographical localization of the study area. Dotted line marks the borderline between bedrock (on the left) and alluvial (on the right).

3.3 METHODS

3.3.1 Field methods and selected variables

Since one of the goals of this study is the analysis of riparian plant species of Santa Lucia river, sampling was carried out considering only floodplain. For the analyses of plant distribution along the river, we used a stratified random sampling design. To avoid the possibility to have grouped plots and with the aim to represent variations in species assemblages and environmental features (Angiolini et al., 2011), the river was divided, starting from source until the mouth, perpendicularly to direction flow into 9 sections of 2 km of length; for each section we placed randomly 2 plots of 10m ×10m. This dimension was found to be adequate to detect the vegetational mosaic of the floodplain, because it made it possible to explain the relationships between species richness and environmental features both in forests (Schuster and Diekmann, 2005) and in grasslands (Gross et al., 2000). For each plot we recorded all vascular plants species from May to July 2008.

The distribution of plots in different lithological types, the description of the lithological types and geomorphology obtained from a GIS (Geographical Information System), using 1:25000 digital maps, are shown in Tab. 1 and Fig. 1. The elevation of each plot was derived from DTM (10 m of resolution) and normalized by a log transformation for statistical analyses. Taxonomic nomenclature followed Conti et al. (2005; 2007).

Life forms were checked in the field and expressed by the abbreviations reported in Pignatti (1982) based on the Raunkiaer's classification (1934), taking into account: phanerophytes (P), nanophanerophytes (NP), hemichryptophytes (H), therophytes (T), geophytes (G) and chamaephytes (Ch).

Tab. 1 Plot distribution and main topographic features of the study area.

Plots	Lithological types	Geomorphology	Elevation
1-10	Bedrock (outcrops of granites and metamorphytes).	Steep sides, from incised in the bedrock gulley to moderately incised	From 402 to 90 m asl.
11-18	Alluvials (pebbles, sands and clays).	Level lands. Accumulation of sediment.	From 50 to 0.5 m asl.

3.3.2 Statistical analyses

Cluster analysis, carried out for the species by plots matrix, was used to investigate if samples groups classified basing only on floristic similarity corresponded to their lithological types. Two-Way INdicator SPecies ANalysis (TWINSPAN; Hill, 1979) is based on division of sequential reciprocal averaging ordinations and separated sample locations into groups according to the presence or absence of species.

Since we are interested to know if there was a correspondence between lithological types and floristic composition, we applied the Sørensen index (Sørensen, 1948) between groups of plots individuated by cluster analysis on the base of their floristic homogeneity (using first and second cut level of cluster) and groups delineated taking into account the lithological types.

Classification was followed also by a Multiple Response Permutation Procedure (MRPP; Mielke, 1984) to test the differences in plant assemblages across the lithological types. The T Statistic measured between-group separability. A large negative *T* value ($\leq$ -9.0) indicates high separability (i.e., the more negative the test statistic, the greater the species differences among the groups). The *A* Statistic estimated the within-group homogeneity and was chance-corrected. The *A* statistic ranges from 0.0 – 1.0 (usually A>0.1 is considered significative) with higher values indicating a high degree of homogeneity. Moreover, *A* is usually < 0.1 when there is a high number of species.

The characteristic species of each lithological type were then explored by an INdicator SPecies ANalysis using the IndVal method (Dufrène and Legendre, 1997) as implemented in PcOrd 4.25 (McCune and Mefford, 1999), which is a useful method to identify indicator species and/or species assemblages that characterise groups of samples. The null hypothesis was no difference in species response across lithological types. The result produced indicator values (IV) (Dufrène and Legendre, 1997), ranging from zero (no indication) to 100 (perfect indication), that stand for the relative frequency within each lithological type. A Monte Carlo test with 499 permutations was used to evaluate the statistical significance of the maximum indicator value recorded for a given species (Dufrène and Legendre, 1997; McCune and Mefford, 1999; McCune and Grace, 2002).

Differences on percentage of life forms and richness values were investigated with a *t-test*. Richness value were log transformed to normalize the data distribution.

To detect if the floristic dominant gradient agreed with cluster analysis results and/or lithological classification, and to evaluate also the length of the gradient, indirect gradient analysis was carried out using Detrended Correspondence Analysis (DCA; ter Braak, 1995). This ordination technique was used also to visually represent if plots from different lithological types showed a different pattern of species richness. We subsequently introduced environmental features (lithology and altitude) as passive variables, which allowed direct comparison of the ordination axes with these variables.

To describe consistent relationships of the lithological types (L) upon the floristic composition, when we have already removed the compositional variability explained by the altitude, we used a partial ordination (Lepš and Šmilauer, 2003). Partial CCAs (gradient length of 4.58 SD) with four-step procedure described by Borcard et al. (1992) were performed. Within each CCA, Monte Carlo tests with 999 unrestricted permutations were performed to determine the significance of the trace statistics and of the first eigenvalue (ter Braak and Šmilauer, 2002).

To determine how much the lithology of the area influenced the floristic composition of the river corridor, we used a measure of beta diversity recommended when sample data can be arranged along a single environmental gradient. This measure is beta turnover (β_t), and has a direct, intuitive meaning of degree of species turnover between adjacent pairs of plots along the longitudinal gradient according to the formula proposed by Wilson and Shmida (1984):

$$\beta_T = \frac{g(H)+l(H)}{2\alpha}$$

Where: *H* is the habitat gradient; *g(H)* and *l(H)* are the number of species gained and lost, respectively, moving along the habitat gradient *H*; α is the average number of species found in plot along *H*. The more dissimilar two groups are, the higher is the index, reaching a maximum of 1 at total dissimilarity. This index is one of the most frequently used indices and results are comparable to those of other β-diversity indices (Koleff et al., 2003; Magurran, 2004). Moreover, analyses carried out on presence/absence data guaranteed that the changes in species composition was genuine species turnover, not merely a change in species/cover abundance (Demars and Harper, 2005).

Clustering was carried out using PC-Ord (McCune and Mefford, 1999), ordination using CANOCO 4.5 (ter Braak and Šmilauer, 2002), and other statistical analyses using STATISTICA 6.0 package (StatSoft Inc., 1995).

3.4 RESULTS

In total, 201 *taxa* were identified along the Santa Lucia river. More than one third of the species were found in only one plot and about an half in less than three plot. Only one species (*Nerium oleander* ssp. *oleander*) was present in more than 70% of plots, while ten species were present in more than 50% of plots (see Tab. 2). The species exclusive of a single lithological type were 90 (44.8%) for bedrock and 53 (26.4%) for alluvial. The mean value of species richness for the study area is 35.06 ± 5.52 SD.

Tab. 2 More frequent species in the riparian vegetation. The number of plots shows where the species is found for the two lithological types. Also the relative percentage of the presence on the total number of plot is shown.

Most frequent species	Number of plots bedrock lithology	 alluvial lithology	 total	%
Nerium oleander ssp. *oleander*	9	5	14	77.8
Rubus gr. *ulmifolius*	9	3	12	66.7
Geranium purpureum	9	2	11	61.1
Sonchus oleraceus	3	8	11	61.1
Piptatherum miliaceum	4	6	10	55.6
Rubia peregrina ssp. *peregrina*	6	4	10	55.6
Salix purpurea ssp. *purpurea*	6	4	10	55.6
Allium subhirsutum	8	1	9	50
Asparagus acutifolius	4	5	9	50
Dittrichia viscosa	1	8	9	50
Phillyrea latifolia	9	0	9	50

Average richness of species was significantly higher in bedrock (40.3 ± 10.25SD) than in alluvial (28.5 ± 8.47SD) (t = 2.48, df = 16, P <0.05). Average percentage of the life forms of bedrock and alluvial species resulted significant different for phanerophytes and nanophanerophytes, with higher frequency in bedrock (24.28 ± 10.2 SD and 10.5 ± 2.6 SD) than in alluvial (18.72 ± 12.99 SD and 2.71 ± 3.75 SD) (t = 1.41, d.f. = 16, P < 0.01 and t = 3.43, d.f. = 16, P < 0.05), and for hemicryptophytes, which have high percentage in alluvial (29.48 ± 4.04 SD) with respect to bedrock (14.87 ± 5.35 SD) (t = -4.32, d.f. = 16, P < 0.01). The other life forms showed no differences between the lithological types.

The hierarchical classification (TWINSPAN, Fig. 2) suggested the existence of two major floristic groups of sites with 59.1% between-group dissimilarity (first cut level, types A and B), almost completely in agreement with the bedrock-alluvial division (see Tab. 1). The indicator species for bedrock plots resulted to be *Allium subhirsutum* and *Phillyrea latifolia.* The two main floristic assemblages were subdivided into four classes at the second cut-level , with 44.4% (A1 and A2 with *Carduus pycnocephalus* and *Olea sylvestris* as indicator species) and 48.5% (B1 and B2) between-group dissimilarity. This result could be partly associated with specific geological substrates (A1= granites; A2= metamorphytes respectively), and partly with the fact that B2 grouped plots located on soils with higher salinity with respect to B1 plots (whit *Eucalyptus camaldulensis* as indicator species), due to the nearness to the sea.

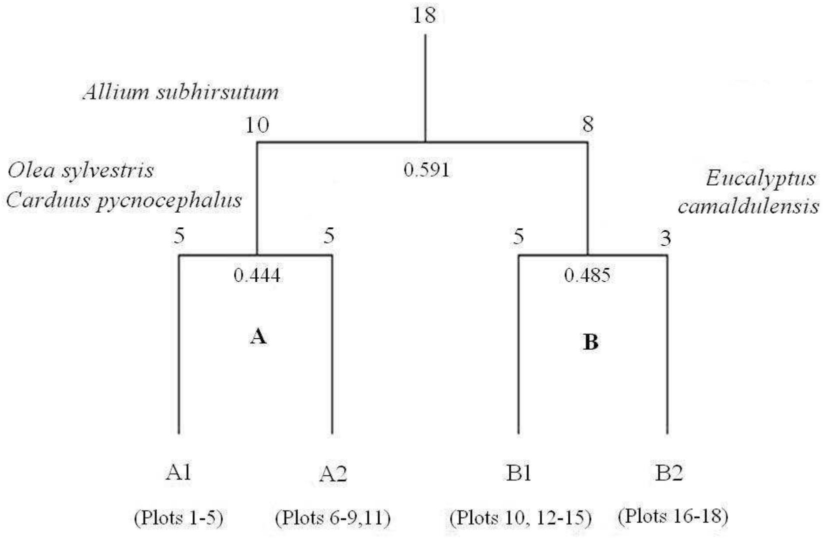

Fig. 2 Dendrogram derived from TWINSPAN showing plots number, eigenvalues and indicator species (where they exist) for each division.

The results of Sørensen index applied between groups of plots derived by cluster analysis and groups of plots delineated using lithological types are shown in Tab. 3. The correspondence between bedrock-alluvial and respectively A-B cluster groups of the first cut level was high. Bedrock matched very well with both A1 and A2. The correspondence of alluvial versus B1 and B2 was anyway high. For all the other combinations, the values of the similarity index resulted substantially low and almost lower than 0.5.

Tab. 3 Sørensen index between cluster groups and bedrock/alluvial. Values of similarity higher than 0.6 are reported in bold.

	Bedrock	Alluvial
A	**0.960**	0.491
B	0.372	**0.839**
A1	**0.872**	0.318
A2	**0.750**	0.570
B1	0.341	**0.616**
B2	0.222	**0.694**

Multiple Response Permutation Procedure (MRPP) clearly indicated a relationship between lithological types (bedrock and alluvial) and plant species composition (Tab. 4). The division among groups was statistically highly significant (p<0.001), both in term of within-group homogeneity and among-group separability. The *T* statistic, which measures between lithological types heterogeneity, was -9.19, signifying that a dissimilarity in plant communities among the lithological types exists. This analysis showed a significant, even if not high, *A* values (A=0.14), which suggested a similarity of plant assemblages within each group.

Tab. 4 MRPP test statistics measuring separability and agreement between bedrock and alluvial plots.

Statistic	Measures	Result	*P* -value
T	Separability between groups	-9.19	*P* <0.001
A	Agreement within groups	0.14	*P* <0.001

INSPAN results revealed that twenty three species (11.4%) exhibited a significant correlation with lithological types based on Indicator Value (IV, Tab. 5). Woody species showed a distinct distribution relative to the geological types; those associated to bedrocks were *Quercus ilex*, *Juniperus oxycedrus* ssp. *oxycedrus* and *Phillyrea latifolia,* while those associated to alluvial were the halophyte *Tamarix gallica* and the exotic *Eucalyptus camaldulensis,* only rarely found in bedrocks. The herbaceous species also showed a distinct distribution pattern corresponding to lithological types. Many pioneer and/or nitrophylous hemicryptophytes were associated with alluvial areas, like *Dittrichia viscosa, Daucus carota, Foeniculum vulgare* and *Sonchus oleraceus*, together with helophytes more likely to be found in slow-flowing waters (*Phragmites australis* and *Cyperus badius*).

Tab. 5 Affinity of the species (Indicator values, IV) for bedrock and alluvial lithologies. Only the significant species ($P < 0.05$) are shown. The number of presences indicates how often the species was found in bedrock/alluvial plots.

	Number of presences			
Species linked to bedrock	In bedrock plots	In alluvial plots	IV	*P*
Allium subhirsutum	8	1	69.2	0.02
Anthemis arvensis	5	0	50	0.04
Arisarum vulgare	6	0	60	0.01
Carex distachya	6	0	60	0.007
Cyclamen repandum	7	0	70	0.002
Geranium purpureum	9	2	70.4	0.01
Hypericum hircinum ssp. *hyrcinum*	5	0	50	0.03
Juniperus oxycedrus ssp. *oxycedrus*	7	0	70	0.004
Lagurus ovatus	5	0	50	0.04
Phillyrea latifolia	9	0	90	0.001
Quercus ilex	6	0	60	0.01
Rubus gr. *ulmifolius*	9	3	63.5	0.03
Selaginella denticulata	5	0	50	0.04
Smilax aspera	7	1	59.4	0.02
Torilis arvensis	7	0	70	0.001
Species linked to alluvial lithology				
Cyperus badius	0	5	62.5	0.007
Daucus carota	0	7	87.5	0.001
Dittrichia viscosa	1	8	90.9	0.001
Eucalyptus camaldulensis	1	5	27.9	0.045
Foeniculum vulgare	0	5	24.7	0.009
Phragmites australis	0	5	62.5	0.005
Sonchus oleraceus	3	8	76.9	0.009
Tamarix gallica	0	7	87.5	0.001

The plots distribution along the first DCA axis, that explained 13.8% of the total variance of species data and 60.8% of species-environmental relation, agreed with TWINSPAN results (Fig. 3). The lengths of the gradient was 4.58 S.D., underlying an high plant species heterogeneity in the riparian corridor. In the first axis, bedrock-alluvial transition seemed to explain the floristic differences along a decreasing altitudinal gradient. Two groups of plots were clearly separated and included: sites of upper course with outcrop of bedrocks (TWINSPAN A) in the left side of axis 1; sites of lower course with alluvial soils (TWINSPAN B) in the right part. Species with the highest fit ranges showed in Fig. 3 were almost the same detected by INSPAN.

