Article

Short-term responses of aquatic and terrestrial biodiversity to riparian restoration measures aimed at controlling the invasive *Arundo donax L.* (Poaceae) in Mediterranean rivers

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Received: date; Accepted: date; Published: date

Abstract: Invasive species are among the top five causes of biodiversity loss worldwide. Namely, the giant reed (*Arundo donax* L.) has progressively colonized the riparian zones of Mediterranean rivers with detrimental effects on terrestrial and aquatic biodiversity, being catalogued as one of the 100 worst invasive species. In order to control this invasive species and restore native riparian vegetation, different methods have been traditionally used depending on the environmental, economic and social context. Here, we assess the effect of repeated above-ground removal of giant reed on aquatic and terrestrial communities, testing two different frequencies of mowing, i.e. quarterly-extensive and monthly-intensive, combined with the plantation of native riparian species within the project LIFE13BIO/ES/001407 RIPISILVANATURA. Specifically, we evaluate if riparian vegetation, birds and aquatic macroinvertebrates show significant responses throughout time and between treatments based on 4-years annual biomonitoring data for period 2015-2018. Changes in taxonomic diversity and ecological quality indices for the different biological communities were tested using mixed-effect models (LMEs). LMEs were also applied to assess how riparian variables were related to bird and aquatic macroinvertebrate indices. NMDS, PERMANOVA and IndVal analyses were performed to detect significant differences in taxa composition. During this short-term assessment, we found increases in riparian and aquatic macroinvertebrate richness and quality indices, as well as a significant decrease in *A. donax* height, density and cover, without significant differences between treatments. However, we detected differential effects between extensive (positive-neutral effect) and intensive treatments (neutral-negative effect) only for bird richness, density and abundance. Given the high-cost methods and the great efforts required for restoration, extensive repeated mowing, together with native species plantation, are specifically recommended on river reaches which are not fully invaded by *A. donax* showing a high ecological interest.

Keywords: Ecological restoration; Biomonitoring; Riparian vegetation; Macroinvertebrates; Birds; Biological invasion; Alien species; Environmental Management; Segura River.

1. Introduction

Invasive species are among the most relevant causes of biodiversity loss [1,2]. Multiple and interacting long-standing human pressures in fluvial systems, as channelization, dam construction, riparian deforestation, agricultural and urban development, have favoured the spread of opportunistic and exotic species [3,4]. Such pressures have detrimental effects on native communities and result in the impairment of aquatic and riparian habitats worldwide [5,6]. Particularly, the giant reed (*Arundo donax* L., Poaceae) has progressively colonized the Mediterranean Basin from the Middle East in Asia [7], being one of the 100 most dangerous invasive species worldwide [8]. In Spain and other Mediterranean countries, the giant reed is widely spread especially in disturbed watercourses where previous riparian fragmentation, flow regulation, and fires had impoverished native riparian communities, leaving empty niches which benefit its growth and expansion [9-11]. The giant reed is a tall (2-8 m), erect, robust, fast-growing (2-10 cm/day) and perennial hydrophyte. Its vegetative reproduction enables its spread from thick rhizomes or stem nodes which, carried downstream and once rooted and established, tends to form large and continuous clonal masses and monospecific stands [12,13]. The stress tolerance of this species has been attributed to its large rhizomes which enable a quick resprouting and, consequently, constitute a competitive advantage following biomass-removing disturbances [14-16]. In disturbed rivers, it can outcompete and replace native plant communities causing additional negative effects in riparian habitats by reducing diversity, quality and heterogeneity [13,17] as well as changes in riparian food webs [17-20]. In addition, the lack of natural competitors outside its natural distribution range can also contribute to its spread and consolidation [21], which makes extremely difficult to revert this riparian invasion without management and restoration measures.

Nevertheless, the ecological effects of *A. donax* invasion go beyond the riparian vegetation. Riparian zones, as transitional areas between aquatic and terrestrial ecosystems, influence both the structure and functioning of instream and terrestrial associated communities through different processes and functions such as microclimate modification, nutrient and sediment retention, bank stabilization, organic matter supply, food and habitat provision, ecological corridor [22-24]. The spread of *A. donax* affects these natural processes by altering nutrient cycling, promoting shade reduction which is especially important in Mediterranean areas in a context of global warming, causing bank erosion and instability due to its large aerial biomass and shallow root system, and favouring instream sedimentation which reduces substrate heterogeneity and enhances siltation. In addition, *A. donax* provides low-quality food and habitat for native species since their stems and leaves contain a wide variety of noxious chemicals, making it unsuitable and unpalatable for vertebrate and invertebrate grazers [25-26]. Regarding aquatic communities, riparian vegetation acts as a buffer that can modify, incorporate, filter or concentrate a variety of substances, such as nutrients, pesticides or sediments from the surrounding catchment before their incorporation to the aquatic phase, therefore influencing instream biodiversity patterns. Moreover, *Arundo*-driven changes in aquatic habitat conditions, e.g. homogenization, and the low nutritional quality of its leaf litter have negative effects on fishes [27] and aquatic macroinvertebrates [17,28,29].

Riparian galleries constitute key habitats due to their high productivity and heterogeneity, providing important resources as food (e.g., riparian invertebrates, emergent aquatic insects, fruits and seeds), excellent areas for reproduction (e.g. nesting and breeding for aquatic and terrestrial birds and some mammals) and ecological corridors even for strictly terrestrial fauna [24]. Among terrestrial communities associated with riparian areas, birds can be considered relevant bioindicators since they are strongly dependent on habitat structure and condition [30]. Native riparian vegetation constitutes a preferential habitat for many birds during migration and juvenile dispersal [31] and may attract over ten times the number of migratory birds in spring than adjacent upland habitats [32]. Nevertheless, the strong habitat simplification that involves *A. donax* invasion reduces the number of species that can feed, inhabit and nest on riparian areas [17,33]. *A. donax* stems are weak and completely vertical, so the lack of a robust horizontal structure impedes most bird nesting. In addition, invertebrates, one of the main food sources for birds, are less diverse and abundant in invaded areas (up to 50% of decline) given the absence of a shrubby understory layer [18]. Although the decrease in bird habitat quality following *A. donax* spread has been well studied [33] and constitutes a matter of concern [20], it has been rarely addressed in the Iberian Peninsula [34,35].

Moreover, to the best of our knowledge the effects of *A. donax* removal and eradication actions on bird community has not been examined in detail to date.

These structural and functional changes caused by *A. donax* in riparian vegetation and associated communities turn into detrimental effects on different ecosystem services, such as the provisioning of material and energy, regulation of local climate, extreme events and biogeochemical cycles and maintenance of the environment for humans and cultural services. In particular, compared to native riparian species, *A. donax* has been related to reduced water quality (lower canopy results in less shade to the river, increasing water temperature and decreasing dissolved oxygen) and quantity (higher evapotranspiration rates and less aquifer recharge), fewer opportunities for recreation and navigation (less water discharge and invaded banks), increased flooding risk (faster runoff and higher sedimentation rates), riparian fires, bank instability and erosion, among others [13,27,36-39].

