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Detecting the imprints of past clear-cutting on riparian forest plant communities along a Mediterranean river

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Abstract

In riparian forests, clear-cutting causes long-lasting changes in both riparian and aquatic biota. In this work, we examined if past clear-cutting events occurred at different times have imprints on riparian forests in a Mediterranean river in central Italy. We carried out a randomized, plot-based vegetation survey of riparian forests in systematically sampled 500 m-long sectors along the whole river, dividing the riparian zone into two internal and two external strips. From historical aerial photos, past clear-cutting events within plots were detected and classified in age classes: (i) cut in the past 8 years (recent); (ii) cut between 8 and 19 years ago (intermediate); (iii) no signs of clear-cutting in the last 19 years (distant). We analyzed the responses of vegetation to clear-cutting and strip position. Alien species richness was higher and woody species richness was lower in recently clear-cut areas compared to those with a distant clear-cutting event. Moreover, recently cut woods had more alien and synanthropic species. Intermediate clear-cut areas had higher levels of invasion by alien species compared to areas with distant cut. Riparian forests of internal strips are impacted by clear-cutting, but seem to recover in 8–19 years thanks to their natural resilience. Conversely, recent or intermediate clear-cutting events did not affect any of the investigated vegetation attributes in the external strips since such forests were already invaded by alien and synanthropic species after human disturbance. Our results confirm that clear-cutting events can have long-lasting effects on Mediterranean riparian forests, confirming the vulnerability of river ecosystems to clear-cutting and suggesting the need for more caution in management practices to improve the conservation status of riparian forests.

KEYWORDS
biodiversity, community composition, disturbance, harvesting, past management, plant diversity, recovery

1 | INTRODUCTION

Riparian areas are nutrient-rich, physically, and ecologically complex ecosystems. They represent transition zones between aquatic and terrestrial environments, being shaped by the variability of flood regimes and characterized by the coexistence of different habitats and local ecotones (Ward et al., 1999). They have a major role in increasing regional biodiversity, being hotspots of plant species

richness and indispensable for the survival of many other organisms of both aquatic and terrestrial environments (Pielech, 2021; Sabo et al., 2005). Riparian zones are among the most impacted and heavily modified ecosystems across the World (Richardson et al., 2007; Rodríguez-González et al., 2022) and they host some of the most threatened habitats of Europe and the Mediterranean (Gigante et al., 2018). Riparian forest vegetation is a complex of communities characterized by a high spatial and temporal variability driven by multiple environmental gradients, such as those generated by bioclimatic, geomorphological, and land-use features (Angiolini et al., 2017). It represents a fundamental component of rivers, supporting a high number of plant species (Gennai et al., 2021; Naiman et al., 2010; Nucci et al., 2012), performing numerous socio-ecological functions (Caneva et al., 2021; Naiman et al., 2010), and providing ecosystem services (Fisher et al., 2009). In the northern hemisphere, riparian forests are dominated by species of the Salicaceae family, this is, *Populus* sp. pl. and *Salix* sp. pl. (González et al., 2018). These species have a series of reproductive, physiological, and morphological adaptations to counteract flooding, sediment deposition, and erosion, which make them one of the most important components of the river ecosystem (Naiman et al., 2010). However, the extent, structural complexity, and naturalness of riparian forests is often significantly compromised (Carli et al., 2016). This is due to anthropogenic disturbance factors such as agricultural or urban land use, human-induced hydrogeomorphological changes, the building of infrastructures (Brown et al., 2018; Dufour & Rodríguez-González, 2019), biological invasions (Lazzaro et al., 2020; Pyšek et al., 2010), and clear-cutting harvesting (Richardson et al., 2007). The latter in particular is one of the most impacting anthropogenic disturbances for riparian forests (Newaz et al., 2019).