DCA analysis demonstrated that richness distribution was not homogeneous along the longitudinal gradient of Santa Lucia river, but instead the bedrock zone harbored more plant species with respect to the alluvial zone. A general pattern of increasing species richness with increasing elevation was also evident.

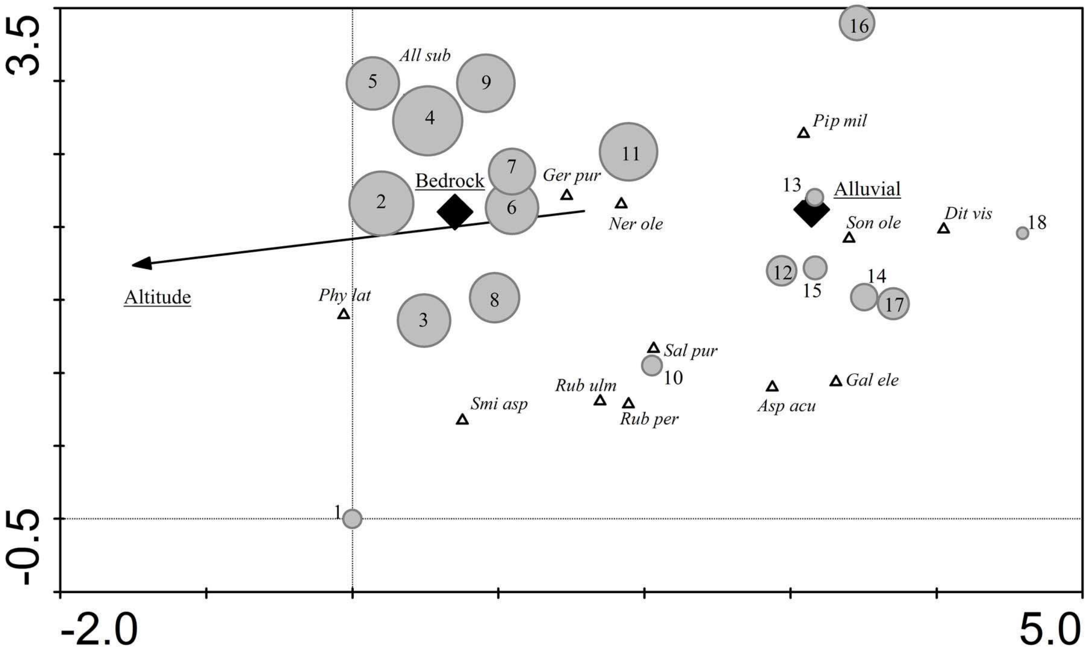

Fig. 3 DCA diagram with plots (circles), species (triangles), altitude (arrow) and lithological types centroids (diamonds); the number showed is the plot number. The bigger circles stand for plots with higher species richness. Only species with fit-range >50 are shown. Abbreviation stands for: ***All**ium **sub**hirsutum, **Phi**llyrea **lat**ifolia, **Ger**anium **pur**pureum, **Ner**ium **ole**ander ssp. oleander, **Pip**tatherum **mil**iaceum, **Dit**trichia **vis**cosa, **Son**chus **ole**raceus, **Gal**actites **ele**gans, **Sal**ix **pur**purea ssp. purpurea, **Rub**us* gr. ***ulm**ifolius, **Asp**aragus **acu**tifolius, **Rub**ia **per**egrina, **Smi**lax **asp**era.*

Partial Canonical Correspondence Analyses were carried out, and the trace and sum of all canonical eigenvalues were calculated for each. The contribution of altitude (A) and bedrock/alluvial lithological types (L) to variance of the species matrix can be partitioned as in the Fig. 4. In total, 20.4% of the variation can be explained. Altitude (A) and lithological types (L) explained 8.6% and 7.3% of the species data and their interaction explained 4.5%. Permutation tests on the trace value showed that the available explanatory variables explained a significant part (p<0.002) of the variation.

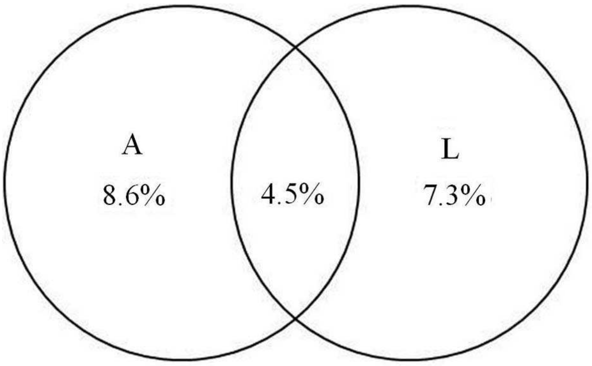

Fig. 4 Variance partitioning (expressed as percentage of variance explained) of the effects of altitude (A) and lithological types (L).

The overall result that emerged from Wilson-Shmida index was the high heterogeneity of plant species composition between all the pairs of plots (values between 0.416 and 0.826). The index underlined also that the turnover in floristic composition was not constant along the riparian corridor but generally higher in the alluvial part (see Tab. 6). The highest value was found between plots 9 and 10, followed by 10 vs 11, underlying in this way that more than 70% of the plant species (respectively 82.6% and 73.9%) changed at the transition between bedrock and alluvial (Tab. 6). For the bedrock controlled part, the highest value was found between plots 1 and 2 (63.4%). Another significant discontinuity (turnover than 60% of the species) appears also in the alluvial controlled section between plots 15 and 16, 16 and 17, 17 and 18.

Tab. 6 Wilson-Shmida Index calculated between adjacent plots along the longitudinal gradient, with the lithology of the pair of plots (B=Bedrock; BA= from Bedrock to Alluvial; A= Alluvial).

Plots	Wilson-Shmida Index	Lithological types
1 vs 2	0.634	B
2 vs 3	0.437	B
3 vs 4	0.583	B
4 vs 5	0.541	B
5 vs 6	0.581	B
6 vs 7	0.420	B
7 vs 8	0.525	B
8 vs 9	0.632	B
9 vs 10	0.826	B
10 vs 11	0.739	BA
11 vs 12	0.653	A
12 vs 13	0.560	A
13 vs 14	0.416	A
14 vs 15	0.500	A
15 vs 16	0.614	A
16 vs 17	0.625	A
17 vs 18	0.645	A

3.5 DISCUSSION

3.5.1 Effect of bedrock-alluvial transition on plant species distribution, richness and life forms

The heterogeneous plant species distribution in this Mediterranean river corridor emerged by the results of various analyses: i) high dissimilarity showed by cluster analysis (first and second cut level); ii) high number of species found in less than three plots; ii) high length of the gradient in the ordination (DCA) and iii) high values of species turnover along longitudinal gradient. These strong differences in specific composition within the riparian vegetation can be explained, in part, by patchiness, or habitat heterogeneity of the floodplain (Begon et al., 1990; Everson and Boucher, 1998; Ferreira and Stohlgren, 1999; Amoros, 2001; Goebel et al., 2003). Nevertheless, also the effect of bedrock and alluvial lithology on floristic assemblages was underlined by the results from the various analytical techniques we applied. The first TWINSPAN division, the negative T value produced in the MRPP analysis and the strong similarities (Sørensen index) between the lithological and cluster groups indicated a distinct difference in floristic distribution patterns occupying the two lithological types.

Result from INSPAN agree with the previous, since 23 species were found to be significantly correlated with lithological types. Among the woody species, sclerophyllous trees, shrubs and all nemoral herbaceous species linked to Mediterranean hardwooded zones like *Arisarum vulgare*, *Carex distachya*, *Cyclamen repandum* and *Selaginella denticulata* were related to bedrock, while the exotic *Eucalyptus camaldulensis* occurred on alluvial, since in the last century woods of this species were planted in coastal areas in order to fight the *malaria*, a typical disease of Mediterranean marshy zones, and were also employed in paper industries. In lowland alluvial areas the presence of *Tamarix gallica* was favoured by high salinity conditions, due to natural and/or man-induced factors, that negatively affect tree health, triggering dieback of many riparian woody species (Salinas and Casas, 2007). There were also clear distinctions in the distribution of understory plants between lithological types, since the nitrophilous, pioneer and hygrophylous species resulted to be more frequent in the alluvial (Wacquant, 1990). All these data evidenced the colonization of all type of riverbanks by terrestrial species, according to other Mediterranean rivers in southern basin due to climatic harshness and intermittent flows (Ferreira and Aguiar, 2006), with *Nerium oleander* ssp. *oleander* and *Rubus* gr. *ulmifolius*, that dominated shrubby extrazonal vegetation along Mediterranean temporary watercourses (Jasprica et al., 2007; Bacchetta et al., 2009), among the most frequent species.

The life forms analysis agreed with previous results, showing that woody species (phanerophytes and nanophanerophytes) were clearly related to woodland landscape of both the upper reaches of the stream and less accessible zones of the basins. Besides, the bedrock-controlled areas have generally narrow river stretches with steep slopes (and consequent lack of alluvial benches) in which the riparian zone tend to take on the characteristics of the adjacent forests (Gregory et al., 1991; Richardson et al., 2005; Landi and Angiolini, 2006). The herbaceous perennial species (hemicriptophytes), which were more strongly related to gradients of light availability and soil moisture than trees and shrubs (Decocq, 2002), were more likely to be found on alluvial lithology. This opposite distributional pattern may also be related to the contrasting life history traits between these life forms, with herbaceous likely to recover from disturbance more quickly than woody species, due to their shorter life-span and higher colonization rates, in particular the most ruderal and xeric-annuals (Tabacchi et al., 1998; Bagstad et al., 2005; Lite et al., 2005; Salinas and Casas, 2007).

The DCA ordination strongly suggested that altitude played a role in determining the distribution of riparian plants between lithological types. In fact along the Mediterranean river corridors, the contrast between bedrock and alluvial produces the separation between two types of altitudinal gradients (strong in the upper part of the river, low in the lower part), with a gradual replacement of the process of erosion with sedimentation (Buer et al., 1989; Bacchetta et al., 2003, 2005; Landi and Angiolini, 2006). Indeed, the lithological and altitudinal variables here employed were found able to explain almost 16% of the total variation and each offered a similar contribution to the explained variation of the species distribution. These two environmental factors were also responsible for the main structure of the surrounding landscape. One expected environmental gradient would be that in lower alluvial controlled stretches of streams with the most favourable areas (low slope, depth of soil, roads, etc.), especially near the coast, human activities (agriculture and urbanization) would generally increase (Corbacho et al., 2003; Bombino et al., 2007). This is supported also by the high percentage of shared variance between lithology and altitude. The unexplained variation was quite high (79.6%), a result that is not uncommon in ecological studies, because species abundance or occurrence data are often very noisy (ter Braak, 1986; Guisan et al., 1999; ter Braak and Šmilauer, 2002). Moreover, other studies using partial CCA have obtained similar levels of unexplained variation (see e.g. Borcard et al., 1992; Borcard and Legendre, 1994; Titeux et al., 2004). The high amount of unexplained variance in the data set may be logically interpreted as evidence of important but unmeasured deterministic factors (i.e. transversal gradient, flooding, surrounding landscape etc.). However, it is also be attributed to the existence of large fractions of random compositional variance in the data or, as recently demonstrated (Økland, 1999), may arise from purely statistical reasons and does not need interpretation.

Species richness was significantly higher in medium-upper bedrock course compared to floodplain in alluvial lithological type, a fact that can be explained by three factors. First, clear cutting of the floodplains of fertile alluvial soils for agriculture, actually mostly covered by crops, has had the greatest impact on riparian vegetation, causing a strong decrease in species richness (Angius and Bacchetta, 2009). Secondly, in small stretches of bedrock controlled streams with steeper slopes, infrequent but intense disturbances (such as landslides and debris flows, for instance in the case of flood events) create high degree of landscape heterogeneity, that play a key role in maintaining high values of species richness (Richardson et al., 2005). Third, in the narrower bedrock controlled riparian sections, the woody species are able to take advantage of a stable, well-drained substrate directly adjacent to the river (Everson and Boucher, 1998). Moreover, bedrock can provide an anchoring medium for the establishment of certain species not able to gain a firm rooting medium on the alluvium (van Coller, 1993), while woody debris offer elevated sites for those species unable to survive on the saturated soil conditions (Fetherston et al., 1995).

The downstream changes in plant species number observed in our study were consistent with what found by many other authors (Vannote et al., 1980; Statzner and Higler, 1985; Nilsson et al., 1989; Tabacchi et al., 1990; Ferreira and Moreira, 1999; Van Looy et al., 2006). Most of these studies predicts a maximum of plant species richness in the central section of river systems, where maximum environmental heterogeneity and intermediate level of disturbance occur. If disturbance is neither too weak nor too strong, the potential species richness is likely to be high, consistent with the Intermediate Disturbance Hypothesis (Nilsson et al., 1989). Contrary, in Santa Lucia only one plot in the upper part of course had a low number of species, while the peak of richness was not only in the medium part but also in the upper one. This happened because our river (and generally Mediterranean rivers) are short, small and do not include (or include only a little part of) headwater section, often ephemeral and not flowing during the study period (Salinas and Casas, 2007). In our river, only one plot corresponded to the headwater while the following plots already belong to the intermediate-sized stream section. Anyway, as hypothesized by Huston (1999), regional patterns of species richness along environmental gradients may result in a large part from very local processes, and, conversely, regional processes may produce local-scale emergent gradients. Although plant species richness vary considerably along riparian corridors (Planty-Tabacchi et al., 1996), and the possible causes of this trend along rivers still remain controversial, a deeper knowledge of plant distribution may help to identify functional stretches in terms of creation of biodiversity hotspots.

3.5.2 Bedrock-alluvial transition and discontinuity

As the classification and ordination analyses had already shown, the peak in beta turnover, occurring between plots in correspondence of the transition bedrock/alluvial (where more than 70% of species changed), indicated a strong discontinuity in species distribution. This high values of turnover index may reflect rapid and ecologically significant environmental changes in the transition between the two lithological types.

Other significant discontinuities appeared also between: i) sites 1 and 2, due to the difference in environmental features (headwater vs intermediate-sized stream) explained above, ii) the plots of the lowest stretch of the river, where new floristic elements appeared probably due both to higher human impact, that have indirectly determined a magnification of between-sites variability along the altitudinal-longitudinal dimension, and to pronounced increase in salinity towards the mouth, as reported for other Mediterranean rivers (Gasith and Resh, 1999; Aguiar et al., 2001; Corbacho et al., 2003; Salinas and Casas, 2007), that strongly conditioned vegetation composition along the gradient of elevation.