Given the intensity and variety of the ecological, economic and social impacts linked to the dominance of the giant reed, different methods have been used to control its populations: above-ground (stem cutting) and below-ground (rhizome extraction) mechanical removal, chemical treatments (mainly the controversial glyphosate sprayed or injected [40]), physical approaches as flooding or the promising plastic coverage and biological control through terrestrial insects [38,41,42]. Despite the methodological advances, burning has been traditionally used by landowners as a quick control method but it has resulted completely ineffective and counter-productive due to the stronger post-fire resprouting exhibited by the giant reed [10]. Most methods are applicable in degraded riparian areas where *A. donax* dominates completely but not in river reaches where this species coexists with native vegetation and/or in protected areas where less aggressive methods are required to avoid negative effects on native communities and ecological processes. Stem cutting campaigns have been generally performed locally (especially in lower reaches where *A. donax* forms extensive monospecific stands), at the request of municipalities or as preventive routine management (before autumn to avoid hydraulic damages during flashflood events in Mediterranean rivers), and with scarce coordination or long-term planning, mostly resulting in high costs and poor results [29]. Nevertheless, *A. donax* clumps are likely to require more than local annual biomass removal, due to the bulk of underground biomass, and the ability of remaining rhizome or stem segments to produce large stands quickly [43]. Thus, river restoration projects should focus on coordinated holistic measures planned at broad scale rather than only local disconnected actions, to develop more effective management strategies [44]. Despite the numerous works addressing how biodiversity responds to different riparian management and restoration strategies [45,46], there is a knowledge gap on the ecological effects of *A. donax* removal on aquatic and terrestrial associated communities with the exception of side-effects of chemical treatments as glyphosate [40].

In this context, the LIFE+ RIPISILVANATURA project (see detailed information at https://www.chsegura.es/chs/cuenca/seguraripisilvanatura) aims to control invasive alien species by strengthening riparian habitats (specially the habitat 92A0 of European Directive 92/43/CEE) in moderately disturbed middle reaches of the Segura River watercourse (SE Spain) where *A. donax* and remnants of native riparian vegetation coexist within or near protected areas. Therefore, this project intends to weaken *A. donax* while expanding native riparian cover through soft-engineering techniques (repeated above-ground stem removal combined with the plantation of native riparian species) in order to enhance the competition exerted by native riparian species. The rationale behind this restoration strategy is to exhaust the rhizome nutritional reserves of *A. donax* by forcing this hydrophyte to constantly replace its stems while native vegetation gets time to be developed and successfully compete with the giant reed for sunlight and riparian space. Although there are some evidences of the effectiveness of the different *A. donax* control and restoration actions, very little is known about the performance, success and ecological effects of this particular combination of methods beyond riparian areas [38]. Complementarily, LIFE+ RIPISILVANATURA is a holistic project that incorporates other ecological, social and educational actions to reach long-lasting successful results, such as the creation of a land stewardship network to involve local population, the launching of a mobile app to create a public alert system for early detection of fire and invasive alien species in riverine habitats, the demarcation of the riparian area to improve ecological integrity and expand riparian habitats and the removal of unnecessary embankments to recover lateral connectivity. It also includes the removal of exotic fauna through the involvement of citizens and environmental agents, environmental voluntary service and awareness campaigns about invasive species (especially students), personnel training, publication of protocols and handbooks to optimise riparian management and conservation, the protection of riparian birds by marking power lines and the creation of bird observatories.

In this study we carried out a short-term evaluation of the effectiveness of the restoration measures applied to control *A. donax*: repeated mowing with two different frequencies (monthly vs. quarterly) combined with the plantation of native riparian species. We also assess if taxonomic composition, condition and species richness of riparian vegetation, birds and aquatic macroinvertebrates showed significant positive responses to these restoration actions. We expected a reduction in *A. donax* cover, height and stem density as well as a parallel increase in native riparian coverage, diversity and ecological status of riparian and aquatic communities. In the case of birds, we hypothesized that they could need more time (beyond the project deadline) and a greater development of planted native species to experience significant changes.

2. Materials and Methods

2.1 Study area

The study was developed in the Segura River basin, a semi-arid Mediterranean catchment located in the South-East of the Iberian Peninsula. In particular, the riparian restorations took place in 52 km along the middle segment of the Segura River including the municipalities of Cieza, Calasparra and Moratalla (Murcia Region, Spain). This area is geologically characterized by the dominance of limestone, sandstone, gypsum and loam substrates and climatically featured by a mean annual precipitation of 300 mm and annual mean temperature of 17 °C. Regarding anthropogenic impacts, this perennial river reach is subjected to intense flow regulation and hydro-morphological alterations [47,48] whereas the main land use in the area is semi-natural (dominant shrubby landscape) and agriculture (mainly rice fields, apricot and peach trees; < 50%), with urban areas being scarce (< 2%). Native riparian vegetation in the area was characterized by 92A0 and 92D0 habitats (Habitat Directive 92/43/CEE), showing a mixture of European and Ibero-African flora (*Salix* spp., *Fraxinus angustifolia*, *Populus* spp., *Tamarix* spp., *Nerium oleander*), which constitutes a distinctive occurrence within the Iberian Peninsula [11,49]. Nevertheless, native habitats have been progressively displaced by *A. donax*, which already occupies nearly a 40% of the whole studied river reach according to the preliminary evaluation carried out to draft the project (Figure 1).

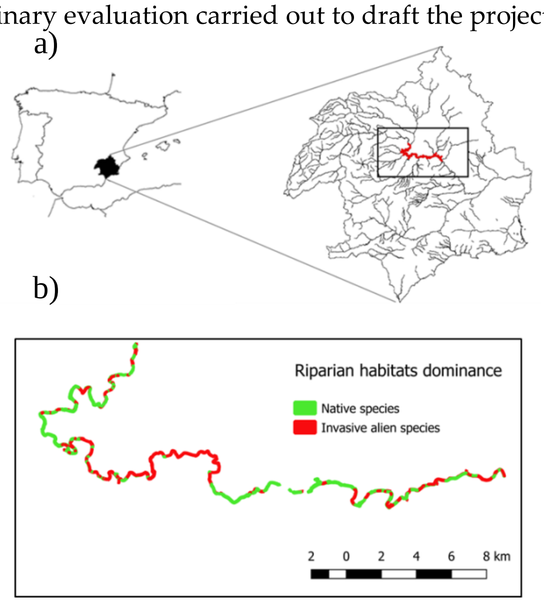

Figure 1. Location of the a) middle section of the Segura River, where restoration actions are taking place in the context of the LIFE+ RIPISILVANATURA project within the Segura River basin in the Iberian Peninsula and b) distribution of dominant native and exotic riparian species in the study area.

2.2 Restoration actions

In order to prioritize restoration areas and measures with higher expectations of success, the following steps were taken:

1) Database and literature searching on native and exotic biodiversity, and ecological quality indices.

2) Field surveys (in the spring of 2015) to complete species inventories, habitat maps and quality assessments.