Clear-cutting has several effects on riparian forests. It alters abiotic components that are essential for the functionality of rivers and it causes a reduction of terrestrial and aquatic habitats (Bladon et al., 2018; Tolkkinen et al., 2020). Moreover, it produces long-lasting changes in the riparian and aquatic biota (Domer et al., 2019; Richardson & Béraud, 2014; Studinski & Hartman, 2015). Concerning plant species richness, there is contrasting evidence about its changes after cutting events, that is, increases (Boch et al., 2013), decreases (Moola & Vasseur, 2004), or no changes (MacDonald et al., 2014; Zenner et al., 2013). Studies about plant life forms, which are extensively used in riparian ecosystems as proxies of functional adaptations to local conditions and as a response to habitat perturbations (Angiolini et al., 2011; Bejarano et al., 2020), showed how clear-cutting events reduce the presence of certain life forms in riparian forests (Biswas & Mallik, 2010; Newaz et al., 2019). Furthermore, there is a substantial agreement among studies that uncut riparian forests significantly differ in species composition from cut riparian forests. Clear-cut forests lose part of their pool of late-seral species and gain ruderal and alien invasive species, which sometimes become the dominant component of such communities (Loya & Jules, 2008; Richardson et al., 2007). Time since the disturbance event is a crucial factor when assessing the effects of forest management on the species richness and composition of riparian vegetation (Roberts & Gilliam, 1995). As regards species richness, an initial decrease is followed by a recovery within a few decades in most cases (Gilliam, 2002; Roberts & Zhu, 2002). On the contrary, changes in composition can last for longer. Some species linked to old forests and of high conservation concern may take even centuries to recover from cutting (Hermy et al., 1999; Loya & Jules, 2008). Moreover, some studies highlighted that riparian forests respond differently to overstory harvesting based on their location along the lateral/upland gradient, with those located in the higher reach and in lateral uplands being less resistant and resilient to disturbance (Decocq, 2002; MacDonald et al., 2014). After cutting, forests located further from the water can be colonized by early-successional and ruderal species at the expense of nemoral species. On the contrary, streamside forests are more resistant to cutting-induced changes in species composition, since they include species typically adapted to natural disturbance regimes (MacDonald et al., 2014).

In the Mediterranean basin, the conservation value of riparian forests as biodiversity hotspots, even when present as remnants, is well documented (Aguiar & Ferreira, 2005; Gennai et al., 2021). At the same time, even today, clear-cutting keeps on being widely used to manage riparian woody vegetation, consequently representing one of the major stressors for these forests (Borrelli et al., 2017). The rivers of the Mediterranean basin need particular attention and constant monitoring since they are often located in highly human-modified landscapes. Consequently, Mediterranean riparian forests are often heavily managed to guarantee waterflow and avoid flooding events in agricultural and urban areas. This makes Mediterranean river ecosystems particularly vulnerable to human modifications and climate change (Stella et al., 2013). In spite of this, studies analyzing the ecological impacts of clear-cutting on riparian forests are only available for boreal regions (Biswas & Mallik, 2010; MacDonald et al., 2014; Mallik et al., 2013; Newaz et al., 2019; Zenner et al., 2012). This lack of knowledge on the effects of clear-cutting on Mediterranean riparian forests implies the missing of scientific bases for a correct planning of management strategies. A better understanding of such issues is thus needed to detect trade-offs between conservation and management purposes (Rodríguez-González et al., 2022).

To fill the above-mentioned gaps in knowledge, in this study we examined the impacts of clear-cutting on riparian forests along a Mediterranean river, collecting original field data and using univariate and multivariate analysis of variance approaches. We hypothesize that clear-cutting has different effects on different vegetation attributes, and that such effects are variable according to time since disturbance and distance from the river. Accordingly, our aims were: (a) to assess how clearcut harvesting affects plant species richness and abundance, life forms, and species composition in relation to time since disturbance and (b) to test if the effects of clear-cutting on vegetation vary according to the distance from the river channel.

2 | MATERIALS AND METHODS

2.1 | Study area

The study was carried out in the riparian corridor of the Arbia river, located in southern Tuscany, central Italy (WGS 84, EPSG 4326:

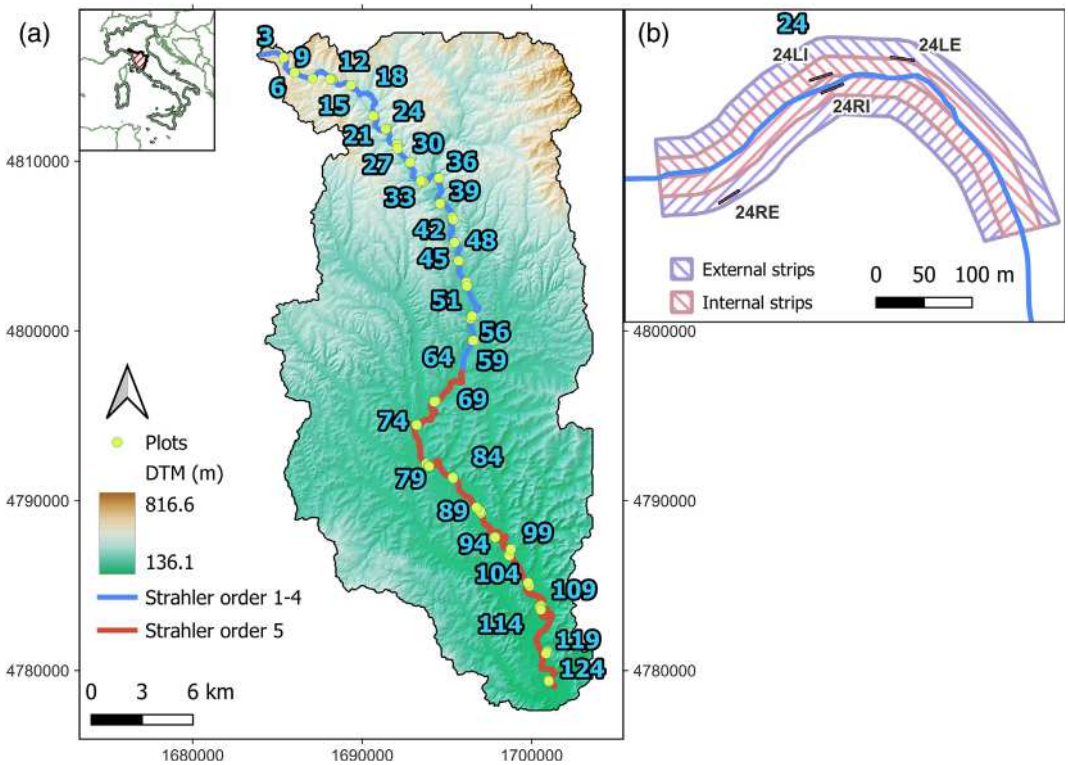

FIGURE 1 (a) Map of the Arbia river and its catchment area, location of the river in Italy, and sampling design. Yellow dots represent plots. Numbers represent the selected sectors; (b) Schematic representation of the position of plots within a sector; each plot is placed in a different riparian strip. Plot codes indicate their sector number, bank side (L, left; R, right), and strip position (E, external; I, internal). Coordinates: EPSG 3003. [Color figure can be viewed at wileyonlinelibrary.com]

11.275 °E, 43.477 °N to 11.475 °E, 43.138 °N) (Figure 1). The river flows North to South for about 63.5 km. It has a catchment area of 573.48 Km^2, and elevation ranges between about 550 and 150 m a.s.l. The bioclimate is transitional between Temperate and Mediterranean (Pesaresi et al., 2017). Geological substrates are represented by carbonatic flysches and marls in the upper reach and by silty-clay Pliocene deposits in the lower reach (Regione Toscana, 2022). The river has a permanent flow, though some reaches almost completely dry out during summer, with seasonal flooding events occurring in spring and autumn. Due to such permanent flow, the natural riparian forest vegetation of the river is represented by azonal woods dominated by *Alnus glutinosa*, *Populus* sp pl., and *Salix* sp. pl., common to many parts of Eurasia and north Africa and well distinguished from the riparian scrub vegetation of intermittent Mediterranean rivers (Mucina et al., 2016).

In the upper reach, land use is represented by broadleaved deciduous forests (mainly *Quercus cerris* and *Q. pubescens* hardwoods), vineyards, and olive groves (Casini et al., 1995). In the medium and lower reaches, the river runs through a valley characterized by urban, industrial, and agricultural land use (De Dominicis & Casini, 1997). Here, the few remnants of natural/semi-natural vegetation are represented by pioneer vegetation of biancana badlands, shrublands, and woods (Maccherini et al., 2011). Natural riparian forests with *Alnus glutinosa*, *Populus* sp. pl., and *Salix* sp. pl. are present where human impact is lower. Such forests are often altered due to the invasion by *Robinia pseudoacacia* and other alien species, spreading after human disturbances (Cierjacks et al., 2013; Motta et al., 2009). Two parts of the river corridor are protected under the European Habitats Directive: the upper reach is included in the Special area of conservation (SAC) "Monti del Chianti" [IT5190002], and a small part of the medium reach is included in the SAC "Crete di Camposodo e Crete di Leonina" [IT 5190004].