Some authors also emphasize the discontinuity in the longitudinal changes of riparian vegetation composition, with high species turnover between reaches of their rivers (Tabacchi et al. 1990; Van Looy et al., 2006). According to Malanson (1993), van Coller et al. (1997) and Rosales et al. (2001), we found that the transition between bedrock and alluvial generates the highest floristic discontinuity. Geology is important in terms or reaction (acid/basic soils), limiting the plant species that can be harbored in an area, but also in term of morphology, influencing landform types (incised valleys/level lands). Moreover, the transition between high and low altitudinal gradient caused a decrease in both the depth and speed of the water, with a consequent increase in sedimentation downstream and a significant variations in the width of the fluvial bed. In addition, in the lower sections of rivers, flatter landscapes allow the presence of agricultural activities and urban centres next to the riparian strip, features that become the main factors responsible for riparian corridor alteration (Décamps et al., 1988; Salinas et al., 2000; Corbacho et al., 2003), as found in many streams of the Mediterranean basin (di Castri, 1991; Gasith and Resh, 1999; Aguiar and Ferreira, 2005). According to what found by Kalliola and Puhakka (1988), vegetation distribution along floodplains have been shown to be highly patchy in relation to the heterogeneous nature of sedimentary patterns.

3.6 CONCLUSIONS

Our results confirmed that the degree of bedrock/alluvial influence is an integral component of the patch structure of a river and strongly influences vegetation distribution patterns. Distributional patterns of riparian plant species and fluvial geomorphic forms and processes linked to bedrock/alluvial transition resulted to be closely integrated environmental phenomena in this Mediterranean river, even along highly human altered stretches. Giving their deep influence, it should be important to identify strong environmental discontinuities along rivers, since they are indicative of present and ongoing species distribution trends, while simultaneously reflecting diverse array of river bed morphology and fluvial dynamic.

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CHAPTER 4:

USING MULTIVARIATE ANALYSES TO ASSESS EFFECTS OF FLUVIAL TYPE ON PLANT SPECIES DISTRIBUTION IN A MEDITERRANEAN RIVER

ABSTRACT

We propose a method to assess the distribution of plant assemblages along rivers delimiting homogeneous fluvial types using cluster analysis applied to morphological features, quantified with aerial photos and geographic information system software. A stratified random sampling design along the elevational gradient was used to analyze riparian plant species. Multivariate statistics were applied to detect patterns of variation in the species data, and among functional and ecological groups. Cluster analysis identified four fluvial types: headwater, low sinuosity, braided, and incised. Canonical Correspondence Analysis, indicator species analyses, and partial ordinations all suggested that fluvial types were characterized by well-defined indicator species. The differences found by Redundancy Analysis and non-parametric analysis of variance for functional and ecological groups also supported the fluvial type division, showing different distributional trends for annual and woody species, and the greatest ecological distance between braided and headwater types. Based on the ordination results, dividing fluvial types according to morphological features was justified by environmental and floristic differences, although plant species variability was only partially described. Our results illustrated that the fluvial type classification created using this methodology was consistent with natural plant species distribution patterns.

Keywords: Ellenberg indicator values, floristic assemblages, functional groups, morphology, riparian vegetation, river classification

4.1 INTRODUCTION

In many regions, riparian areas constitute a small proportion of the total watershed area, yet they play a prominent ecological role. They are important pathways and migration corridors for the flow of energy, matter, and organisms across the landscape, and act as ecotones between terrestrial and aquatic zones (Malanson, 1993; Forman, 1997). Moreover, riparian habitats are considered hotspots of biodiversity (Dècamps and Tabacchi, 1994; Dudgeon et al., 2006). Unfortunately, streams and rivers throughout the world have been degraded by human activities (Baattrup-Pedersen et al., 2005). Mediterranean rivers, in particular, have a long history of human disturbances at basin and corridor scales (di Castri, 1991; Aguiar and Ferreira, 2005). Given the magnitude of past loss and conversion of floodplains, as well as on-going threats, we should better understand how best to conserve remnant habitats. Rapid assessment of plant species diversity and distribution along rivers would be useful (Stohlgren et al., 1997), but resources or expertise to quantify total biodiversity of an area are lacking (Pharo et al., 1999; Hermy and Cornelis, 2000). Determining the main factors influencing plant species distribution in riparian areas has become a priority.

Recent studies revealed river morphology to be a strong determinant of riparian ecosystem function. Reviews by Steiger et al. (2005) and Corenblit et al. (2007) establish how landforms and physical processes drive the dynamics of biological communities. Strong linkages exist among watershed morphometry, stream hydro-geomorphology, and riparian plant communities in ephemeral stream networks (Shaw and Cooper, 2008). An examination of the influence of landform features on the distribution of vegetation on floodplains along small channels in North America (Mollot et al., 2008) found that landforms exerted a strong influence on the distribution of trees, shrubs, and understory plant species. Vegetation along a Chinese river was mostly influenced by soil characteristics, and both vegetation and soil were influenced by topography (Xu et al., 2008). In Mediterranean areas, Tabacchi et al. (1998) assumed that since every river system has its own unique geomorphological structure, reciprocal control between hydrology and vegetation could be analyzed from a geomorphological template. However, few studies have assessed plant species distribution in Mediterranean riparian areas in relation to riverbed morphology. As a result, a limited understanding exists of how landforms define plant species assemblages, and particularly of how a morphological classification of riparian ecosystems is consistent with actual riparian species patterns (Puhakka et al., 1992; Nilsson et al., 2002) or how it can be used as a local scale environmental surrogate (Lombard et al., 2003; Olivier et al., 2004).

Classification of freshwater ecosystems is essential to developing biological assessment frameworks (Gerritsen et al., 2000). A variety of classification systems to assess alluvial river channel patterns have been developed, but no definitive classification system has emerged (Corenblit et al., 2007). A common problem encountered in riparian ecosystems is that biological information is not always consistent with fluvial or stream type classifications derived from remote sensing and geographic information systems (GIS) (Kupfer and Franklin, 2000). In order to address these problems and to investigate whether fluvial types can serve as biodiversity surrogates at local scales, we present a scientifically sound but easily applicable method using GIS and multivariate statistics to determine river types and to link morphological classification to ecological types. It is based on the classification of readily recognized morphological features, measured through the use of aerial photos to identify major fluvial types. Advances in computer technology and GIS now enable modelling of large landscapes (Barrett, 2001). While there is nothing particularly new about using GIS and remote sensing for mapping and spatial analysis, its application for assessing riparian landscape structure has rarely been exploited (Herzog et al., 2001). We propose using multivariate analyses to examine how the distribution of riparian plant assemblages varies with morphological river types along the length of a medium sized Mediterranean river, to assess the relative importance on floristic composition of fluvial type with respect to elevation, and finally to test the correspondence between fluvial types and floristic analyses of plots.

4.2 STUDY AREA

The study was conducted in the Tuscan part of the Fiora river (central Italy, between 42°34’ N, 11°34’E and 42°49’N, 11°35’E). This area is a natural river corridor protected under the European Habitats Directive through its designation as a Site of Community Importance (Fig. 1a,b). The river corridor is about 32 km long with elevation ranging from 687 to 130 m asl; its catchment area is about 423 km^2. The geology consists of shales, sandstones, and cobbles in the upper part, with effusive and pyroclastic rocks in the lower part. On the valley floor, apart from bedrock reaches, there is extensive drift of fluvial alluvium. Climate is humid Mediterranean (Barazzuoli et al., 1993), with total annual rainfall ranging from 903 to 1003 mm and a mean temperature range of 11.2 to 14.5°C. The river typically dries during summer, and flood events occur in autumn and spring. The catchment area is primarily covered by forest, including *Fagus sylvatica* forest mixed with *Abies alba* and oak forest dominated by *Quercus cerris* or mixed *Q. cerris* and *Quercus pubescens* (De Dominicis et al., 1992), with scattered pasture and cropland (mostly cereal and fodder crops). Disturbance associated with low intensity agro-pastoral systems has not resulted in native complexes being replaced by non-native ones. Thus, natural dynamic processes mainly affected the structure of the riparian vegetation.

4.3 METHODS

4.3.1 Derivation of map-based measurements

Analyses were based on information derived from digital aerial photos (2003), a Digital Elevation Model (DEM), and geological layers. Although the scale chosen for most studies involving river morphology is usually 1:10.000 (Ward et al., 1999; Gurnell et al., 2000; 2001), we decided to use a more detailed scale (1:5000) for all the GIS analyses to improve detection of environmental features and derive parameters chosen for morphological classification more precisely and consistently. To identify the floodplain, we first selected areas with alluvial lithology, then we removed any cultivated land near the river. In the resulting floodplain area, a total of 15 river segments (*sensu* Poole, 2002) were drawn at 2 km intervals along the river, from the source to the valley. For the morphological characterization of the river segments we chose to consider physical features that are widely used in riparian morphology studies including: slope, sinuosity, number of nodes, gross active zone width, gross riparian zone width, and full channel width (Ward et al., 1999; Gurnell et al., 2000; Parsons and Gilvear, 2002). Using DEM (75 x 75 m), the slope of each segment was calculated from the difference in elevation between the beginning and the end of the segment, measured in the channel thalweg. Sinuosity was calculated (according to Ward et al., 1999) as the ratio of the channel thalweg length/length of each segment. We derived the number of nodes for each segment within the channel network by interpreting aerial photographs. The gross active zone width was the width of the currently active zone of the river, including water-filled channels, areas of bare sediment (mainly gravel), and islands. The gross riparian zone width was the width of the currently active zone of the river plus adjacent areas of riparian woodland, and usually corresponded to the contemporary floodplain (see Gurnell et al., 2000). Finally, since one of the most important features that characterizes stream ecosystems is the rate of flow, which is related to the width of the channel (Jowett, 1997), we decided to also take into account the full channel width (at the time of map survey), which when measured where multiple channels were present was the width of the main channel. Following Gurnell et al. (2000), these last three parameters were measured every 500 m using aerial photos, and mean values for each segment were calculated.

4.3.2 Sampling design

Using a stratified random sampling design, we placed 3 plots (each 10 × 10 m) in each of the 15 segments previously delineated, resulting in 45 plots. The 100 m^2 plot size should be adequate to detect vegetational variation in the floodplain because it has previously been used to explain relationships between species richness and environmental features in forests (Schuster and Diekmann, 2005) and grasslands (Gross et al., 2000).

4.3.3 Floristic composition

For each plot we recorded presence or absence of all vascular plant species from May through July 2007. To test whether functional groups of plants, defined as groups of species that share the same adaptive features in relation to a well-defined function (McIntyre et al., 1995), respond differently to the physical characteristics of distinct fluvial types, species were classified into groups as follows: a) woody species (phanerophytes and nanophanerophytes); b) herbaceous perennial species (geophytes, hemichryptophytes, and chamaephytes); and c) annual species (therophytes). Hydrophytes were not classified as a functional group because occurrence was very low (2 species out of 405 total).

We also considered alien species because they can show an elevated frequency along rivers and their dispersion seems to be related to fluvial corridors. High risk plant groups, including protected or threatened species, were also considered because they are priorities for conservation efforts. Species nomenclature followed the checklist of Italian flora by Conti et al. (2005), while Pignatti (1982) was used to define functional groups. To assess ecological responses of plant species with respect to the fluvial type, we used Ellenberg indicator values (Ellenberg et al., 1992) recently defined for Italy by Pignatti (2005) including: light preference (L), ranging from 1 (full shade) to 9 (full sunlight); soil reaction (R), ranging from 1 (highly acidic) to 9 (highly calcareous); soil moisture (U), ranging from 1 (very dry soil) to 12 (water); soil fertility (N), ranging from 1 (extremely nitrogen-deficit soil) to 9 (extremely nitrogen-rich soil); and temperature (T), ranging from 1 (cold temperature, typical of high mountains) to 9 (extreme warm conditions). These values are based on data from over 5000 species, validated in other Mediterranean areas, to describe variation among plant communities in space and time (Ertsen et al., 1998; Diekmann, 2003; Böhling, 2004; Fanelli et al., 2008).

4.3.4. Data analyses

A morphology-based hierarchical agglomerative cluster analysis (complete linkage with Euclidean distance) was performed for geomorphic characterization of fluvial types. The number of nodes, sinuosity, slope, gross active zone width, gross riparian zone width, and full channel width were standardized as z-scores (mean = 0 and standard deviation = 1) to reduce both the size and variability to a common scale, and these represented the input variables. The aim was to provide an objective classification of the river, identifying segments with similar morphological features (fluvial types) that could be used as a qualitative tool to assess variation in riparian plant assemblages. To compare differences in morphological features (dependent variables) among fluvial types (categorical predictors) detected by the cluster, a series of Kruskal-Wallis one-way ANOVAs was performed. In all analyses we used non parametric statistics because data were not normally distributed.

For multivariate analyses regarding floristic composition we used a set including all species recorded (405 species, presence/absence data). Characteristic or indicator species for each fluvial type were then explored by an INdicator SPecies ANalysis (INSPAN) using the IndVal method (Dufrène and Legendre, 1997) as implemented in PcOrd 4.25 (McCune and Mefford, 1999).

Two types of ordination, indirect and direct gradient analysis were performed to study the relationship between fluvial types and the patterns followed by the species (Palmer, 1993). To interpret species composition data and propose environmental gradients to which species were responding, indirect ordination of the floristic data was performed using Detrended Correspondence Analysis (DCA). Using this technique we were also able to check whether data were unimodal. Because the length of the gradient was 3.93 standard deviations (SD), we assumed that the use of a unimodal method would be appropriate (Lepš and Šmilauer, 2003). To detect patterns of variation in the species data that could be explained by the fluvial types and the species linked to them, environmental-species and environmental-plot relationships were investigated by Canonical Correspondence Analysis (CCA), with the fluvial types identified by the cluster analysis as dummy environmental variables. The options chosen for DCA and CCA were down-weighting rare species and inter-species distances by Hill's scaling (ter Braak and Šmilauer, 2002); otherwise default options were accepted.