3) Definition and identification of reference and good quality conditions and river reaches, respectively (based on riparian and aquatic habitat information).

4) Selection of river reaches with intermediate ecological status and favorable vegetation dynamics to reinforce soft-engineering restoration actions following these criteria: closed to well-conserved natural riparian habitats to enhance connectivity, technically feasible, socially accepted (adjacent landowners and local users) and with potential synergies with other ongoing projects (e.g., LIFE+ RIVERLINK see https://www.chsegura.es/chs/cuenca/segurariverlink/riverlink/ for details).

5) Selection of initial method (mechanically or manually), for cutting *A. donax* depending on the riparian vertical structure as well as native and exotic species abundances.

6) Definition of case-specific compositional and structural plantation design (arboreal, shrubby and herbaceous species) depending on local environmental features of each river reach, such as ecological status, presence of native vegetation remnants, species abundance, bank slope, vertical distance to water table or riparian width. The species pool used in restorations (Table 1) mainly arised from the two riparian habitats detected in the area (Mediterranean deciduous broadleaf forests, Habitat Directive 92/43/CEE): 92A0-*Salix alba* and *Populus alba* galleries and 92D0 Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*). Furthermore, seedlings for the different species were obtained and produced from native populations to avoid genetic hybridization. Such a strategy is supposed to increase the probability of survival of the new individuals given the previous adaptation to local environmental conditions.

Table 1. Total pool of riparian species used to define each case-specific restoration action.

Trees	Shrubs	Herbs
Celtis australis	*Coriaria myrtifolia*	*Cladium mariscus*
Crataegus monogyna	*Genista spartioides*	*Iris pseudacorus*
Fraxinus angustifolia	*Nerium oleander*	*Saccharum ravennae*
Populus alba	*Pistacia lentiscus*	*Scirpus holoschoenus*
Populus nigra	*Rhamnus alaternus*	*Scirpus maritimus*
Salix alba	*Rosa pouzinii*	*Sparganium erectum*
Salix atrocinerea	*Salix purpurea lambertiana*	
Salix fragilis	*Sambucus nigra*	
Salix neotricha	*Smilax aspera*	
Tamarix boveana		
Tamarix canariensis		
Tamarix gallica		
Ulmus minor		

Finally, this methodological scheme resulted in the selection of 37 riparian patches where soft-engineering restoration actions (removal of above-ground *A. donax* stems) and extensive (quarterly) or intensive (monthly mowing) maintenance have been applied in combination with the case-specific plantation of native riparian vegetation (Figure 2). The first mowing campaigns were done in the winter 2015-2016 before the beginning of the vegetative season (i.e., spring). After the first mowing, different combinations of native riparian species were planted in late winter (February-March 2016). Subsequent cuts were made with different temporal frequency (monthly vs quarterly) depending on the patch, and including a pause during dormancy period (winter), resulting in a maximum of 8 mowing campaigns until spring 2018. These cuts were done manually (portable electric lawn mower machine) to minimize the ecological disturbance of repeated mowing on autochthonous and planted vegetation but also on the aquatic and terrestrial associated communities. Because of the semi-arid climate and high evapotranspiration in the study area, auxiliary irrigation was applied in summer to increase the survival of the saplings of planted native species.

Figure 2. Segura River in Almadenes canyon a) 2015, before the beginning of restoration actions and b) 2016, after the initial mowing campaigns to remove *A. donax*.

2.3 Biomonitoring and ecological indicators

The effectiveness of restoration measures accounting for potential differences between extensive and intensive treatments (frequency of *A. donax* cutting) was assessed through a BACI design (2015 Before; 2016-2018 After Control-Impact), selecting as monitoring sites more than 25% of restored river reaches (half of them located in sections with monthly and quarterly mowing, respectively). Different ecological indicators related to the diversity of riparian (native and exotic plants, birds) and aquatic (macroinvertebrate) groups, as well as ecological quality indices for the different biological communities were annually monitored in spring during the growing vegetative season and just before the next mowing campaign (Figure 3).

Regarding riparian vegetation, longitudinal transects (1-5 depending on the width of riparian area) were done in 16 river reaches to estimate the composition and abundance (semi-quantitave ranging from 1 to 6, corresponding from occasional to dominant, respectively) of riparian species, percentage of native and exotic vegetation cover, and to assess riparian quality (Riparian Quality Index-RQI, [50]). In addition, 5 quadrats of 1 m^2 (1 x 1 m) were systematically placed along each river reach to record the density and height of *A. donax*. Riparian bird community was monitored twice per year in early (15 April-15 May) and late (15 May-15 June) spring, through line transects based on visual and auditory detection [51], which has been recognized as the less biased method to obtain density estimates [52]. This procedure was extended during at least 1 hour within the first 4 hours of sunlight in 14 reaches affected by restoration action, to obtain annual species richness, density and abundance (Kilometric Abundance Index-KAI). Finally, aquatic macroinvertebrates were annually sampled in late spring (maximum aquatic invertebrate activity) in 15 river reaches with a kick net (500 μm mesh) through a multihabitat standardized protocol where sampling effort was proportional to each habitat occurrence [53]. Kick-samples were pooled into a unique sample per site and preserved in 96% ethanol. In the laboratory, organisms were identified at family level, except for Hemiptera and Coleoptera that were identified at species level. This information was used to calculate the Iberian Biomonitoring Working Party (IBMWP index, [54]) and three richness metrics: total family richness, Coleoptera and Hemiptera species richness as surrogates of the total macroinvertebrate community species richness [55,56]. IBMWP is the official invertebrate biomonitoring index currently used in Spain to assess the ecological status of rivers and assigns to each detected family a score ranging from 1 to 10 according to their known tolerance to pollution. Complementarily, water samples were taken in the same sites to determine pH, water conductivity and temperature (measured in situ), total and volatile suspended solids, and nitrate concentration (photometric method Spectroquant Merck, detection range 0.1-25 mg/l NO3-N).