2.2 | Sampling design

To investigate the status of riparian forests after clear-cutting events, we carried out a plot-based vegetation survey along the entire longitudinal gradient of the Arbia riparian corridor. Sampling effort was higher in the upper reach, since the river is geomorphologically more complex there. In fact, geomorphological complexity directly affects the heterogeneity of plant communities by generating a higher number of different ecological niches (Tukiainen et al., 2019). Moreover, the amount of forested area was much higher in the upper reach. To distinguish between the upper and lower reaches, we classified the river according to Strahler (1957). Reaches having a Strahler order from one to four were considered the upper reach. Reaches having a Strahler order of more than four were considered the lower reach. To include biotic and abiotic variations along the longitudinal gradient, we divided the course of the river in 125 sectors of 500 m-length, 63 in the upper reach and 62 in the lower reach (Angiolini et al., 2011;

Nucci et al., 2012). Each sector was centered on the river channel and included both banks, with a fixed width of 40 m per side (Clerici et al., 2013; Sutula et al., 2006). Nineteen sectors—one each three—were selected in the upper reach and 13 sectors—one each five—were selected in the lower reach, for a total of 32 sectors (Figure 1a). Each bank (left/right) was divided in two contiguous 20 m wide strips (4 strips per sector), to guarantee a homogeneous sampling effort along the lateral gradient. The strips close to the river were defined as "internal strips," while the outer ones were defined as "external strips." One plot was randomly placed within each strip (Figure 1b). Of the resulting 128 plots, we a-posteriori selected the 60 forest plots, that is, where the tree canopy exceeded 50% of the overall plot cover. Of these 60 plots, 42 were located in the internal strips and 18 were located in the external strips. All the selected plots had a rectangular shape (25×2 m^2) and were oriented with their longer side running parallel to the river channel to reduce the heterogeneity of vegetation along the lateral gradient (Lite et al., 2005; Pielech, 2021; Popescu et al., 2021).

2.3 | Vegetation survey

The field sampling was carried out between May 2021 and July 2021. To follow plant species phenology, we started the survey from the lowest part up to the source of the river. In each plot, we recorded all the occurring species of vascular plants and visually estimated the percentage cover of each species. For the cover assessments we used a 0.1, 0.5, 1, 2 ..., 10, 15 ... 100% scale. Species nomenclature and classification into native and alien taxa follow Bartolucci et al. (2018) for native species and Galasso et al. (2018) for alien species, with their following updates (Portal to the Flora of Italy, 2022). We classified all vascular plant species according to their Raunkier life form following Pignatti et al. (2017). Species were then arranged in three main life form groups: annual species (Therophytes), herbaceous perennials species (Geophytes, Hydrophytes, Helophytes, and Hemicryptophytes), and woody species (Phanerophytes, Nanophanerophytes, and Chamaephytes).

2.4 | Classification of clear-cutting events

To classify and define clear-cutting events in our plots, we visually interpreted aerial orthophotos at 7 years (2002, 2005, 2007, 2010, 2013, 2016, 2019—Regione Toscana, 2022) in the software QGIS v. 3.20.3 (QGIS Development Team, 2021). Diachronic analyses of orthophotos are commonly used to detect spatiotemporal changes and structural transitions caused by management in riparian vegetation (Miller et al., 1995; Sawtschuk et al., 2014). We defined clear-cutting as the removal of at least 90% of the overall tree vegetation cover among two subsequent orthophotos at a given sampling site (Appendix A, Supplementary Material 1). We categorized clear-cutting events in 3 age classes, according to their distance in time from the present: (i) recent cut (hereafter "R"): plots that have been cut in the past 8 years (transition periods: 2013–2016, 2016–2019); (ii) intermediate cut (hereafter "I"): plots that have been cut between 8 and 19 years ago (transition periods: 2002–2005, 2005–2007, 2007–2010, 2010–2013); (iii) distant or absent cut (hereafter "D"): plots that have not been cut in the last 19 years (reference orthophoto of year 2002).

2.5 | Statistical analyses

We calculated the following attributes for each plot: (i) species richness; (ii) species richness of each life form group and of alien species and (iii) abundance (cumulated percentage species cover) of each life form group and of alien species. After checking for the non-collinearity of the categorical variables (function VIF in the package *car* of R [R Core Development Team, 2022]), to investigate the effects of clear-cutting factor and strip position on these univariate attributes, we used two-way factorial ANOVA models with clear-cutting age classes (R, I, D) and strip position (internal, external) as fixed factors. When the clear-cutting factor was significant, we carried out post hoc pairwise Tukey tests. Moreover, if the clear-cutting factor or its interaction with strip position was significant, pairwise Tukey tests were carried out to assess differences between clear-cutting age classes within internal and within external strips. ANOVA models were calculated using type III sum of squares. All the tests were performed using the software Paleontological Statistics (PAST—Hammer et al., 2001).