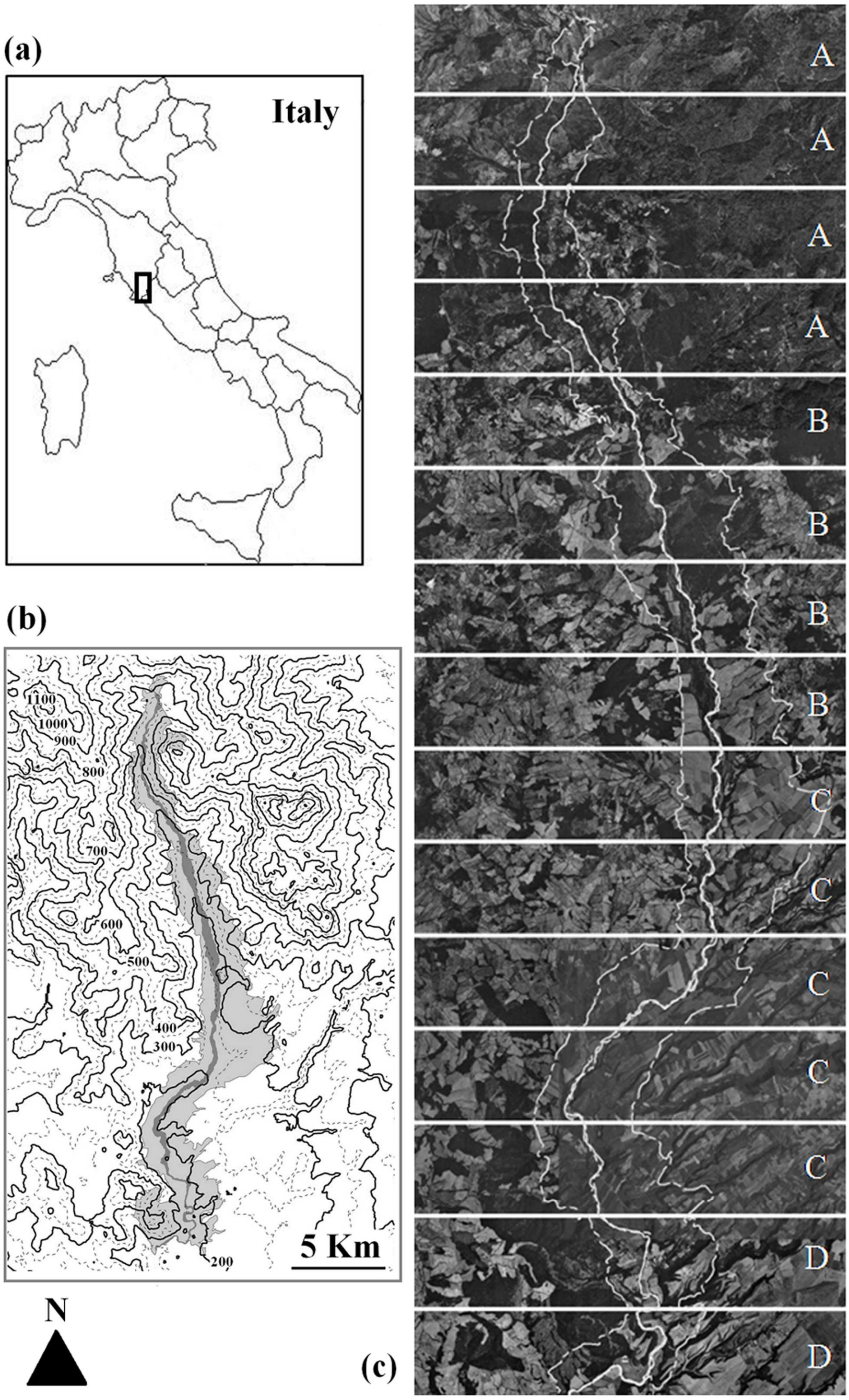


Fig. 1 (a) Location of Fiora river, Tuscany (central Italy); (b) Map of the study area with contour lines of 50m. The light grey area stands for the protected area (SCI, Site of Community Importance), and the dark grey area for the study floodplain; (c) Division of the river into fluvial types. The horizontal lines separate the 2 km segments. The letters on the right refer to the cluster groups: A=headwater; B=low sinuosity; C=braided; D=incised. The dotted line shows the boundary of the SCI area, while the central line represents the bed of the Fiora river

In order to assess the relative importance of fluvial types and elevation on the floristic composition, we used a partial ordination (Lepš and Šmilauer, 2003), where partial CCAs with the four-step procedure described by Borcard et al. (1992) were performed. To search for potential patterns of variation in the functional and ecological groups among the fluvial types, Redundancy Analysis (RDA) was also performed with functional types and Ellenberg Indicator values as species, and fluvial types as dummy variables. These values were used after calculating the weighted average of their values in the plots. We assumed that the response curve would be monotonic. We used RDA because the length of the gradient in the DCA was only 1.91 SD. Since the first axis in the RDA explained a high percentage of variance, while the second had weak explanatory power, we performed another RDA with the scaling focused on inter-sample distances (Lepš and Šmilauer, 2003). A (nonparametric) analysis of variance (ANOVA) was used to identify significant differences in the distribution among the fluvial types of the different plant functional and ecological groups considered. This analysis was performed on the basis of various analyses by (partial) RDAs using only one species (plant functional or ecological group) as an environmental variable and the remaining species as covariables; partial constrained methods enabled us to examine the effects of the environmental variables of interest after partialling out the effect of the covariables (Lepš and Šmilauer, 2003).

Finally, in order to test the reliability of fluvial types for explaining variation of floristic data, the values of ordination analyses were compared and sample scores on the first two axes were analyzed by standard linear regression to compare the ordination of species and plots provided by DCA vs. CCA and RDA. The goodness-of-fit of the regression lines was interpreted as an expression of ordination similarity. According to ter Braak (1986), if ordination of species and sites by indirect and direct gradient analyses are not fundamentally different, no important environmental variable has been overlooked.

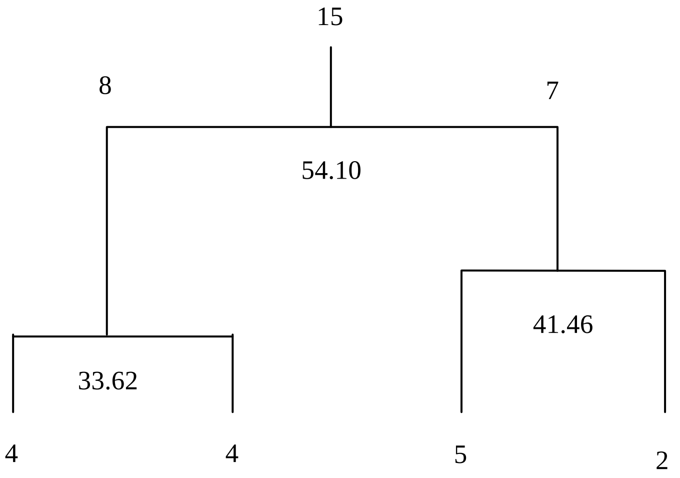
Monte Carlo tests (499 random permutations) were used to test the significance of indicator species from INSPAN, ordination axes and environmental variables in all the ordinations, and the trace statistics and the first eigenvalue in the partial CCAs performed in this study. The significance level of the tests in the partial RDAs was adjusted using Bonferroni correction to rectify type I errors due to repeated statistical tests. We used STATISTICA (StatSoft Inc., 1995) for univariate analyses, and PcOrd 4.25 (McCune and Mefford, 1999) and CANOCO 4.5 (ter Braak and Šmilauer, 2002) for multivariate analyses.

4.4 RESULTS

4.4.1 Fluvial types

Four clusters provided the most informative classification of segments (Figs. 1c, 2), and other clusters provide additional, but less well-defined, morphological patterns (< 70% similarity). The four clusters differed significantly (Kruskal-Wallis test, Fig. 2) and key morphological features defining them were active zone width, riparian zone width, full channel width, and number of nodes.

Cluster A consisted of four segments located in the uppermost part of the study area. Important features of this portion of the river were steep slopes (average 3.4%), narrow active zones, narrow full channels, and a low number of nodes. We denote this group as “headwater”. Cluster B consited of four segments with wider riverbeds, a high number of nodes, and low and very homogeneous sinuosity values. We denote this group as “low sinuosity”. Cluster C consisted of five segments characterized by the widest active zones and most contemporary floodplain of the entire river. The slope values were homogeneous but the number of nodes was high. We denote this group as being “braided”. Cluster D consisted of the lowest two segments, where riverbeds were constrained into narrow channels. Key features of these segments were: low slopes (only 0.05% to 0.5%), high sinuosity values, narrow riparian zones, and wide full channels. We call this fluvial type “incised”.



	A **Headwater**	**B** **Low sinuosity**	**C** **Braided**	**D** **Incised**	*P*
Active zone (m)	18.6 (9.67 – 22.6)	52.3 (39 - 72.6)	104.2 (65.40 – 140)	20 (16 – 24)	**0.007**
Riparian zone (m)	154.13 (134.8 – 173.6)	371.6 (291 – 435)	262.6 (208 – 291.6)	94.4 (83 – 105.8)	**0.005**
Slope (%)	3.43 (0.65 - 5.9)	1.5 (0.35 - 2.5)	0.75 (0.3 - 1.75)	0.3 (0.05 – 0.5)	0.105
Sinuosity	1.22 (1.13 - 1.29)	1.21 (1.20 - 1.26)	1.20 (1.16 - 1.82)	1.2 (1.59 – 2.38)	0.229
Number of nodes	3 (0 – 9)	19 (16 – 19)	17 (5- 22)	4.5 (4 – 5)	**0.021**
Full channel (m)	3	3.5 (3 -5)	8 (6 -13)	14 (13 – 15)	**0.006**

Fig. 2 Cluster diagram and physical features of the river segments within the study area. Segments were classified on the basis of morphological variables to derive the four fluvial types shown in the dendrogram. Euclidean distance (as objective function) and number of plots is shown at each split of the dendrogram. In the table (at the bottom) the median and range of variation (min-max) of the features for each fluvial type are reported. The column on the right side of the table shows the Kruskal-Wallis one-way ANOVAs p-levels (significant results in bold).

4.4.2 Relationship between floristic composition and fluvial types

In total, 405 plant species were found, of which 35.1% were unique to one of the clusters. INSPAN indicated that 17% of the species (67) were significantly associated ($p < 0.05$) with one fluvial type compared to the others. Headwaters were the fluvial type with the highest number of indicator species (23), including hygrophilous species (*Alnus glutinosa* and *Eupatorium cannabinum*), woody species (trees: *Acer pseudoplatanus, Robinia pseudacacia*; shrubs: *Cornus sanguinea, Crataegus monogyna, Euonymus europaeus, Prunus spinosa, Rubus ulmifolius*), and herbaceous forest species (*Hedera helix, Melica uniflora, Viola alba, Brachypodium sylvaticum, Stachys sylvatica*). The low sinuosity segments had 12 indicator species, mostly herbaceous species linked to succession following the abandonment of crop fields on silty-clayey soils that are able to retain moisture for long periods (*Avena barbata, Foeniculum vulgare, Gastridium ventricosum, Lolium multiflorum, Melica transsylvanica*) or had low xerotolerance (*Osyris alba, Santolina etrusca, Cistus creticus*), or were acidophilous shrubs (*Cytisus scoparius*) associated with garigue formations typical of these areas. Braided segments also had a high number of indicator species (21), including therophytes (*Avena fatua, Trachynia distachya, Bromus hordeaceus, Catapodium rigidum, Knautia integrifolia, Medicago lupulina, M. orbicularis*) and chamaephytes (*Anthemis tinctoria, Convolvulus cantabrica, Origanum vulgare*), in addition to *Dittrichia viscosa* that in Tuscany characterizes garigues of wide riverbeds, often disturbed by flood events (Scoppola and Angiolini, 1997). Incised segments had 12 indicator species, which were characterized mostly by mesothermophilous woody species (*Acer monspessulanum, Ostrya carpinifolia, Quercus pubescens, Cornus mas*), but also by aquatic (*Veronica anagallis-aquatica, Apium nodiflorum*) and nitrophilous species (*Urtica dioica, Bidens tripartita*).

Using DCA ordination (Fig. 3), we found that the distribution of plots among the four fluvial types exhibited a gradient from a narrow to a wide gross active zone along the first axis, explaining 6.6% of the total variance. There was a distinct floristic separation between the headwater (grey triangles) and incised (white diamonds) fluvial types on the negative side of the axis, and the low sinuosity (grey circles) and braided (white squares) types on the positive extreme of the axis.

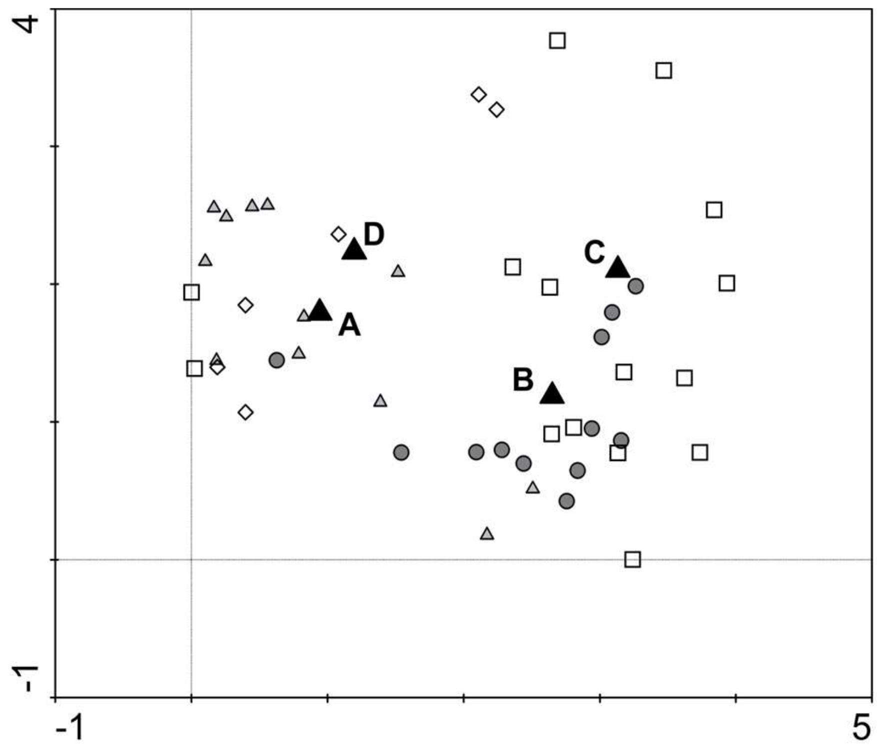


Fig. 3 DCA ordination diagram with centroids of fluvial types (triangles; A=headwater; B=low sinuosity; C=braided; D=incised). Plots of different fluvial types are represented as: grey triangle=A (headwater); grey circle=B (low sinuosity); white square=C (braided) and white diamond= D (incised)

CCA ordination (Fig. 4) that was performed with the four fluvial types as dummy environmental variables mostly agreed with the INSPAN results. The first axis and all canonical axes were significant ($p < 0.01$). The first axis explained 4.5% of the variance in species data, with a clear gradient that agreed with the DCA biplot. The species unique or preferential to a particular fluvial type included: 1) woody species: *Alnus glutinosa*, *Abies alba*, *Lonicera caprifolium*; nemoral species: *Euphorbia amygdaloides, Melica uniflora, Brachypodium sylvaticum*; and hygrophilous species: *Molinia caerulea, Equisetum arvense*, *Arctium nemorosum* for the headwater; 2) xerophilous species such as *Melica transsylvanica, Osyris alba, Santolina etrusca* for low sinuosity; 3) prevalently annual species (*Crepis sancta, Medicago lupulina, M. orbicularis, Bromus sterilis, Dittrichia viscosa*) for braided type; and 4) alien (*Chenopodium ambrosioides, Lycopersicon esculentum*) and ruderal (*Cirsium arvense, Urtica dioica, Verbascum thapsus*) species often unique to incised segments.