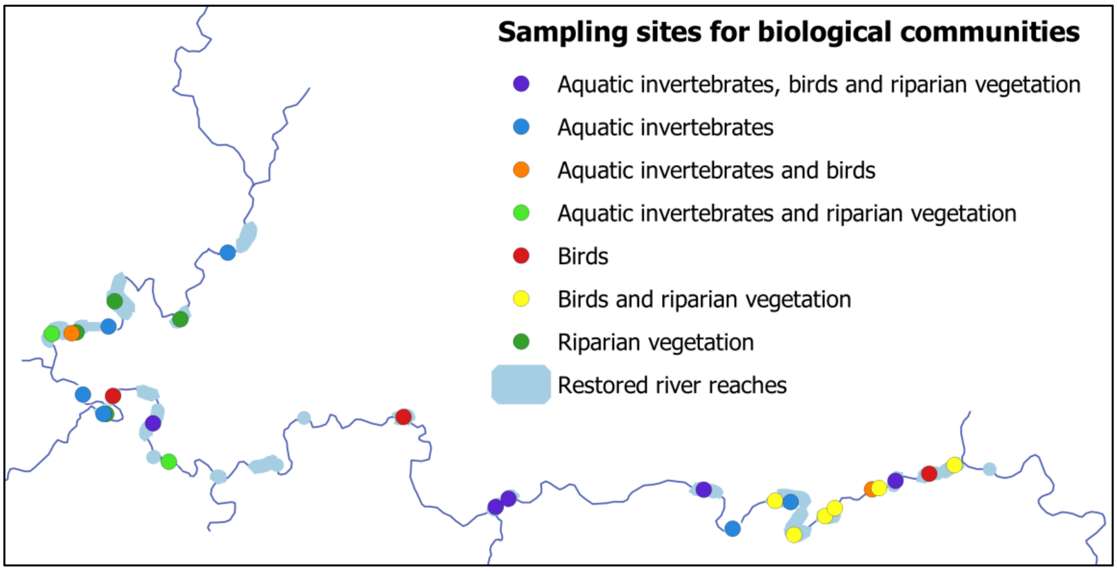

Figure 3. Restored river reaches along Segura River and sampling sites to monitor the evolution of aquatic macroinvertebrates, birds and riparian vegetation.

2.4 Data analysis

Changes in riparian vegetation (species richness, quality-RQI, native and exotic cover, averaged *A. donax* height and stem density per river reach), aquatic invertebrate metrics (IBMWP score, family richness, Coleoptera and Hemiptera species richness) and birds (species richness, density and abundance) among years (2015, 2016, 2017 and 2018) and treatments (intensive-monthly vs extensive-quarterly mowing) were tested using linear mixed-effect models (LMEs). If applicable, Tukey-based post-hoc paired comparisons were executed to identify when meaningful responses started. LMEs were performed considering "year" and "treatment" as fixed factors and sampling sites as random factors. Similarly, LMEs were also applied to identify the influence of riparian variables on macroinvertebrate and bird indices (considering sampling sites as random factors). In addition, the relationship between water quality (nitrates, conductivity, total and volatile suspended solids) and aquatic macroinvertebrate variables were also studied through LMEs. Homoscedasticity (Levene's test) and normality (Shapiro–Wilk test) of residuals were checked. Logarithmic or square root transformations were applied on response variables if model assumptions were not met to improve linearity and reduce data variability. Non-metric Multidimensional Scaling (NMDS), Permutational Multivariate Analysis of Variance (PERMANOVA) and Indicator Value (IndVal) analysis were applied on abundance (riparian vegetation and birds) or occurrence (aquatic macroinvertebrates) data to detect spatial (treatments) and temporal (years) differences in the taxonomic composition of the different biological communities. All statistical analyses were performed using R statistical software (libraries: "ade4", "car", "indicspecies", "lme4", "lmerTest", "multcomp", "MuMIn", "nlme" and "vegan"; [57]).

3. Results

A total of 134 plant species, 77 aquatic macroinvertebrate families (including 24 species of aquatic coleoptera and 9 of aquatic hemiptera) and 64 bird species were detected in the study area between 2015-2018 (complete lists available in Table S1). We observed a significant reduction of *A.*

donax height, density and cover, an improvement of the riparian quality index (RQI), as well as an increase in riparian species richness throughout time, without significant differences between treatments (extensive and intensive maintenance) during the studied period (Table 2, Table S2). No significant differences among years nor treatments were found for native plant cover. Regarding aquatic macroinvertebrates, we detected a significant increase in the IBMWP index and richness values (family richness and Hemiptera species richness) after 2017. No significant differences among years or treatments were observed for Coleoptera species richness. In the case of birds, at first glance LMEs did not show significant temporal differences between years for bird density, abundance and species richness (Figure S1). Nevertheless, there was a significant interaction between date and treatment pointing to differential effects between extensive (positive effect) and intensive treatments (neutral-negative effect) on bird community through time (Table 2, Figure 4).

Table 2. Results of linear mixed-effect models (LMEs) on riparian vegetation, aquatic macroinvertebrate and bird community metrics. Marginal R^2 (R^2m) and *p*-values for the whole model and the different terms (year, treatment and the interaction between them) are shown. The signs or trends of the relationships are also displayed. Significant results ($p < 0.05$) have been highlighted in bold.

	Model		Year		Treatment		Year: Treatment	
Riparian vegetation	*P* – value	R^2m	*P* – value	Trend	*P* – value	Trend	*P* – value	Trend
Species richness	**$5.5*10^{-12}$**	**0.33**	**$1.66*10^{-8}$**	**+**	0.45	=	0.33	=
Riparian Quality	**0.049**	**0.08**	**0.031**	**+**	0.34	=	0.63	=
Native cover	0.68	-	0.97	=	0.3	=	0.39	=
A. donax stem density	**0.006**	**0.12**	**0.017**	-	0.11	=	0.12	=
A. donax height	**$2.2*10^{-16}$**	**0.73**	**$2*10^{-16}$**	-	0.9	=	0.07	=
A. donax cover	**0.006**	**0.08**	**0.005**	-	0.67	=	0.14	=
Aquatic macroinvertebrates								
IBMWP score	**0.003**	**0.26**	**0.004**	+	0.47	=	0.67	=
Family richness	**0.047**	**0.2**	**0.013**	**+**	0.8	=	0.94	=
Coleoptera richness	0.92	-	0.9	=	0.32	=	0.83	=
Hemiptera richness	**$4.31*10^{-5}$**	**0.4**	**$9.12*10^{-5}$**	+	0.65	=	0.05	=
Birds								
Species richness	**0.048**	**0.21**	0.34	+/=	0.1	=	**0.04**	Ext(+)[1], Int (=)[2]
Density	**0.033**	**0.15**	0.17	+/-	0.76	=	**0.03**	Ext(+), Int(-)
Abundance	**0.016**	**0.2**	0.18	+/-	0.17	=	**0.04**	Ext(+), Int(-)

[1] Ext: Extensive maintenance treatment; [2]Int: Intensive maintenance treatment