To investigate the effects of clear-cutting factor and strip position on community composition (presence and abundance of each species), we used permutational analysis of variance (PERMANOVA—Anderson, 2001) using type **III** sum of squares. When the clear-cutting factor was significant, we carried out pairwise comparisons with the PERMANOVA t statistic to detect significant differences between clear-cutting age classes. Moreover, if the clear-cutting factor or its interaction within strip position was significant, pairwise t-tests were carried out to test for differences between clear-cutting age classes within internal and within external strips. All the tests were performed with 9999 permutations of residuals under a reduced model (Anderson & Ter Braak, 2003).

We carried out a similarity percentage analysis (SIMPER—Clarke, 1993) to highlight the species contributing the most to the dissimilarity between plots with different clear-cutting age classes and placed in different strips, when these two factors significantly explained differences in the PERMANOVA model. We used a non-metric multidimensional scaling ordination (NMDS) to visualize the patterns of species composition in relation with strip position and clear-cutting age class, plotting the species having a Spearman correlation > 0.45 with the NMDS axes. Both the PERMANOVA model and NMDS solutions were calculated using Bray–Curtis distances.

Before the ANOVA, PERMANOVA, and NMDS analyses, data were Log_2 $(x + 1)$ transformed to reduce the right-skewness of data distribution and the influence of species with high covers. We set alpha at 0.05. The SIMPER analysis was instead carried out on untransformed percentage cover data, to display real species abundances.

TABLE 1 Effects of clear-cutting age class, strip position, and their interaction on the richness of all the species and on the richness and abundance of alien species and life-form groups in the 60 plots, based on the ANOVA.

		Species richness					Species abundance (% cover)			
		Overall	AlS	AnS	HPS	WS	AlS	AnS	HPS	WS
Source of variation	Df	F	F	F	F	F	F	F	F	F
Clear-cutting age class	2	0.667	9.423***	2.482	0.262	4.004*	6.413**	1.332	2.202	2.165
Strip position	1	7.222**	0.487	2.601	9.648**	0.345	8.835**	3.564	2.802	1.844
Clear-cutting age class × strip position	2	0.3598	0.5333	0.2293	0.5906	0.82	0.759	0.547	0.545	0.588
Residuals	54									
Total	59									

Abbreviations: AlS, alien species; AnS, annual species; HPS, herbaceous perennial species; WS, woody species.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

PERMANOVA was performed using the PERMANOVA routine in PRIMER 6, including the add-on package PERMANOVA+ (Gorley & Clarke, 2008). The NMDS analysis was performed using the function *metaMDS* in the package "vegan" in R (Oksanen et al., 2020).

3 | RESULTS

3.1 | General results

Recent clear-cutting events were detected on 19 plots. Intermediate clear-cutting events were detected on 13 plots. Distant or absent clear-cutting events were detected on 28 plots. Full plant community data are available in Appendix B.

We recorded a total of 349 vascular plant species, belonging to 220 genera and 72 families. Herbaceous perennial species were 182, annual species were 103, and woody species were 64. *Populus nigra*, *Robinia pseudoacacia*, *Acer campestre*, and *Alnus glutinosa* were the most frequent tree species. Among shrubs, *Rubus caesius*, *R. ulmifolius*, *Cornus sanguinea*, and *Euonymus europaeus* were the most frequent. *Clematis vitalba* and *Hedera helix* were the most frequent vine species. *Chaerophyllum temulum*, *Galium aparine*, *Brachypodium sylvaticum*, and *Poa sylvicola* were the most frequent herbaceous species.

3.2 | Univariate analyses

The richness of both alien and woody species significantly differed between clear-cutting age classes, with the former being higher in R and the latter being higher in D (Table 1; Figure 2a). The abundance of alien species was significantly higher both in R and I in comparison to D (Table 1; Figure 2b). Concerning strip position, both overall and herbaceous perennial species richness were significantly higher in the internal strips (Table 1; Figure 3a). The abundance of alien species was significantly higher in the external strips (Table 1; Figure 3b). No significant interactions were detected between clear-cutting age classes and strip position (Table 1).

We highlighted different effects of clear-cutting within strips. Namely, the number of alien species was higher in R and the number of woody species was higher in D within the internal strips. Conversely, clear-cutting had no effects on univariate vegetation attributes in the external strips (Figure 4).

3.3 | Multivariate analyses

Both clear-cutting age class and strip position significantly affected species composition (Table 2). Conversely, there was no significant interaction among factors. Regarding clear-cutting age classes, R and D were significantly different in species composition. Concerning clear-cutting age classes in relation to strip position, R and D resulted to be significantly different only within the internal strips (Table 3).