RDA analysis (Fig. 5) ordered the high risk species and functional and ecological groups along one main axis. This first axis and all the canonical axes were significant ($p < 0.01$), and the first axis explained 28.4% of the variation. The resultant diagram, which focused on inter-sample distance to display the differences among fluvial types, emphasized that the greatest ecological distance was between the headwater type, rich in woody plants and species with higher moisture (U) and reaction (R) values, and the braided type, with numerous annuals with light values (L). Alien species, high risk species, perennial herbs, and N values did not contribute significantly to separation (see Table 1).

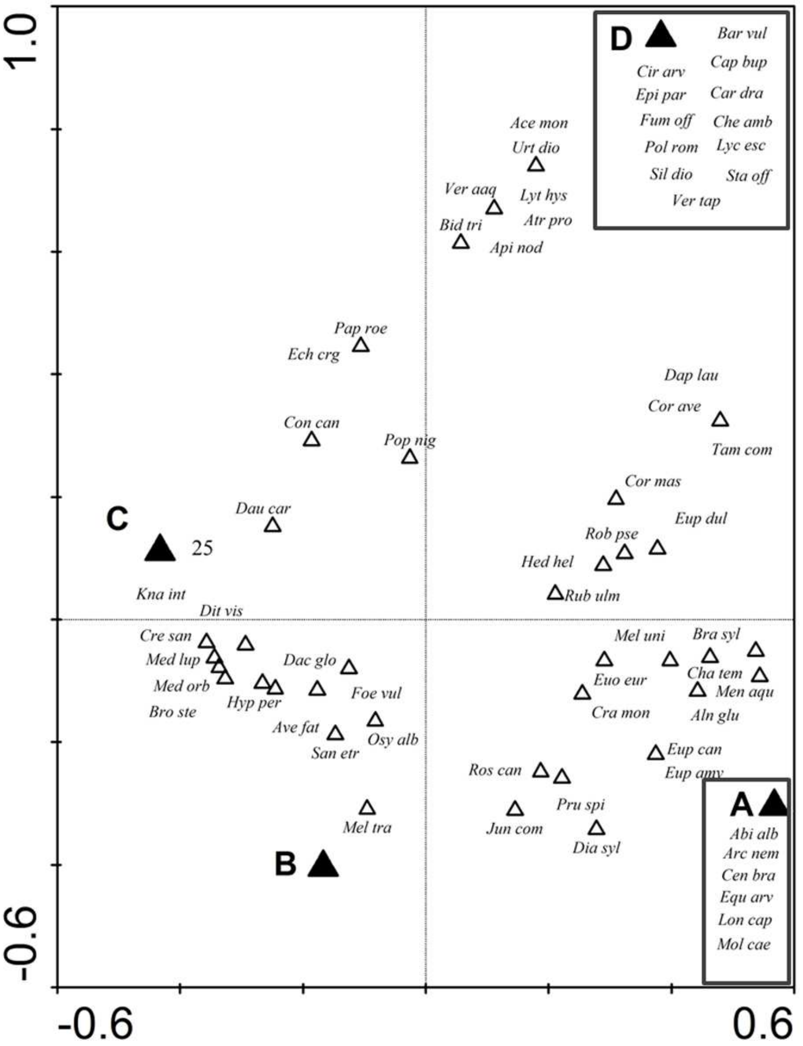


Fig. 4 CCA ordination diagram; species and centroids of fluvial types are represented by empty and solid triangles, respectively. Only the most confident species with a fit range ≥15 are represented; the species exclusive to a fluvial type are included in a square. Letters refer to fluvial types: A=headwater; B=low sinuosity; C=braided; D=incised. Legend for species abbreviation (letters in bold): ***Abi***_es_ ***alb***_a;_ ***Ace***_r_ ***mon***_spessulanum;_ ***Aln***_us_ ***glu***_tinosa;_ ***Api***_um_ ***nod***_iflorum;_ ***Arc***_tium_ ***nem***_orosum;_ ***Atr***_iplex_ ***pro***_strata;_ ***Ave***_na_ ***fat***_ua;_ ***Bar***_barea_ ***vul***_garis;_ ***Bid***_ens_ ***tri***_partita;_ ***Bra***_chypodium_ ***syl***_vaticum;_ ***Bro***_mus_ ***ste***_rilis;_ ***Car***_daria_ ***dra***_ba;_ ***Cap***_sella_ ***bu***_rsa-_***p***_astoris;_ ***Cen***_taurea_ ***bra***_cteata;_ ***Cha***_erophyllum_ ***tem***_ulum;_ ***Che***_nopodium_ ***amb***_rosioides;_ ***Cir***_sium_ ***arv***_ense;_ ***Con***_volvolus_ ***can***_tabrica;_ ***Cor***_ylus_ ***ave***_llana;_ ***Cor***_nus_ ***mas***_;_ ***Cra***_taegus_ ***mon***_ogyna;_ ***Cre***_pis_ ***san***_cta;_ ***Dac***_tylis_ ***glo***_merata;_ ***Dap***_hne_ ***lau***_reola;_ ***Dau***_cus_ ***car***_ota;_ ***Dia***_nthus_ ***syl***_vestris;_ ***Dit***_trichia_ ***vis***_cosa;_ ***Ech***_inochloa_ ***cr***_us-_***g***_alli;_ ***Equ***_isetum_ ***arv***_ense;_ ***Epi***_lobium_ ***par***_viflorum;_ ***Euo***_nymus_ ***eur***_opaeus;_ ***Eup***_atorium_ ***can***_nabinum;_ ***Eup***_horbia_ ***amy***_gdaloides;_ ***Eup***_horbia_ ***dul***_cis;_ ***Foe***_niculum_ ***vul***_gare;_ ***Fum***_aria_ ***off***_icinalis;_ ***Hed***_era_ ***hel***_ix;_ ***Hyp***_ericum_ ***per***_foratum;_ ***Kna***_utia_ ***int***_egrifolia;_ ***Jun***_iperus_ ***com***_munis;_ ***Lon***_icera_ ***cap***_rifolium;_ ***Lyc***_oprsicon_ ***esc***_ulentum;_ ***Lyt***_hrum_ ***hys***_sopifolia;_ ***Med***_icago_ ***lup***_ulina;_ ***Med***_icago_ ***orb***_icularis;_ ***Mel***_ica_ ***tra***_nssylvanica;_ ***Mel***_ica_ ***uni***_flora;_ ***Men***_tha_ ***aqu***_atica,_ ***Mol***_inia_ ***cae***_rulea;_ ***Osy***_ris_ ***alb***_a;_ ***Pap***_aver_ ***roe***_has;_ ***Pol***_ygonum_ ***rom***_anum;_ ***Pop***_ulus_ ***nig***_ra;_ ***Pru***_nus_ ***spi***_nosa;_ ***Rob***_inia_ ***pse***_udacacia;_ ***Ros***_a_ ***can***_ina;_ ***Rub***_us_ ***ulm***_ifolius;_ ***San***_tolina_ ***etr***_usca;_ ***Sil***_ene_ ***dio***_ica;_ ***Sta***_chys_ ***off***_icinalis;_ ***Tam***_us_ ***com***_munis;_ ***Ver***_bascum_ ***tha***_psus;_ ***Ver***_onica_ ***a***_nagallis-_***aq***_uatica;_ ***Urt***_ica_ ***dio***_ica._

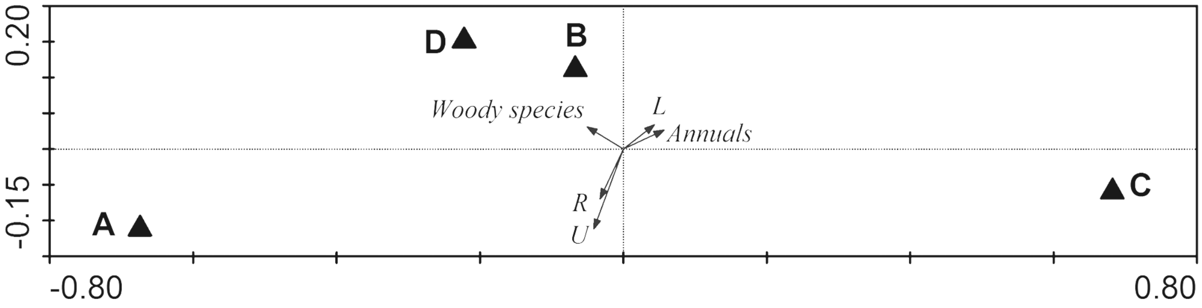


Fig. 5 RDA ordination diagram with significant functional types and Ellenberg indicator values (arrows; L = light, R = soil reaction, U = soil moisture) and centroids of fluvial types (triangles; A=headwater; B=low sinuosity; C=braided; D=incised). Scaling focused on inter-sample distances

Tab. 1 Results of the analysis of variance obtained by (partial) RDAs for the different plant functional groups and averaged Ellenberg values distribution among the fluvial types (F = F-ratio; p-level=Monte Carlo significance level, 499 permutations). n.s.=not significant

	F	p-level
Woody species	23.48	<0.05
Annuals	27.17	<0.05
High risk species	3.82	n.s.
Aliens	1.22	n.s.
Perennial herbaceous	1.25	n.s.
L - Light	58.56	<0.05
U – Soil moisture	41.98	<0.05
R – Soil reaction	20.11	<0.05
T - Temperature	15.06	n.s.
N – Soil fertility	10.50	n.s.

Using pCCAs, we compared the power of elevation relative to fluvial type to explain variation in riparian plant species distribution. The overall percentage explained by elevation and fluvial types was 13.4%. But fluvial type and elevation differed considerably in their ability to explain floristic variation. Elevation alone explained 4.2% of the variation in species composition whereas fluvial types alone explained 10.7%. The overlap in the proportion of the variance explained was 1.5%. Permutation tests on the trace values showed that the available explanatory variables explain a significant part ($p < 0.01$) of the variation.

4.4.3 Evaluation of the correspondence between fluvial types and the floristic analysis of plots

The cumulative percentages of variance of species data explained by the first two DCA axes (12%; Axis 1=6.6%, Axis 2=5.4%) and CCA axes (8.1%; Axis 1=4.5%, Axis 2=3.6%) were quite similar. Furthermore, the linear regressions between sample scores for axis 1 of DCA vs. CCA were significant (R^2=0.895, p=0.002), but not for axis 2 (R^2=0.343, p=0.12). Thus no fundamental differences in the ordinations carried out by indirect and direct gradient analysis existed along axis 1. The environmental variables selected by CCA (fluvial types) therefore effectively explained species and site ordination on this axis. Correspondence between sample distributions along the first DCA and RDA axis was also high (R^2=0.692, p=0.01), indicating similar responses for species and functional and ecological groups along the gradient.

4.5 DISCUSSION

Our data demonstrated the value of environmental gradients to clearly separate among different fluvial segments, as the same gradients emerged whenever species, fluvial type, or plant functional or ecological group was considered. Results revealed that fluvial types consistently played an important role in structuring plant assemblages, explaining >10% of the floristic variance, and we found that about 35% of species were unique to and 17% were significant associated with, a single fluvial type.

The widths of the active zone, riparian zone, and full channel were the main morphological features distinguishing fluvial sections. These morphological features, represented by axis 1 in the DCA and CCA, were also the main factors affecting changes in plant species composition in the different fluvial types. Specifically, significant variation in the width of the fluvial bed, between the headwater and incised types on the one hand and low sinuosity and braided types on the other, were caused by a decrease in both the depth and speed of the water in the latter types, with a consequent increase in sedimentation. In Mediterranean rivers with wide beds, low slopes, and active lateral adjustments with an abundant sediment supply (i.e., braided and low sinuosity types in this study) promote the spread of annual plants, which are typically pioneer and ruderal species (Grime, 1977). Distributions for these species were strongly influenced by the amplitude of active and riparian zones, and as also noted by Salinas and Casas (2007), showed a significant positive response to higher light availability, higher temperature values, and more intense drought (higher values for L and T; lower values for U). These species were well suited to marked edaphic dryness and unconsolidated soils with prevalent sediment deposition (Barbero et al., 1990; Molina et al., 2004), and were linked mostly to non-hygrophilous plant communities (Landi and Angiolini, 2006). Our results also indicated an increase in the frequency of nemoral species in the narrowest riverbeds (headwater and incised segments), a response that could be partly attributed to lower light availability (see Everson and Boucher, 1998). This compositional change may be related to the presence of forests, which tend to reduce solar radiation to the soil, thus preventing germination, growth, and survival of heliophilous herbaceous species (e.g., many therophytes). Hygrophilous species (e.g., *Alnus glutinosa, Equisetum arvense, Eupatorium cannabinum*, *Mentha aquatica*) and shrubby species (e.g., *Cornus sanguinea, Crataegus monogyna, Euonymus europaeus*) were found mainly in headwater segments, a pattern that is in line with the observations of Lite et al. (2005) in semi-arid riparian habitats. Plant species found in the headwater section had a high moisture level index, reflecting the dominant environmental features that differentiate this fluvial type from the others. Suitable environmental conditions for these species were probably due, in part, to the corresponding elevational increase in summer rainfall, and perhaps also to cooler temperatures and lower evaporative stresses that allow for higher soil moisture and less stressful growing conditions. However, it should be pointed out that aquatic species were less frequent than riparian ones in our study area, probably because of the steep slopes associated with headwaters, a condition that determines a general scarcity of alluvial areas capable of hosting these species (Richardson et al., 2005). Instead, it was the incised segments that possessed the suitable environmental characteristics (high canopy cover due to the narrow channel, low energy flow due to the low slope) for these species, which were found only in the lower part of the river. As for other Mediterranean riparian ecosystems (see Salinas and Casas, 2007), forest associated with the upper part of rivers (headwater type) was quite different from the lower areas (incised type). Headwaters generally showed a lower level of human disturbance; among its indicator species there were woody alluvial taxa such as *Alnus glutinosa,* a pioneer tree for riparian habitat of the upper parts of European river corridors, often associated with *Acer pseudoplatanus. Alnus glutinosa* cannot withstand even brief periods of inundation and is confined to high terraces (Ward et al., 2002; Corbacho et al., 2003). Incised segments at lower elevations have different bioclimate (lower rainfall and higher temperature, Alcaraz et al., 1997), coupled with increased human impacts. These environmental conditions supported higher numbers of more drought-tolerant (mesothermophilous) pioneer woody species (*A. monspessulanum* and *O. carpinifolia*).