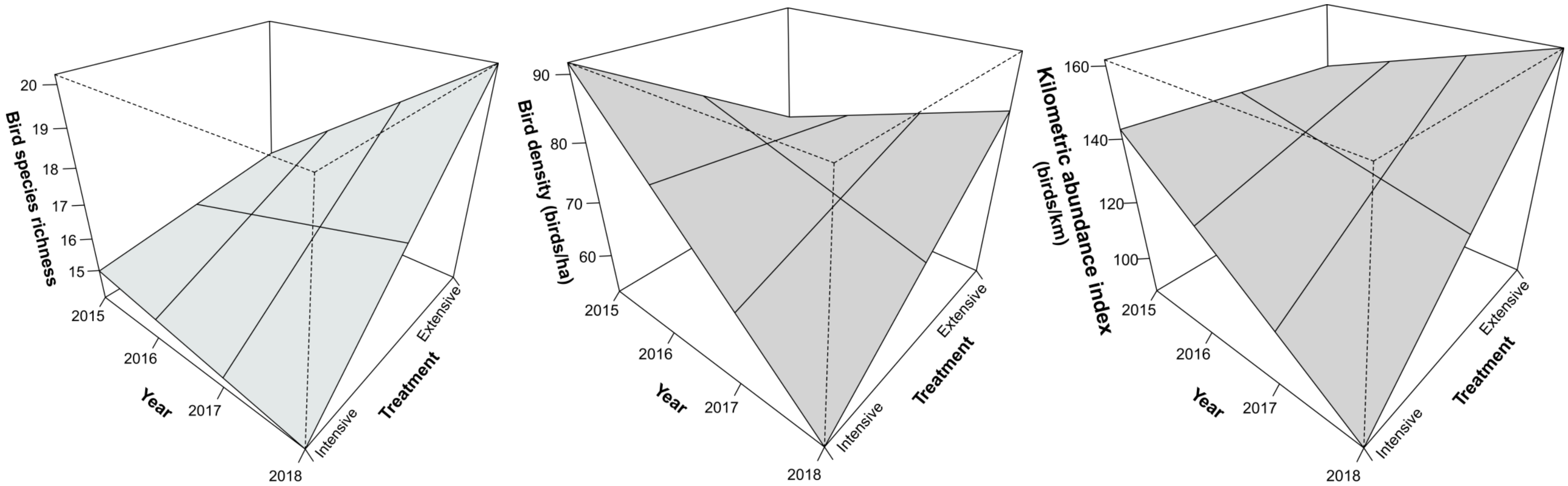

Figure 4. Three-dimensional plots between year, treatment and bird community variables with significant results for interaction terms in linear mixed-effect models (LMEs).

According to Tukey post-hoc paired comparisons (Table 3), the riparian metrics (Figure 5) that first responded to restoration actions were riparian richness and *A. donax* height (first significant increase and decrease, respectively in 2016, $p < 0.001$). Similarly, *A. donax* density started to decrease in 2016 (significant differences between 2015 and 2016, $p < 0.05$) but this reduction was not consolidated until 2018 (differences 2015-2018, $p < 0.05$). The riparian quality index (RQI) and *A. donax* density did not respond until the second (differences 2016-2017, $p < 0.05$) and third year of restoration actions (differences 2015-2018, $p < 0.01$), respectively. Similarly, macroinvertebrate-based biomonitoring index (IBMWP), family richness and Hemiptera species richness showed significant responses from 2017 (differences 2016-2017, $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively) and concordant patterns between 2016-2018 ($p < 0.01$; Figure 6, Table 4).

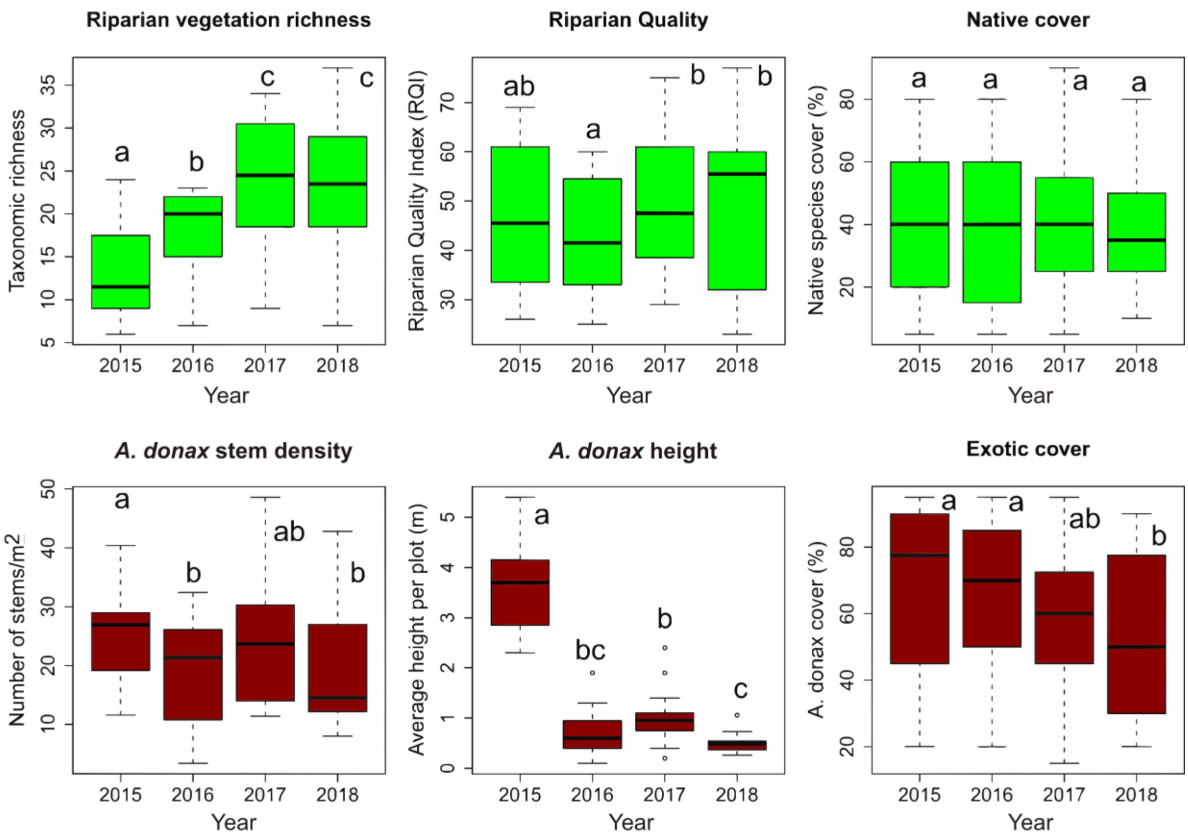

Figure 5. Results of linear mixed-effect models (LMEs) and Tukey post-hoc paired comparisons relative to the temporal evolution of native (light green) and exotic (brown) riparian vegetation-related variables. Letters (a, b, c) depict the significant differences found among years (see Table 3).

Table 3. Results of Tukey post-hoc paired comparisons for riparian vegetation variables.

	Riparian richness			**Riparian Quality index**			***A. donax* stem density**			***A. donax* height**			***A. donax* cover**		
	Estimate	*Z*-value	*P*-value	Estimate	*Z*-value	*P*-value	Estimate	*Z*-value	*P*-value	Estimate	*Z*-value	*P*-value	Estimate	*Z*-value	*P*-value
2016 – 2015	47.500	4.232	**<0.001**	-41.250	-1.931	0.2150	-0.375320	-2.574	**0.0492**	-29.563	-14.811	**<0.001**	-0.9375	-0.228	0.99582
2017 – 2015	108.125	9.634	**<0.001**	21.a875	1.024	0.7353	-0.091882	-0.630	0.9224	-26.500	-13.277	**<0.001**	-78.125	-1.901	0.22782
2018 – 2015	100.000	8.910	**<0.001**	16.250	0.761	0.8721	-0.373548	-2.562	**0.0498**	-31.894	-15.979	**<0.001**	-134.375	-3.269	**0.00572**
2017 – 2016	60.625	5.402	**<0.001**	63.125	2.955	**0.0165**	0.283438	1.944	0.2097	0.3062	1.534	0.4168	-68.750	-1.672	0.33828
2018 – 2016	52.500	4.678	**<0.001**	57.500	2.692	**0.0354**	0.001773	0.012	10.000	-0.2331	-1.168	0.6471	-125.000	-3.041	**0.01275**
2018 – 2017	-0.8125	-0.724	0.8875	-0.5625	-0.263	0.9936	-0.281666	-1.932	0.2146	-0.5394	-2.702	**0.0349**	-56.250	-1.368	0.51928

Table 4. Results of Tukey post-hoc paired comparisons for aquatic macroinvertebrate-related variables.