R and D plots had an average dissimilarity of 83.44. Alien and ruderal species such as *Artemisia verlotiorum*, *Robinia pseudoacacia*, *Anisantha sterilis*, and *Urtica dioica*, but also pioneer riparian trees like *Populus nigra*, were linked to R. Conversely, nemoral grasses like *Brachypodium sylvaticum* and riparian trees like *Alnus glutinosa* and *Corylus avellana* were more abundant in D (Table 4). Plots positioned in internal and external strips had an average dissimilarity of 80.54. Plant communities in the internal strips were characterized by a higher cover of typical riparian trees such as *Populus nigra*, *Alnus glutinosa*, and *Corylus avellana*, as well as of native herbaceous species like *Brachypodium sylvaticum* and alien herbaceous species like *Artemisia verlotiorum*. Conversely, the external strips were characterized by a higher abundance of alien and synathropic taxa, such as *Robinia pseudoacacia* and *Ailanthus altissima* in the tree layer and *Anisantha sterilis* and *Urtica dioica* in the herbaceous layer. Here, also non-riparian native woody species are more abundant, for example, *Acer campestre*, *Ligustrum vulgare*, and *Rubus ulmifolius* (Table 4).

The two main gradients highlighted by the NMDS of plot are consistent with the SIMPER results. Along the first axis, there is a transition from synanthropic species, linked to R, to nemoral species, linked to D. Similarly, the second axis highlights a turnover from aquatic and nemoral species in internal strips to synanthropic species in external strips (Figure 5).

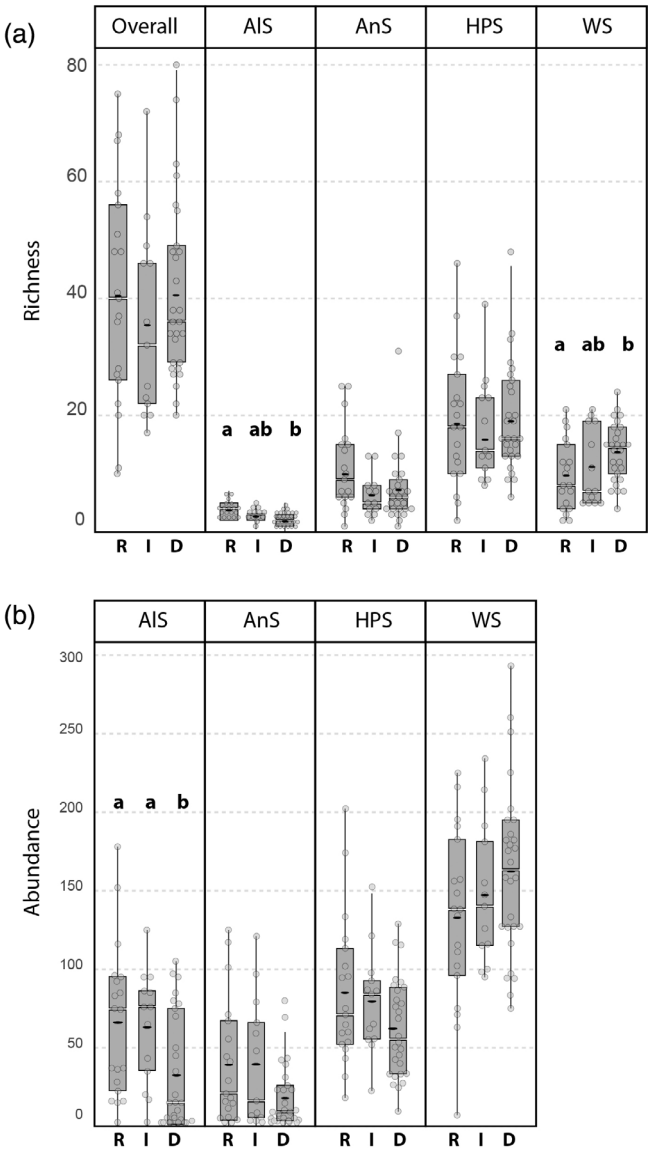

FIGURE 2 Boxplots showing species richness (a) and abundance (cumulative percentage cover) (b) in the studied riparian forest communities according to clear-cutting age classes. Single values are shown as dots. Mean values are shown as black lines. AlS, alien species; AnS, annual species; D, distant or absent cut; HPS, herbaceous perennial species; I, intermediate cut; Overall, total species richness; R, recent cut; WS, woody species. Different letters indicate statistically significant differences at $p < 0.05$ (Tukey tests).