Alien species richness, in contrast to other studies in riparian communities (Deferrari and Naiman, 1994; Stromberg and Chew, 1997; Hood and Naiman, 2000), was very low in this river (2.9% of the total). A similar trend has been observed in other Mediterranean rivers (Tabacchi et al., 1996) and in more mesic rivers in Portugal, where aliens represented only 10% of all species or less (Ferreira and Moreira, 1995; Aguiar et al., 2001). Our results, in line with those of Groves and di Castri (1991), showed that aliens are not suited to the riparian semi-arid habitats that are frequent in the Mediterranean region, particularly in wider riverbeds. Generally speaking, alien and nitrophilous species richness increases downstream (Ferreira and Moreira, 1995; Planty-Tabacchi et al., 1996; Tabacchi et al., 1996; Aguiar et al., 2006). But this pattern failed to emerge in our study, probably because even if the (lower) incised part of the river was surrounded by cultivated lands, the gulley valley provided a (vertical) spatial separation, thus minimizing direct contact with human impacted areas.

In our study area, fluvial type did not substantially affect the distribution patterns of high risk species or perennial herbaceous species. Many studies have demonstrated that different vegetation layers have unique and independent responses to environmental gradients in riparian areas (Lyon and Sagers, 1998; Decocq, 2002; Lite et al., 2005).

The relatively weak differences in floristic composition among the fluvial types and a lack of agreement between axis 2 of the DCA and CCA, suggests that other environmental factors, only marginally linked to fluvial types (i.e., transversal gradients), may have a significant influence on the distributional features of the floristic assemblages in our study river. For example, results from partial CCA demonstrated that elevation influenced plant species distribution, although less than fluvial type. Based on our statistical analyses, we can affirm that dividing fluvial types according to morphological features was an effective way to assess floristic differences, including indicator species and functional/ecological groups (although variability was only partially described). The DCA floristic analysis indicated a congruence with fluvial types that was restricted to the first ordination axis. At this ordination level, different physical conditions (narrow/wide fluvial bed, soil deposition/erosion) also corresponded to different biological conditions (and thus to different floristic composition). In contrast to what observed by Hawkins et al. (2000) for invertebrates, we found that the physical features of riparian ecosystems influenced floristic similarity more than spatial continuity between sites. The headwater and braided types were characterized best, with numerous indicator species and particular distributional patterns for functional and ecological groups.

4.6 CONCLUSIONS

Our method demonstrated the clear influence of fluvial types on plant species assemblages, which were found to differ significantly by species compositions and functional and ecological groups. Our results allowed us to consider morphological classifications as a potential surrogate for riparian plant assemblages in a Mediterranean river with low human-impact. In fact, our strategy could be a preliminary, rapid, and cost-effective approach to define plant species distributions at local scales, thus providing basic knowledge for conservation management, particularly in areas where critical datasets are either not available or of poor quality. Further investigations on other rivers are clearly required for validation.

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CHAPTER 5:

MORPHOLOGICAL AND LAND-USE CLASSIFICATIONS FOR RIPARIAN VEGETATION:
ARE THESE CONCORDANT ACROSS RIVERS AND PREDICTIVE OF PLANT DISTRIBUTION?

ABSTRACT

We examined the concordance among morphological, land-use and hydrid classifications in four Mediterranean rivers. Our goal was to test how consistently different classifications account for variation of other physical features, and in particular if site groupings based on river morphology can detect also significant differences in land-use, and if these classifications have enough classification power to be used as a surrogate for riparian vegetation distribution.

Our results revealed that classification concordance varied among the rivers. The lack of concordance reflected the fact that morphology and land use can vary in different manner along the longitudinal gradient of rivers. Moreover, there was also a poor correspondence between broad-scale classification and biological communities. Anyway, although none of the classifications accounted for a large degree of variation in biological characteristics, some of them performed better than others, suggesting that some factors at landscape scale could contribute to predict differences in biological characteristics at local scales. Morphology emerged to be the most important determinant of riparian flora in Tuscan rivers, while on the contrary in Sardinian rivers land use (and thus hybrid classification) resulted to have a well defined zonation along the river course, accounting for a significant amount of plant species variability.

This study suggested that that all classifications performed poorly at explaining biological variability. One of the main cause was the dynamic nature or riparian areas, with several key environmental factors (such as transversal gradient, microtopography, soil features) that are likely to vary considerably within each segment, thus creating an high environmental heterogeneity. Moreover, localized environmental variations can strongly affect riparian plant composition, potentially account for an high within-group variability. Stronger CSs, and hence better predictions, may be found if local factors (e.g. substrate composition, water and soil chemistry) would be added to classification.

Keywords: classification strength, community concordance, land use, Mediterranean basin, morphology, riparian vegetation.

5.1 INTRODUCTION

When studying the biodiversity and ecological features of rivers, it is essential to be able to account for natural spatial variability. Despite often treated as a single ecosystem type, running-water reaches in close proximity one another has been shown to differ greatly (Turak and Koop, 2008). Provide spatial order and structure to these complex patterns of biotic variation is nowadays one of the major research need (Huang and Ferng, 1990), especially in the frame of conservation and management of freshwater ecosystems.

For this propose, methods for grouping sites that are relatively homogeneous with respect to one or more biotic and/or abiotic characteristics have been developed (see Naiman et al., 2005; Johnson and Host, 2010). Among the most widely used approach there are geographic classifications, become an integral part of efforts to study, monitor, and manage ecosystems (van Sickle and Hughes, 2000) especially in data-poor regions (Higgins et al., 2005; Thieme et al., 2007), based on environmental features derived remotely and used as surrogates reflecting the variability of biodiversity.

Landscape classifications are frequently used as source of information to predict the conditions that should occur at individual sites (Bailey, 1995). The idea that site conditions can be at least partially specified from landscape features is based on the view that ecological attributes of aquatic ecosystems are strongly influenced by their catchments (Hynes, 1975; Johnson and Goedkoop, 2000). However, the strength of the relationships between landscape features and site-specific biota is poorly known (Hawkins et al., 2000). Landscape classification for predictive vegetation mapping, recently suggested as potential shortcuts for conservation planning (Heino and Mykra, 2006), are based on knowledge relating the vegetation units to mapped physical data. Within Mediterranean basin rivers, morphology and land use are among the most important determinants of riparian plant assemblage, thereby providing a potential basis for physical surrogates. As reported by the recent reviews of Steiger et al. (2005) and Corenblit et al. (2007), many studies revealed river morphology to be a strong determinant of riparian ecosystem function. Landforms and physical processes drive the dynamics of biota, deeply influencing riparian plant communities (Mollot et al., 2008; Xu et al., 2008), particularly in ephemeral stream networks (Shaw and Cooper, 2008). In agreement with this view, Tabacchi et al. (1998) assumed that since every river system has its peculiar geomorphological structure, reciprocal control between hydrology and vegetation could be analyzed from a geomorphological template, particularly in Mediterranean areas. Apart from the recent study of Hupp and Rinaldi (2007) and Angiolini et al. (2011), where a morphology based riparian classification was successfully applied, few studies have assessed plant species distribution in Mediterranean riparian areas in relation to riverbed morphology. Also human activities along a river and its valley are known to influence plant species distribution along rivers (Malanson, 1993; Kondolf et al., 1996; Ferreira et al., 2005; Meek et al., 2010), disrupting the ecological interactions between landscape dynamics and fluvial ecological processes (Gregory et al., 1991; Jungwirth et al., 2002), with the subsequent fragmentation of riparian vegetation and changes in structure and composition (e.g., Décamps et al., 1988; Knight et al., 1994; Planty-Tabacchi et al., 1996). What is more, Mediterranean landscapes are characterized by a long-lasting history of intensive land use (di Castri et al., 1990; Corbacho et al., 2003), which probably interferes with riparian vegetation.

Given the importance of these variables, the degree to which they are linked together remains largely unknown, as also their ability to characterize the riparian vegetation. For this reason, we aimed to examine the concordance between a morphology-based and a land use-based classification of rivers in Mediterranean basin. We applied a measure of classification strength, that is a function of within-class homogeneity and between-class separation, to compare the strength of these classifications in accounting for riparian plant species and functional groups distribution in four different rivers. Moreover, we wondered if a cross classification between morphology and land use would be more successful at explaining plant species variation than either of the separate approaches. Incorporating many landscape classifications in biodiversity surrogate schemes should thus increase concordance with biotic groups (Heino and Mykra, 2006). According to Lombard et al. (2003), land classes derived by integrating remotely derived environmental variables with land class mapping (vegetation based) should better reflect biological heterogeneity.

On the contrary of many tests of concordance, that detected rather strong spatial congruence among groups examining relationships between ordination solutions or pairwise correlations among site scores on direct and indirect ordination axes (e.g. van Coller et al., 1997; 2000; Heino et al., 2005; Shaw and Cooper, 2008; Vogiatzakis et al., 2009), we assessed the transferability of one GIS-based landscape classification to other variable groups in a series of cross-tests. We preferred this kind of approach since many studies regarding freshwater ecosystem conservation and quality assessment use clustering techniques as starting point (Paavola et al., 2003).

Despite the amount of research regarding biodiversity classifications, there is a dearth of studies actually showing concordant patterns between such classifications and biodiversity (Wessels et al., 1999; Ferrier, 2002; Mac Nally et al., 2002; Oliver et al., 2004). Particularly, one of the most common finding of the studies based on benthic macroinvertebrates was that the poor classification strength could be referred to the presence of largely spread *taxa* that contributed to homogenize the classes (Heyno and Mykra, 2006; Hawkins and Vinson, 2000; Hawkins et al., 2000). For this reason, we wondered if removing the most spread species would improve the strength of our classification, and decided to test for classification strength of our GIS-based models taking into account at first all plant species, and subsequently removing the most frequent species of each area, in order to reduce the noise in the datasets.

Our specific goals were: (i) to measure the strength and the concordance among all the different classifications examined; (ii) to understand the degree to which these classifications allowed us to account for (and thus predict) variation among sites in plant species composition.

5.2 STUDY AREA

From two different Mediterranean regions (Sardinia and Tuscany, Italy), four rivers originating from the most important reliefs of the study areas were selected. These are among the main rivercourses of the regions and own the hydrological features common also to many other Mediterranean rivers, with lower and wider parts that dry up almost totally during summer, while in autumn and spring are affected by flood events (Landi and Angiolini, 2006; Angius and Bacchetta, 2009). Moreover, they provide classical examples of river systems in

Mediterranean-climate regions, which often have relatively pristine upper catchments, but have been heavily transformed by anthropogenic activities in the lower reaches (Meek et al., 2010).

Santa Lucia and Leni rivers (about 25 and 50 Km of length, respectively) are located in the south-western part of Sardinia. More than 2/3 of the Leni riverbed flow in Campidano valley, the most important graben of the whole island, while Santa Lucia river is almost equally distributed between the two geological substrates of siliceous rocks and sediments. Woodlands are dominant in the mountain part, that is is sparsely populated and with low intensity agro-pastoral systems as the main human disturbance, while in the lower part there are industries, villages and agricultural lands. Particularly, the alluvial lower part of Leni river is dislocated in highly transformed agricultural landscapes with intensive cereal crops and affected by the presence of human settlements. Albegna river (about 50 Km of lenght) is located in south Tuscany, while Fiora river (about 70 Km of lenght) is located partly in southern Tuscany, partly in northern Latium. But since more than half of Fiora river flows in Tuscany, and in order to make the results and discussion easier to understand, from here on we will refer to both these rivers as “Tuscan rivers”. The mountainous upper parts are not intensively cultivated, and sheep farming is the principal activity, with isolated farmhouses and small villages. As a result, the structure of the riparian vegetation is still mainly determined by natural dynamics. The slopes of the area are mostly covered by woods, while the alluvial lower part dominated by grassland and sheep-grazing, and a marginal part dedicated to cereal crops. The lower alluvial parts of both rivers are surrounded by intensive agricultural lands and human settlements.

5.3 METHODS

5.3.1 GIS data derivation

5.3.1.1 Derivation of morphological data

Morphological data (following Angiolini et al., 2011) were derived from digital aerial photos (2003), Digital Elevation Model (DEM), and geological layers. Although the scale chosen for most studies involving river morphology is usually 1:10.000 (Ward et al., 1999; Gurnell et al., 2000; 2001), we decided to use a more detailed scale (1:5000) for all the GIS analyses to improve detection of environmental features and derive parameters chosen for morphological classification more precisely and consistently. To identify the floodplain, we first selected areas with alluvial lithology, then we removed any cultivated land near the river. In the resulting floodplain area, river segments (*sensu* Poole, 2002) were drawn at 2 km intervals along the river, from the source to the valley. For the morphological characterization of the river segments we chose to consider physical features that are widely used in riparian morphology studies including: slope, sinuosity, number of nodes, gross active zone width, gross riparian zone width, and full channel width (Ward et al., 1999; Gurnell et al., 2000; Parsons and Gilvear, 2002). Using DEM (75 x 75 m), the slope of each segment was calculated from the difference in elevation between the beginning and the end of the segment, measured in the channel thalweg. Sinuosity was calculated (according to Ward et al., 1999) as the ratio of the channel thalweg length/length of each segment. We derived the number of nodes for each segment within the channel network by interpreting aerial photographs. The gross active zone width was the width of the currently active zone of the river, including water-filled channels, areas of bare sediment (mainly gravel), and islands. The gross riparian zone width was the width of the currently active zone of the river plus adjacent areas of riparian woodland, and usually corresponded to the contemporary floodplain (see Gurnell et al., 2000). Finally, since one of the most important features that characterizes stream ecosystems is the rate of flow, which is related to the width of the channel (Jowett, 1997), we decided also to take into account the full channel width (at the time of map survey), which, when measured where multiple channels were present, was the width of the main channel. Following Gurnell et al. (2000), these last three parameters were measured every 500 m using aerial photos, and mean values for each segment were calculated.

All morphological features were standardized as z-scores (mean = 0 and standard deviation = 1) previous to all statistical analyses to reduce both the size and variability to a common scale.

5.3.1.2 Derivation of land use data

The CORINE Land Cover (CLC) map represents the European environmental landscape based on the Interpretation of Landsat images. Developed by the European Environment Agency (EEA), its objective is to provide a unique and comparable set of land cover data for European Countries, of use for environmental analysis and for policy makers (Heymann et al., 1994). The CORINE land cover nomenclature is hierarchically organized at three levels that can be progressively expanded into further detailed categories depending on the resolution and the scope of the mapping process. In this way, the CORINE land cover protocol has a general validity but, at the same time, the hierarchic structure and the flexibility of its nomenclature make it possible to obtain precise information irrespective the peculiarities of a specific area. At the national level some countries, including Italy, have compiled an extended CLC legend including more detailed categories in order to better inventory particular habitats.

In the present work, CORINE land cover expanded to the fourth level of detail was followed. As first step, original land-use types were grouped into nine classes, which we considered to be representative of main land uses of the area: 1) urban and industrial areas; 2) intensive crops; 3) pastures and extensive crops; 4) orchards, vineyards and olive groves; 5) scrubland and macchia type vegetation; 6) mixed woodlands; 7) forest plantations; 8) gravel, sand and exposed rock; 9) wetlands and salt ponds. To obtain the influence of the surrounding land cover types on the riparian vegetation, we calculated cover data of each land-use type in every segment. To doing so, we created in both the banks a buffer zone 1.5 km wide of the water way (because this was the average distance from the waterway to the top of the nearest hill), and then calculated the percentages of land-use types in each resulting area of 2 x 3 km.