	IBMWP			**Family richness**			**Hemiptera species richness**		
	Estimate	*Z*-value	*P*-value	Estimate	*Z*-value	*P*-value	Estimate	*Z*-value	*P*-value
2016 – 2015	-11.778	-1.541	0.41318	-20.000	-1.372	0.51700	-0.6667	-1.691	0.3282
2017 – 2015	11.556	1.512	0.43047	26.667	1.829	0.25942	11.111	2.819	**0.0246**
2018 – 2015	23.778	3.110	**0.00998**	30.000	2.058	0.16705	0.8889	2.255	0.1085
2017 – 2016	23.333	3.052	**0.01231**	46.667	3.201	**0.00722**	17.778	4.510	**<0.001**
2018 – 2016	35.556	4.651	**<0.001**	50.000	3.430	**0.00343**	15.556	3.947	**<0.001**
2018 – 2017	12.222	1.599	0.37932	0.3333	0.229	0.99579	-0.2222	-0.564	0.9428

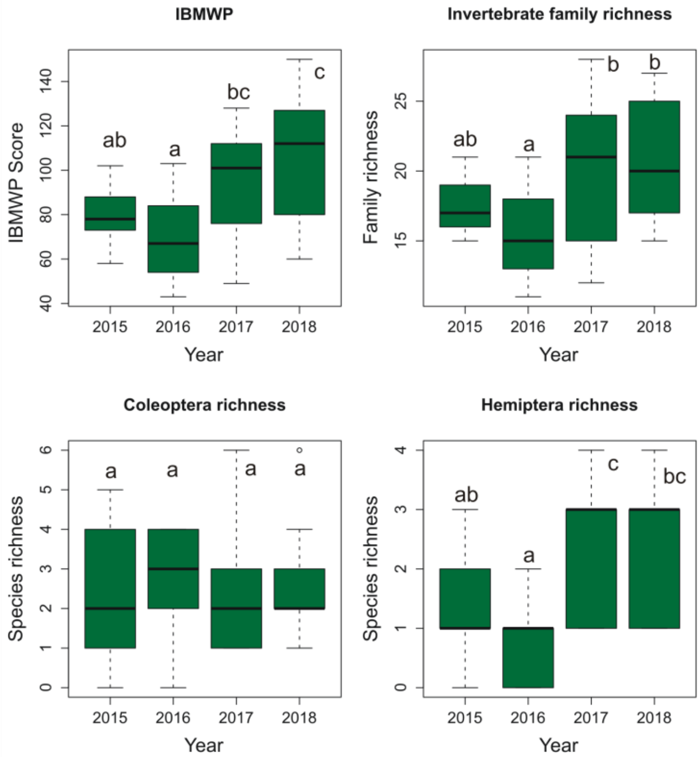

Figure 6. Results of linear mixed-effect models (LMEs) and Tukey post-hoc paired comparisons relative to the temporal evolution of aquatic macroinvertebrate-related variables. Letters (a, b, c) depict the significant differences found among years (see Table 4).

Regarding the relationships between riparian vegetation and faunal communities (explored through LMEs, Figure 7), exotic cover negatively influenced the IBMWP score, ($R^2m = 0.17$, $p < 0.05$), family richness ($R^2m = 0.11$, $p < 0.05$) and bird species richness ($R^2m = 0.08$, $p < 0.05$). Riparian species richness and quality were positively related to Coleoptera ($p < 0.05$, $R^2m = 0.14$ and $R^2m = 0.19$, respectively) and Hemiptera species richness ($p < 0.05$, $R^2m = 0.18$ and $R^2m = 0.17$, respectively). In addition, riparian richness also enhanced bird richness ($R^2m = 0.09$, $p < 0.05$). *A. donax* stem density was negatively associated with bird species richness ($R^2m = 0.08$, $p < 0.05$), density ($R^2m = 0.07$, $p < 0.05$) and abundance ($R^2m = 0.2$, $p < 0.001$). Finally, no significant relationships were found between water quality (nitrates, conductivity, total and volatile suspended solids) and aquatic macroinvertebrate community variables ($p > 0.05$).