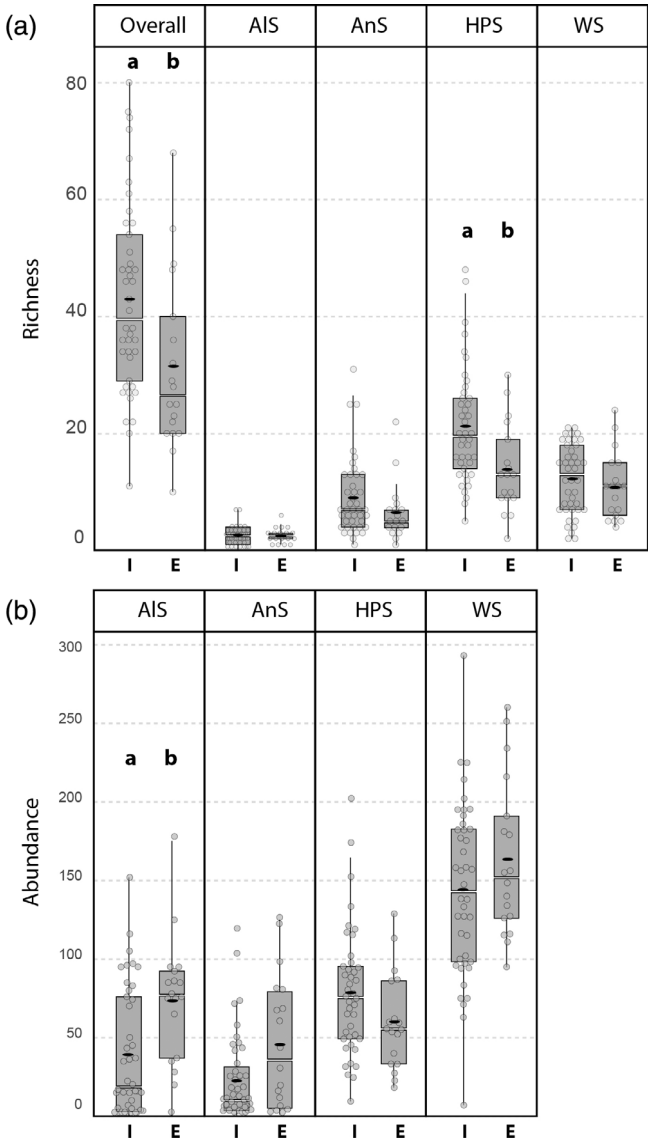

FIGURE 3 Boxplots showing differences in species richness (a) and abundance (cumulative percentage cover) (b) in the studied riparian forest communities according to strip position. Single values are shown as dots. Mean values are shown as black lines. AlS, alien species; AnS, annual species; E, external strip position; HPS, herbaceous perennial species; I, internal strip position; Overall, total species richness; WS, woody species. Different letters indicate statistically significant differences at $p < 0.05$ (Tukey tests).

4 | DISCUSSION

Despite clear-cutting being one of the most relevant anthropogenic pressures on riparian forests, to the best of our knowledge no studies have documented its impacts on such ecosystems in the Mediterranean basin. We assessed whether past clear-cutting events have imprints on riparian forests by analyzing the responses of several vegetation attributes, and confirmed our initial hypothesis that the effects of this kind of disturbance differ across time, space, vegetation types, and different response variables.

We did not detect any effect of different clear-cutting age classes on the overall plant species richness. Previous evidence is contrasting in such terms. Some studies in boreal zones highlighted an increase of species richness immediately after cutting, due to the colonization by heliophilous native and alien species (Roberts & Zhu, 2002). In fact, clear-cut forests are highly heterogeneous and contain a high number of ecological niches. This allows them to host more species than homogeneous ecosystems like undisturbed forests (Davis et al., 2000). Other studies, in accordance with our results, found no effects of clear-cutting on the species richness of riparian forests (MacDonald et al., 2014; Zenner et al., 2013). This is supported by resource-rich environments like riparian ecosystems being more resistant to changes after disturbance, including those in species richness (Hamilton & Haeussler, 2008; Slocum & Mendelssohn, 2008).