5.3.2 Field sampling

Using a stratified random sampling design, we placed 2 plots (10 × 10 m) in each of the segments previously delineated, resulting in 189 plots (25 plots in S. Lucia, 48 in Leni, 68 in Fiora, 48 in Albegna). The 100 m^2 plot size should be adequate to detect vegetational variation in the floodplain because it has previously been used to explain relationships between species richness and environmental features in forests (Schuster and Diekmann, 2005) and grasslands (Gross et al., 2000). For each plot we recorded presence or absence of all vascular plant species from May through July 2007-2009.

5.3.3 Data analyses

All multivariate analyses were conducted using the PC-Ord computer package (version 4.17; McCune and Mefford, 1999), while CS analyses were conducted using MRPPCONV (Van Sickle,1997).

5.3.3.1 Classification and cluster validation

Given the high degree of floristic differences detected in a previous study conducted in the same study area (see chapter 2), we chosen to study each river separately from the others. We first created a hierarchical site classification by using cluster analysis, separately for each set of variable used for classifications. Thus, three hierarchical agglomerative cluster analyses with Ward's linkage or minimum increment of sum of squares based on Euclidean distance as a dissimilarity coefficient (Ward, 1963; Legendre and Legendre, 1998) were performed, taking into account i) morphological features alone (number of nodes, sinuosity, slope, gross active zone width, gross riparian zone width, full channel width); ii) land use features alone (urban, intensive crops, pastures and extensive crops, orchards, scrubland, woodlands, forest plantations, sand, wetlands); iii) morphological and land use features together to create an hybrid classification.

We validated each final division by using Multiple Response Permutation Procedures (MRPP) (Zimmerman et al., 1985; Biondini et al., 1988). A division was only accepted if the groups differed significantly ($P < 0.05$) according to MRPP. MRPP is a data-dependent permutation test, mathematically allied with analysis of variance, in that it compares dissimilarities within and among groups, but has the advantage of requiring few assumptions about the distribution structure of the data (Zimmerman et al., 1985). This makes it ideal for testing among-group differences in ecological data, even because the number of plots differs between rivers. MRPP consists of two statistic tests: the A Statistic estimates within-group homogeneity and the T Statistic measures between-group separability. Higher values of A Statistic (ranges 0.0-1.0) indicating a high degree of homogeneity within groups while a large negative T value ($\leq$-10.0) indicates high separability between group. Moreover, $A = 0$ when the within group community heterogeneity equals that expected by chance and $A < 0$ when heterogeneity exceeds that expected by chance (McCune and Mefford, 1999). The null distribution of the test statistic (chance corrected within-group similarity, A) is based on the collection of all possible permutations of the objects into groups of a specified size.

5.3.3.2 Cluster concordance

We tested the performance of each classification by subjecting the final groupings of each classification to a MRPP analysis using the other two data sets. To do so, the cluster groups were subjected to a set of cross-tests on the other two physical features groups using randomization protocol (Paavola et al., 2003). In MRPP, the null hypotheses of no differences among groups was assessed through a Monte Carlo permutation procedure with 999 permutations.

We also used the classification strength (CS) approach of Van Sickle (1997) to assess the performance of each cross-test. CS is based on a comparison of the mean of all between-class similarities (B) and the mean within-class similarity (W). We calculated B and W using Sørensen similarity coefficient. CS is defined as the difference between these similarities (CS = W - B). Values of this measure range from zero to one, values near zero indicating that sites are randomly assigned to classes. The observed values of CS were compared with permuted values, obtained through 1000 random reassignments of sites to groups. To obtain a measure against which we could gauge the results of the cross-tests, we ran a series of self-tests for each typology, subjecting each classification to the same set of analysis (MRPP and CS) as in the cross-tests, but using the original data matrix for each respective cluster typology. As a final test of concordance, we used the Mantel test to compare the degree of concordance among similarity matrices (Sørensen distance) constructed for each classification. It uses the standardized Mantel statistic (r), analogous to correlation coefficient, to evaluate the strength of the relationship between two matrices, with high values of r indicating strong congruence (McCune and Mefford, 1999). The statistical significance of r was tested by Monte Carlo permutations (n = 9999 permutations).

MRPP and CS were also used to assess the performance of each GIS-based classification in detecting differences in plant species with presence-absence dataset, considering classification strength with respect to: 1) functional group, defined as groups of species that share the same adaptive features in relation to a well-defined function (McIntyre et al., 1995), with species classified into groups: woody species (phanerophytes and nanophanerophytes), herbaceous perennial species (geophytes, hemichryptophytes, and chamaephytes), annual species (therophytes), hydrophytes; 2) all plant species dataset; 3) plant species dataset after removing frequent species (the most frequent species in all study area was recorded in 51% of plots; we removed the species with frequency > 40% and > 35% respectively).

5.4 RESULTS

5.4.1 Concordance among classifications

In the cluster analyses (dendrograms not shown) the cut levels which provided the most informative classifications of segments were selected (the number of the resulting cluster groups for each river is reported in Tab. 1). Since in S. Lucia river the land-use classification matched the hybrid classification division, in Tab.1 and Tab. 2 they are merged in the same row with the label “L (land use), M + L (morphology + land use)”.

With only 6 exceptions, all cross-validation tests among morphology, land use and hybrid classification showed statistical evidence ($p<0.05$) of greater CS than would be seen for randomly grouped sites (Tab. 1). However, these CS values were very different among the rivers investigated and in general showed comparable values for rivers of the same region. Sardinian rivers resulted to have similar responses. Morphology had no statistical significance and low values of CS when tested vs land use and vs the hybrid classification. For this variable, CS value was low also in the self test. Land use had instead the largest numerical values both in the self and in the cross test vs the hybrid classification, followed by the hybrid classification. Consistently, also the values of *T* and *A* statistics indicate a poor homogeneity inside and weak differences between the cluster groups for morphology in all the cross-tests and also in the self tests, while for land use and the hybrid classification the values raised. Tuscan rivers resulted to have different responses. CS test for Fiora revealed high levels of concordance among all classifications, while in Albegna all classifications resulted to be weak both in the self and in the cross tests. The values of *T* and *A* statistics in these rivers indicated a certain degree of correspondence between all classifications, with the highest values of *A* statistic of the whole study area in Fiora river above all. The hybrid classification resulted to be significant in all the cross-test, and apart self-test values, it had the best results of classification strength and of separability among group and homogeneity inside groups.

Tab. 1 Results of the cross-tests based on Multiple Response Permutation Procedures (MRPP) of different classifications (n=number of cluster groups of each classification) using data on other physical feature groups. A statistic of MRPP and classification strength (CS) are given for each tested pair. The results of these self-tests are given in bold. M=morphology, L= land use, M+L= morphology + land use.

		MORPHOLOGY				LAND USE				MORPHOLOGY + LAND USE			
	n	*A*	*T*	CS	P	*A*	*T*	CS	P	*A*	*T*	CS	P
Sardinian rivers													
S. Lucia													
M	2	**0.177**	**-5.123**	**0.093**	**0.000**	-0.049	0.692	-0.053	n.s.	0.004	-0.071	0.006	n.s.
L, M+L	2	0.084	-2.397	0.065	0.025	**0.570**	**-7.935**	**0.679**	**0.000**	**0.450**	**-7.796**	**0.428**	**0.000**
Leni													
M	3	**0.219**	**-6.993**	**0.075**	**0.000**	0.000	-0.007	-0.003	n.s.	0.043	-1.163	0.027	n.s.
L	4	0.091	-2.572	0.035	0.014	**0.515**	**-10.631**	**0.434**	**0.000**	0.432	-10.333	0.273	0.000
M + L	5	0.117	-2.714	0.316	0.009	0.569	-9.674	0.412	0.000	**0.480**	**-9.473**	**0.259**	**0.000**
Tuscan rivers													
Fiora													
M	6	**0.716**	**-11.131**	**0.463**	**0.000**	0.345	-5.983	0.253	0.000	0.543	-10.188	0.373	0.000
L	6	0.372	-6.536	0.198	0.000	**0.654**	**-12.803**	**0.424**	**0.000**	0.488	-10.351	0.289	0.000
M + L	7	0.706	-10.600	0.368	0.000	0.526	-8.810	0.344	0.000	**0.649**	**-11.758**	**0.379**	**0.000**
Albegna													
M	5	**0.541**	**-9.021**	**0.190**	**0.000**	0.043	-0.743	0.026	n.s.	0.301	-7.027	0.129	0.000
L	4	-0.001	0.015	0.001	n.s.	**0.451**	**-10.609**	**0.212**	**0.000**	0.226	-7.102	0.086	0.000
M + L	5	0.489	-8.253	0.151	0.000	0.178	-3.144	0.090	0.004	**0.353**	**-8.315**	**0.134**	**0.000**

Mantel tests confirmed the previous results and underlined different patterns of concordance among the different classifications in the four rivers investigated (Tab. 2). The highest value of concordance was found in Leni and in Albegna between hybrid classification vs land use, and in Fiora also between hybrid classification vs morphology. Albegna had the lowest values of concordance between hybrid classification vs morphology, while Mantel test for land-use vs morphology was not significant. According to the results of cross-validations, the hybrid classification had the higher level of concordance with the other 2 classifications.

Tab. 2 Results of Mantel test. M=morphology, L= land use, M+L= morphology + land use.

		MORPHOLOGY		LAND USE	
		r	*P*	r	*P*
S. Lucia	M				
	L, M+L	0.429	0.003		
Leni	M				
	L	0.271	0.017		
	M + L	0.345	0.003	0.984	0.001
Fiora	M				
	L	0.535	0.001		
	M + L	0.888	0.001	0.831	0.001
Albegna	M				
	L	0.080	n.s.		
	M + L	0.290	0.017	0.701	0.001

5.4.2 Classification strength in relation to plant assemblages and functional groups

Each biological dataset of four rivers gave highly significant results in almost all the cross-tests with the 3 classifications, but all the divisions performed poorly (CSs<0.20, according to Hawkins et al., 2000) (Tab. 3). Particularly, functional groups resulted in all cases in insignificant values of classification strength and low values of *T* and *A* statistic.

Classification strengths were generally of similar magnitude when tested on biological dataset of rivers belonging to same region. In both Sardinian rivers, land use and hybrid classifications had the highest CS values (Tab. 3). Tuscan rivers instead resulted to have the higher values of CS, *A* and *T* when morphology and hybrid classification were tested on plants dataset.

On the contrary to what expected, floristic datasets with the most frequent species removed didn't improved classification performance. In almost all the cases, they resulted merely to follow the trend already detected by the cross-tests with all plant species, with quite similar

CS values. Moreover, the “cut level” of 35% of frequency resulted to tone down classification strengths.

Tab. 3 Results of the classification tests using biological (plant species and functional groups) data based on Multiple Response Permutation Procedures (MRPP). Plants were analyzed considering 1) all floristic dataset (signed as “all”), 2) floristic dataset after removing species with frequency>40% (signed as “<40%”), 3) floristic dataset after removing species with frequency>35% (signed as “<35%”). A statistic of MRPP and classification strength (CS) are given for each tested pair.

		MORPHOLOGY				LAND USE				MORPHOLOGY + LAND USE			
		A	T	CS	P	A	T	CS	P	A	T	CS	P
S. Lucia													
Fun. groups		-0.02	0.838	-0.009	n.s.	0.099	-4.202	0.058	0.004	0.099	-4.202	0.058	0.004
Plants	all	-0.012	1.326	-0.017	n.s.	0.064	-6.922	0.108	<0.001	0.064	-6.922	0.108	<0.001
	<40%	-0.011	1.198	-0.015	n.s.	0.061	-6.776	0.108	<0.001	0.061	-6.776	0.108	<0.001
	<35%	-0.011	1.257	-0.016	n.s.	0.061	-6.771	0.108	<0.001	0.061	-6.771	0.108	<0.001
Leni													
Fun. groups		0.021	-1.221	0.007	n.s.	0.144	-6.874	0.054	<0.001	0.143	-5.823	0.043	<0.001
Plants	all	0.018	-2.978	0.016	0.009	0.087	-11.96	0.104	<0.001	0.087	-10.17	0.091	<0.001
	<40%	0.0172	-2.954	0.017	0.009	0.078	-11.254	0.097	<0.001	0.078	-9.549	0.084	<0.001
	<35%	0.0174	-3.047	0.017	0.007	0.075	-10.948	0.093	<0.001	0.075	-9.384	0.082	<0.001
Fiora													
Fun. groups		0.098	-4.255	0.029	0.001	0.135	-6.137	0.042	<0.001	0.156	-6.308	0.049	<0.001
Plants	all	0.091	-14.275	0.115	<0.001	0.093	-15.391	0.095	<0.001	0.121	-17.72	0.123	<0.001
	<40%	0.121	-17.859	0.125	<0.001	0.095	-15.71	0.098	<0.001	0.121	-17.86	0.125	<0.001
	<35%	0.116	-17.769	0.123	<0.001	0.093	-15.974	0.099	<0.001	0.116	-17.77	0.123	<0.001
Albegna													
Fun. groups		0.135	-4.625	0.045	0.001	0.099	-4.147	0.036	0.002	0.228	-7.814	0.082	<0.001
Plants	all	0.053	-5.835	0.055	<0.001	0.044	-5.898	0.049	<0.001	0.053	-5.835	0.055	<0.001
	<40%	0.053	-6.016	0.053	<0.001	0.042	-5.873	0.049	<0.001	0.073	-8.358	0.082	<0.001
	<35%	0.05	-5.952	0.049	<0.001	0.037	-5.447	0.043	<0.001	0.063	-7.65	0.07	<0.001

5.5 DISCUSSION

5.5.1 Classifications concordance

Several alternative classifications of rivers have been proposed (see the review of Jonhson and Host, 2010), and a general finding from these studies was that, although landscape classifications are increasingly being used in conservation planning and biodiversity management, stream assemblages often showed statistically significant differences between landscape classes, but with rather weak classification strengths (Hawkins et al., 2000). Our results agree with this view, showing that the groups identified by all classifications significantly reflected differences of the other variables, thus showing a certain (even if in most of the cases not high) degree of coherence.

The most obvious mechanism causing concordance is similar but independent response by the variables to major environmental gradients (Paavola et al., 2003). According to this, the strong correspondence between morphology and land use in one river (Fiora), and thus the derived hybrid classification, performed well in catching at the same time the variability of these two features (as showed by cross-tests and Mantel test), probably because land use generally covaries with topography and then with the longitudinal gradient (Allen et al., 1999). But the same environmental features cannot vary in the same way within a region (Neilson et al., 1992), and this was the possible explanation of weak or non-significant relationship between morphology and land use in other three rivers (Sardinian rivers and Albegna), where they probably had different pattern along the longitudinal gradient. Moreover, in Sardinia morphological divisions resulted to have low values of CS also in the self-test, thus confirming the scarce importance of this environmental feature in these rivers. Land use classification instead was able to identify morphological (even if weak) differences, thus playing a predominant role also in the hybrid classification.