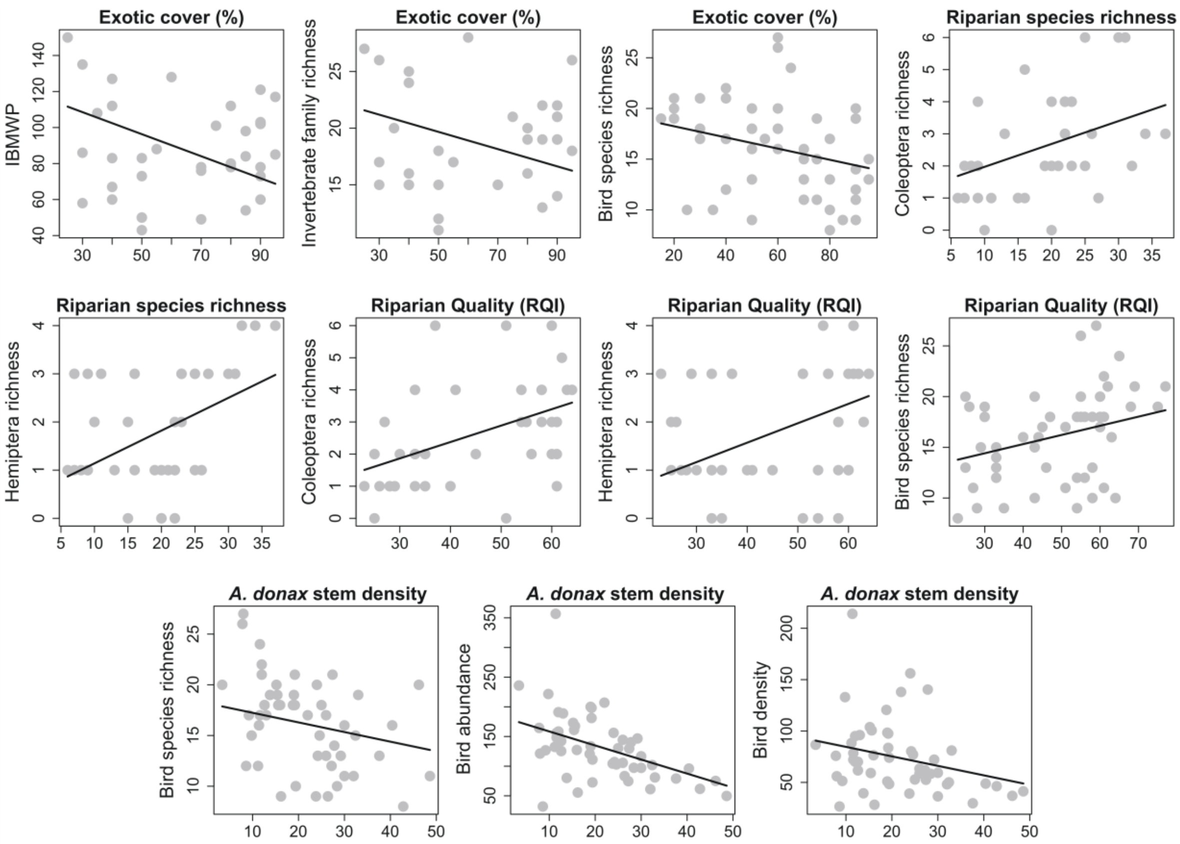

Figure 7. Significant relationships ($p < 0.05$) between riparian vegetation-related variables and aquatic macroinvertebrate and bird community indexes according to linear mixed-effect models.

NMDS (Figure 8) and PERMANOVA results pointed to significant temporal taxonomic changes between 2015 (before the restoration actions) and 2018 for aquatic macroinvertebrates ($p = 0.001$, $R^2 = 0.12$) and riparian vegetation ($p = 0.001$, $R^2 = 0.15$) consisting of an increase in multivariate dispersion and species diversification. However, no meaningful temporal changes were detected for birds ($p = 0.19$). Similarly, differences between treatments (extensive and intensive maintenance) were not significant for any biological community ($p > 0.05$). Finally, although IndVal analyses did not identify any indicator species for riparian vegetation before the beginning of restoration measures (2015), it did in 2018 selecting the most sucessful planted species, *Salix purpurea*, *Salix neotricha*, *Nerium oleander, Fraxinus angustifolia, Rosa Canina* and *Sambucus nigra* ($p = 0.001$) as the most significant riparian species. Regarding macroinvertebrates, Planorbidae was the unique indicator taxon ($p = 0.001$) in 2015 whereas Tabanidae ($p = 0.002$), Platycnemididae (p = 0.006) and Thiaridae ($p = 0.033$) were indicators for the aquatic community observed in 2018. Finally, no significant indicator species were identified for birds in any of the periods (2015 or 2018).

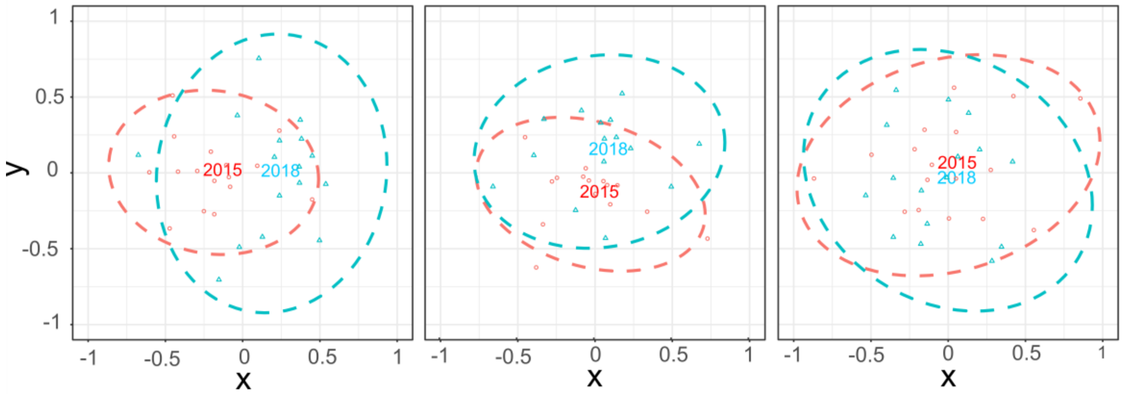

Figure 8. Non-metric Multidimensional Scaling (NMDS) comparing taxonomic composition before the beginning of restoration actions (2015) and the current situation (2018) for: a) riparian vegetation, b) aquatic macroinvertebrates, and c) bird communities. Ellipses group communities by year (2015-red or 2018-blue located at the centroid of the community).

4. Discussion

Repeated mowing in combination with the plantation of native riparian species has partially succeeded in the control of *A. donax* and the recovery of biological communities three years after the start of restoration actions in the middle section of the Segura River. In particular, a significant reduction of *A. donax* height, density and cover, and a parallel increase in the riparian quality index (RQI) and riparian vegetation richness were detected as a consequence of the restoration actions to control *A. donax* and strengthen native plant communities. This improvement of riparian condition was paired with an increase in aquatic macroinvertebrate richness mainly associated to the decrease in *A. donax* cover and the increase in riparian quality and richness. Extensive and intensive treatments based on the differential frequency of mowing exerted similar ecological effects, except for birds which were favored by the extensive maintenance and not the intensive one.

The temporal sequence of riparian recovery and associated biological communities seem to follow a logical ecological pathway; first, *A. donax* height and density decreased after the first year of implementation of restoration actions as a consequence of repeated mowing. Next, riparian richness started to increase due to the plantation of native riparian species and regeneration of existing plants. This riparian improvement was followed by meaningful changes in aquatic macroinvertebrate richness and IBMWP scores after the second year of restoration actions. Finally, although birds recently started to show increases in density, abundance and richness with extensive treatment, they probably need greater development of native planted species to experience noticeable changes in species composition and diversity. In fact, although most native saplings were established and in good condition, their small size and the lack of lateral spread can explain the absence of significant changes in native cover. Considering the current modest development of native planted species and the high growth rate and competitive ability of *A. donax*, the persistence of extensive maintenance could be desirable to underpin the ecological positive effects of restoration actions already implemented in the study area. Despite the initial changes observed in riparian vegetation, aquatic macroinvertebrate and bird assemblages after applying *A. donax* control methods and riparian restoration actions, long-term biomonitoring would be desirable to confirm this positive pattern and analyze, with greater details, the associated biological responses.

4.1 Riparian vegetation

Although native riparian communities would benefit from an extension of *A. donax* control actions, a general improvement in riparian condition has been observed. Thus, the establishment and consolidation of planted species has increased riparian richness in all monitoring sites since the beginning of the restoration actions. Thus, riparian plantations have strengthened habitat 92A0 through the increase in richness and abundance of native riparian species as *Populus alba*, *P. nigra*, *Nerium oleander,* and *Salix* spp., among others. This is quite promising since previous studies have demonstrated the effectiveness of willows to successfully compete with *A. donax* for the space and nutritional resources and, consequently, in depleting its productivity and extension [58]. Nevertheless, given that values of the riparian quality index (RQI) and native cover are still far from reference values, the extension of control and associated biomonitoring actions seems necessary to observe a greater improvement of riparian communities. At this moment, although native riparian communities have experienced a compositional diversification, woody planted species need more time to develop and outcompete *A. donax*, occupying progressively the riparian space and intercepting sunlight by closed canopies [41].