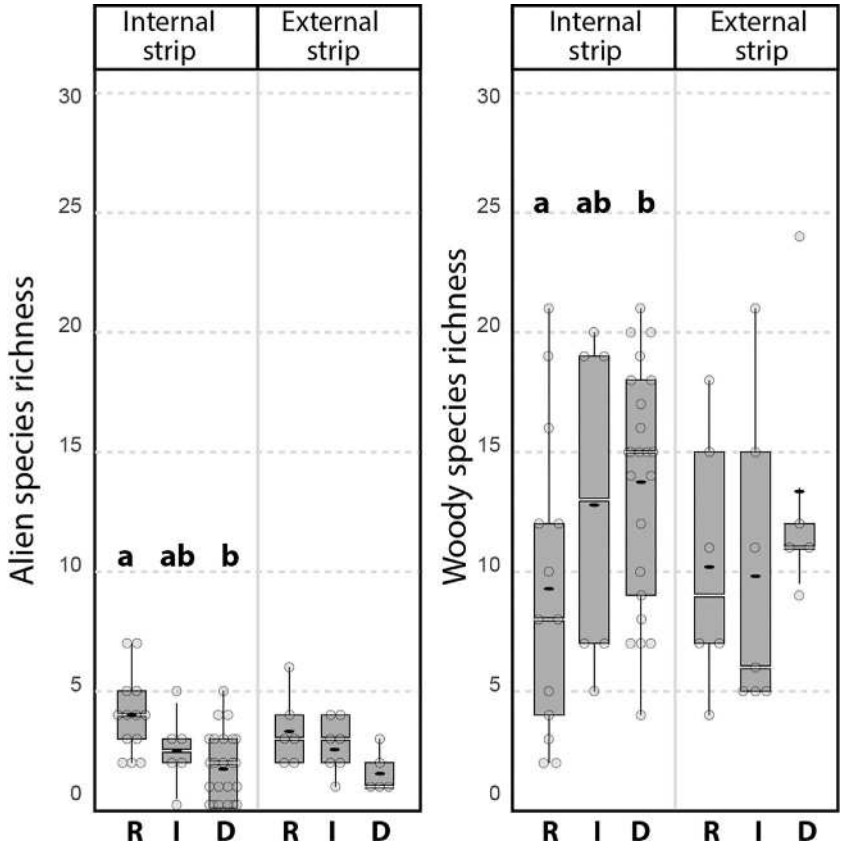

FIGURE 4 Boxplots of alien and woody species richness within strips. Single values are shown as dots. Mean values are shown as black lines. D, distant or absent cut; I, intermediate cut; R, recent cut. Different letters indicate statistically significant differences at $p < 0.05$ (Tukey tests).

TABLE 2 Effects of clear-cutting age class, strip position, and their interaction on species composition according to the PERMANOVA.

Source of variation	Df	Pseudo-F
Clear-cutting age class	2	1.8339*
Strip position	1	2.855**
Clear-cutting age class × strip position	2	0.6586
Residuals	54	
Total	59	

*$p < 0.05$; **$p < 0.01$.

TABLE 3 Differences in species composition between plots according to different clear-cutting age classes and to different clear-cutting age classes within strips (*t*-test).

	Clear cutting age classes	*t*
All the plots	R-I	1.087
	R-D	1.573**
	I-D	1.326
Within internal strips	R-I	0.855
	R-D	1.556**
	I-D	0.816
Within external strips	R-I	1.051
	R-D	1.242
	I-D	1.344

**$p < 0.01$.

However, species richness alone is not a good indicator of the modifications of plant communities, since the number of species might remain the same even after important species turnovers following disturbance events (MacDonald et al., 2014; Newaz et al., 2019).

R plots had a higher richness of alien species than D plots. Moreover, both R and I plots had higher abundance of alien species than D plots, with special regards to *Artemisia verlotiorum* and *Robinia pseudoacacia*. Thus, the effects of clear-cutting in favoring biological invasions were still detectable up to 19 years after disturbance. This was expectable, since disturbances generate environmental changes, such as increases in light availability, which favor the spread of alien species (Richardson et al., 2007; Tolkkinen et al., 2020). Many alien invasive species, such as *R. pseudoacacia*, extensively colonize fluvial terraces after cutting (Schnitzler et al., 2007). Once established, such species are highly competitive and efficiently spread at the expense of native species, maintaining their abundance over time (Lazzaro et al., 2018, 2020). Furthermore, river ecosystems are naturally prone to the invasion by alien plants due to their dynamic hydrology and because they act as corridors facilitating the dispersal of propagules (Planty-Tabacchi et al., 1996).

Woody species richness was negatively affected by clear-cutting, showing a significant decrease in R compared to D. Consistently, cutting is one of the main factors affecting woody species richness in riparian forests (Zenner et al., 2012). Our results agree with previous