In Albegna river, the almost total lack of concordance between classifications suggested that here both morphology and land use performed poorly at significantly indentify homogeneous river stretches. One of the possible causes of this results can be the high environmental heterogeneity of this river, together with its landscape fragmentation. Human disturbance was the main factor responsible for fragmentation, particularly where land use schemes of extensive and intensive agricultural production are present, accounting for riparian corridor alteration and for the broken of natural successional gradient of riparian vegetation (and naturalness) along the longitudinal gradient (Chorbacho et al., 2003). Low values of W imply in fact a large amount of within-class heterogeneity that was not accounted for in the classification (Hawkins et al., 2000). Here the best classification was the hybrid one, since it manages to merge the variability of both the variables. For this reason, the hybrid classification resulted generally to perform better that the others, showing to effectively (and significantly) account for land use and morphological features.

Anyway, the lack of studies using this kind of approach on rivers' classifications concordance precludes a wider comparison, and any explanations for the lack of parallel response by different environmental features are necessarily tentative.

5.5.2 Classification strength in relation to plant assemblages and functional groups

Our effort to test 3 different classifications using the same data from the same area suggested that landscapes models may never account for a high degree of variation at local scales. According to many other authors, also in our rivers there was a poor correspondence between broad-scale classification and biological communities (e.g. van Sickle and Hughes, 2000; Kupfer and Franklin, 2000; Olivier et al., 2004; Heino and Mykra, 2006). Anyway, although none of the classifications accounted for a large degree of variation in biological characteristics, some of them performed better than others, suggesting that some factors at the landscape scale could contribute to predicting differences in biological characteristics at local scales.

All the tests agreed that morphology was not the most important environmental factor in Sardinian rivers, and in fact didn't detected significant floristic differences. This result can be related to the length of the river itself, since environmental features that strongly influence the distribution of biota do not vary appreciably within small streams (Hawkins and Vinson, 2000). On the contrary, land use (and thus hybrid classification) resulted to have a well defined zonation along the rivercourse, accounting for a significant amount of plant species variability (CS value of about 10%). All classification performed instead poorly in Albegna river (CS value on average of 5%). This result can be due to many reasons: i) individual *taxa* varying independently and continuously over environmental gradients (Hawkins and Vinson, 2000); ii) the high environmental heterogeneity and fragmentation of the riparian segments and surrounding area, that tend to decrease within-group homogeneity and between-group heterogeneity (Ferrier, 2002); iii) important environmental heterogeneity that may exist among sites but not accounted for by landscape classification (Hawkins et al., 2000). On the contrary, in Fiora river all classifications performed well about plant species, and especially the hybrid one. This result was probably liked, similarly to what already explained for the cluster concordance, to the fact that morphology, land use and riparian vegetation varied in similar manner along the longitudinal gradient of the river. Moreover, we can argue that here morphology acted as main gradient (see chapters 2 and 4), affecting the resulting land use and consequently the floristic assemblages, and thus determining a clear zonation of both biotic and abiotic features. The presence of many ecological gradients along the rivers, not detected by the landscape classification, tend insted to create different distributional patterns, thus limiting the ability of a classification to generate useful prediction on other environmental variables (as probably in the case of Albegna river).

Generally speaking, in all the study area functional groups had the lowest values of classification strength, within group homogeneity and between group separability. This result could be due to the fact that different river stretches can have the same vegetation structure (i.e. dominance of herbaceous/woody vegetation), but with completely different specific composition. For instance, as for other Mediterranean riparian ecosystems (see Salinas and Casas, 2007), woods associated with the upper part of rivers were quite different from those lower down. Moreover, several studies have demonstrated that various vegetation layers have a different and independent response to environmental gradients in riparian areas (Lyon and Sagers, 1998; Decocq, 2002; Lite et al., 2005). For these reasons, our classifications showed to better reflect floristic instead that functional groups differences.

Despite showing highly significant results in the cross-tests, all the classifications performed poorly in detecting floristic variability. One of the main causes would be the absence of a strong relationship between environmental attributes at large scales and local community composition, primarily attributed to high within-class heterogeneity (e.g. Hawkins and Vinson, 2000). High within-class heterogeneity can be caused by inadequate models that fail to account for variation in landscape attributes or, landscapes may naturally show a high degree of patchiness that is difficult to capture for any type of landscape model (e.g. catchments or ecoregions). Many authors moreover suggested that the cause of poor classification performance could be due to the widely distributed *taxa*, that occur across all stream types, while only few species show high fidelity to a given stream type (Hawkins and Vinson, 2000). Many *taxa* are rare, in the sense that they are present in only a small % of collections. These *taxa* may be restricted to very specific ecological conditions or their occurrence may be a function of stochastic colonization processes. In either case, if they are patchily distributed within a region, they may contribute little to the discrimination of groups and thus promote low values of W (Hawkins and Vinson, 2000). In this way, rare species increase noise and decrease within-group similarity, contributing to low classification strength (Heino and Mykra, 2006). On the contrary, *taxa* occurring nearly everywhere will potentially obscure real biological differences among sites and would tend to promote relatively large values of B (Hawkins et al., 2000; Olivier et al., 2004). Our results did not agree with these findings, underlying how in riparian vegetation probably also the most spread species were however more likely to be found in particular river stretches. For instance, in our study areas (but also in Mediterranean rivers in general, Chorbacho et al., 2003), the higher level of homogenization of riparian flora was localized in the areas with the higher human impact and landscape modifications (see chapter 2), conditions more present in the lowlands of Sardinian rivers and also, even if with low magnitude, in Albegna river. Given these results, we can say that the choice to remove the most frequent species from the analyses was not the best key to substantially improve CS. In fact, where the classification resulted to perform well, removing the most frequent species led to an improvement of the model, but where classification was weak, this operation makes the model even weaker.

One of the aspects of classification that may also influence predictive capability is the number of plots. When the number of plots increases, both W and B decrease, probably as a function of an increase in total biotic heterogeneity that would occur as new sites are added to classification, thus causing classes to be more similar to one another (Hawkins and Vinson, 2000). Moreover, for the *a priori* classifications, random sampling effects are likely responsible for the high variability in estimates of W, even if this effect is more important with small sample size.

In our case, the dynamic nature or riparian areas, that in turn decrease inside-group homogeneity and between-group differences, was probably the main cause of floristic heterogeneity (Gregory et al., 1991). In fact, although several key environmental factors follow our stream type classification (e.g. stream width, slope, lad use changes from source to mouth), others (such as transversal gradient, microtopography, soil features) are likely to vary considerably within each segment. Localized environmental variations can strongly affect riparian plant composition (Ferreira and Aguiar, 2006), potentially accounting for an high within-group variability in riparian plant assemblages and thus a poor match between stream classification and vegetation. Ecological distinctions may need to be determined using attributes other than those used for developing the river typologies presented here, or adding more local environmental features in the model (Hawkins et al., 2000). Stronger CSs, and hence better predictions, may be found if local factors (es. substrate composition, water and soil chemistry) would be added to classification.

5.6 CONCLUSIONS

Good classifications are accurate and precise and thus allow unbiased, sensitive assessments; those that are inaccurate or imprecise will lead to biased or insensitive assessments. However, streams are notoriously heterogeneous both biologically and physically, especially over the large geographic areas within which assessments are now being made. As a consequence, it can be especially difficult to develop classifications that work well for assessing impairment of stream ecosystems.

One of the major result of the study was that all classifications performed poorly at explaining plant species variability. But this is not surprisingly. In fact, while there is no doubt that there are real ecological differences among rivers in any large geographic area, the river types defined here and the boundaries placed between them are necessarily artificial. This classification, like many other ecosystem classifications, simplifies nature by representing complex, continuous and dynamic spatial patterns as static, discrete entities. A further simplification is introduced when rules are developed to identify river types across a large area using only remotely derived data (Turak and Koop, 2008). Anyway, recent studies regarding conservation planning strategies suggest that environmental surrogates, although appearing of limited value, are a desiderable approach, since there are few alternatives to them (Olivier et al., 2004). If resources are limited, landscape classifications provide a preliminary, rapid and cost-effective starting point for conservation planning actions, although no single biotic group shows a perfect match with any class. The classes in which the river is divided do not aim to describe the exact floristic composition of the segment, and to make precise predictions of the occurrence of a species, but the assignment of any river segment to a class should provide an indication of the main ecological condition and composition of riparian vegetation to be expected in that segment, thus offering a basis knowledge for conservation management, particularly in areas where critical datasets are either not available or poor quality. Nevertheless, the match between classification and community composition (vegetation in this case) could be increased by adding more or more detailed variables in classification schemes, leading to a more reliable and effective approach for conservation planning of riparian areas.

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CONCLUSIONS

The high number of plants species found at both regional and local scale confirmed that riparian areas had a high floristic biodiversity. This result underlined the importance of riparian landscapes for biodiversity conservation, particularly in Mediterranean areas. At the same time, the flora revealed to possesses a naturally low richness in truly aquatic species (i.e. hydrophytes), due to the hydrological intermittency of the rivers, and to human interferences in the flow regime.

One of the main finding of the study was that, despite some floristic similarities between the two areas, always emerged the high floristic heterogeneity between the two regions. The geographical differentiation resulted to be the main variable affecting the distribution of riverbed floras, thus confirming the primary role of geography in driving riparian plant species distribution at regional scale, confirming that biogeographical differences do not only account for variation in zonal vegetation, but also for variation within azonal vegetation, like riparian corridors. However, this finding could be also a specific outcome of these rivers, being two of them in an island and two in continental areas. When these regional differences were removed from the analyses, the main gradient at regional level was found to be the longitudinal gradient of the river course and the parallel human disturbance increasing gradient and structural transition from mountain woody to herbaceous lowland areas. At local level, longitudinal and lateral gradients confirmed to be the most important gradients for riparian vegetation, but with a basic difference between the two areas. In Sardinia, rivers seemed less affected by the lateral gradient than in Tuscany, because here floodplains were not much wide, and subsequently the vegetation patterns developed in the prevalent (longitudinal) gradient, while the lateral riparian zonation was not present. In Tuscany instead the lateral gradient resulted to be the principal gradient of the area, as noted in other semi-arid rivers, linked both to particular morphological features of these areas and to more natural conditions in the medium/lower reaches of the rivers, with a distinct riparian zonation. The importance of the longitudinal gradient, strongly affecting riverbed flora patterns in these Mediterranean rivers, thanks even to many environmental factors (climate, topography, erosion, land use) that change along this gradient, was underlined also by variance partitioning.

Sardinian rivers were particularly rich in endemic *taxa*, confirming the trend of the island/ total Sardinian flora, but at the same time resulted in an higher rate of alien species. Distributional trend of endemic and alien species followed in general to the naturalness gradient of increasing human impact going toward the sea, but the study evidenced the presence of different degree of naturalness between the two rivers, nevertheless the presence of protected areas in both of them. The analysis of more frequent species and of functional groups revealed that in Santa Lucia there were mostly woody species and endemics, while in Leni perennial and alien species. These findings were a reflection of the dominant morphology of the area, since Leni river flow in the main level land of the whole island, with resulting higher human impact and few natural riparian vegetation. Santa Lucia instead doesn’t flow between towns or agricultural lands, since its alluvial part it’s much short, and it flows from the mountain directly into the sea, thus preserving a more natural flora. The most critical areas thus resulted to be the middle course of the rivers, where endemic species coexist with alien species and overall with human impacted area in the surroundings. These resulted also to be the areas where should concentrate further conservation efforts, for istance maintaining a buffer area to protect both the aquatic and the riparian zones. The general information obtained using this method allowed to rapidly detect the main ecological features of rivers and the most critical areas, useful information to be used as starting point for following ecological studies of conservation planning.

The clear influence of geological and morphological features on the variation of riparian plant species composition along a Mediterranean river had been proved by the test of riparian vegetation distribution along the bedrock-alluvial transition. Lithology resulted to exert an important influence on the distribution and richness of riparian plants, but also of life forms. Particularly, the distribution patterns of species along the river suggested that the transition from bedrock to alluvial marked the highest species turnover, generating an deep floristic discontinuity, overall because of the different degree of human disturbance in bedrock-controlled and alluvial-controlled areas. Geology was thus proved to be an integral component of the patch structure in Mediterranean environments, strongly influencing riparian plant species distribution, since affecting the resulting geomorphology and in turn influencing landform types (incised valleys/level lands) and human disturbance.

Starting from the previous findings, a classification based on riparian morphology have been created and applied in a Tuscan river. The method proposed as surrogate to assess the distribution of riparian flora demonstrated that fluvial types here detected consistently played an important role in structuring riparian plant assemblages, since the division operated with this classification was justified by environmental and floristic differences. This method allowed in fact to identify fluvial types characterized by well-defined indicator species, different distributional trends of functional and ecological groups, and detected real ecological differences. Nevertheless floristic variability was only partially described, results illustrated that the fluvial type classification created using this methodology was consistent with natural plant species distribution patterns. However, other environmental factors, only marginally linked to fluvial types (i.e., surrounding land use), may have a significant influence on the distributional features of the floristic assemblages in the studied river, and their inclusion in the model would substantially improve the classification performace.

The last step of this research was devoted to search for a reliable broad scale classification of the rivers investigated. One of the major result was the poor correspondence found between broad-scale classifications and biological communities. Anyway, although none of the classifications accounted for a large degree of variation in biological characteristics, some of them performed better than others, suggesting that some factors at the landscape scale could contribute to predict differences in floristic characteristics at local scales. Morphology and land use effect had a quite different magnitude between the two regions, as also the correspondence between the two resulting classification. The hybrid classification instead, since accounting at the same time for the variability of both the variables, had the better performance in all the cases.

The fact that all classifications performed poorly at explaining biological variability is not surprisingly. The dynamic nature or riparian areas, with several key environmental factors (such as transversal gradient, microtopography, soil features) that are likely to vary considerably within each segment, cause an high floristic heterogeneity, that tend to decrease classification strenght. Moreover, localized environmental variations can strongly affect riparian plant composition, potentially account for an high within-group variability and thus a poor match between stream classification and vegetation. Stronger Classification Strenghts, and hence better predictions, may be found if local factors (e.g. substrate composition, water and soil chemistry) would be added to classification.

In short, despite the present work is far from being exhaustive about all the variables influencing plant species distribution along Mediterranean rivers, can provide basic indications on the most important environmental and floristic gradients of the study area, to be used as guidelines to develop the best management strategies.

The classifications here tested gave insight into the most important environmental features of each river, and despite their application in new areas is clearly needed for validation and improvement, they can be regarded as potential surrogates for river management and conservation. Particularly, further developments should be addressed to add more environmental features to the models, in order to improve their classification strenght.

RINGRAZIAMENTI

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