Non-chemical control treatments are usually based on the removal of the rhizome of *A. donax*. However, the application of this method in sensitive areas is not recommended, due to the strong physical and ecological impact it implies in the initial phases. In this context, although *A. donax* shoots can resprout from rhizomes located at one-meter depth [59,60], repeated mowing can also reduce *A. donax* underground biomass [61]. Given the very high photosynthetic rate of *A. donax,* which enables new stems to become rapidly independent of rhizome reserves [62], coordinated, periodical and scheduled control actions are essential to mitigate the invasion of *A. donax* in Mediterranean rivers. Thus, short time-lags are recommended to exhaust underground nutritional reserves more rapidly [38]. Nevertheless, we did not find significant differences between quarterly and monthly mowing on restoration success. Despite the lack of studies assessing the effectiveness of repeated mowing in combination with the plantation of native species, this approach was able to reduce *A. donax* height (-80%), density (-50%) and cover (-35%), which was similar to the results obtained in the evaluation of just repeated mowing [63-65]. Final evaluation after the end of the project (2019) will provide additional key data on the survival rates of planted saplings to identify the most successful species outcompeting *A. donax* in habitat 92A0 and 92D0. It will also allow for checking if restoration actions have turned aquatic and terrestrial communities more similar to those inhabiting reference reaches (there were five non-invaded reaches distributed along the study area). This information will be very valuable when promoting their replication in further restoration schemes.

4.2 Aquatic macroinvertebrates

The ecological quality (sensu IBMWP), family richness and Hemiptera species richness have experienced meaningful increases after the implementation of restoration actions. Furthermore, we detected a diversification in taxonomic composition through time and species of high conservation interest in the study area. Despite the restored river reaches are affected by flow regulation due to the presence of upstream dams, most of the sampling sites reached at least good ecological condition based on IBWMP index during the last year of the monitoring campaign (2018). The only exceptions were the “Moratalla river mouth” and “La Maestra” reach in the Segura River probably due to their proximity to upstream and downstream dams, which cause artificial flow intermittence and flow retention, respectively [66]. Changes in the dominance between native and non-native riparian species can influence the quality, quantity, and timing of allochthonous resource inputs which, in turn, may favour the diversity and structure of invertebrate communities [67,68]. In fact, riparian habitats dominated by exotic species are associated to lower invertebrate density, diversity and evenness than riparian habitats dominated by native vegetation [69]. Namely, *A. donax* promotes homogeneous and uniform river banks and less woody debris, resulting in lower diversity of microhabitats (e.g. tree roots) for aquatic macroinvertebrates. The reduction of *A. donax* dominance could have boosted the recovery of aquatic macroinvertebrate community since this invasive species reduces insect growth as it constitutes an exceptionally poor resource with an allelopathic potential effect [28]. The higher resource quality of native species debris coupled with a gain of native litter as consequence of restoration action could have long-term beneficial effects on secondary production of aquatic macroinvertebrates utilizing large-particle organic matter [28]. Particularly, streams in which biotic assemblages are structured by allochthonous organic inputs, shifts from *A. donax* to native riparian communities could influence higher trophic levels by increasing the relative contribution of shredder macroinvertebrates as a resource for predators [70].

According to our results, the observed temporal trend could be due to the reduction of *A. donax* cover, the increase of riparian species richness and the improvement on the quality of riparian areas and river banks as a consequence of the restoration actions. Nevertheless, it could be also related to the good physico-chemical water parameters found along the study area (nitrates <5 mg/l, water conductivity <1000 μS/cm, total and volatile suspended solids <5 mg/l; measured at the same time than macroinvertebrates sampling), with the exception of local and punctual disturbances in some sampling sites located near rice fields which affected water quality occasionally. The unexpected lack of significant relationships between physico-chemical water parameters and macroinvertebrate indices could be due to the relatively good water quality found on the whole river section during all the project (lack of spatial and temporal variability). This good physico-chemical state is probably related to the notable reduction of organic pollution occurred in the last decades due to a better management of wastewater and the construction of many water treatment plants along the Segura river basin [71]. However, further conservation and management actions are highly recommended considering that alien invertebrate species as *Procambarus clarkii*, *Corbicula fluminea* and *Potamopyrgus antipodarum* were widely detected during this short-term assessment, showing an expansion across the Basin in some cases [72]. Finally, it seems worth to stress that the endemic mollusk *Melanopsis lorcana*, considered as "vulnerable" in the Spanish red book of invertebrates [73], has been recurrently recorded during the entire monitoring period, its corresponding family (Thiaridae) being one of the few indicator taxa for the 2018 sampling campaign. Moreover, we have detected the occurrence of species related to well-conserved riparian forests (e.g. *Potamophilus acuminatus,* Coleoptera) and, also, other taxa associated to artificial watercourses (e.g. *Heliocorisa vermiculata,* Hemiptera) pointing that this possible transition to better conditions is still underway.

4.3 Birds

Only birds were differentially affected by the frequency of repeated mowing. The extensive treatment was associated with an increase in species richness, density and abundance, whereas the intensive one exerted neutral (species richness) and even negative effects (density and abundance) on bird communities. The intensive treatment could represent an excessive frequency of mowing (monthly), hindering bird nesting during the critical months of May, June and July, which must be considered in future management and restoration actions. Thus, only extensive treatment (quarterly mowing) should be extended in time to reduce exotic cover without detrimental effects on bird communities. At the moment, 54 bird species have been recorded through transects in the last sampling campaign (2018), and a total of 64 species (Table S1) have been detected in the restored reaches during the entire project, an amount noticeably higher than other monitoring programs in forest habitats in the region (45-56 species; [74]). Bird species richness also fluctuates as a result of seasonal habitat changes and community replacement, particularly due to the seasonal influx of migratory species. During spring and autumn passage, numerous migrant birds concentrate in the Iberian Peninsula along riparian galleries [30,75,76]. Although this is a feature only partially captured by our sampling design, an improvement in the carrying capacity of restored habitats as migration stopovers and corridors is also expectable if treatments are maintained in the mid-term.

Aquatic and riparian bird communities are highly influenced by landscape-scale factors like vertical and horizontal structure of riparian vegetation and adjacent land use [77,78]. *A. donax* invasion is a matter of concern due to the potential negative effects on birds that rely on native riparian vegetation stands for foraging and nesting [79,80]. In particular, the giant reed stands in semi-arid Mediterranean areas present a depauperated passerine community in comparison with other similar riparian and reedbed formations, lacking mainly the set of birds that are more selective and adapted to palustrine habitats [81]. This could be due to differences in certain environmental characteristics between native and alien biotopes, as the lower availability of preys (invertebrates) associated with monospecific *A. donax* stands. This probably applies to our riparian habitats, where *Arundo* outcompetes reedbeds of *Phragmites australis* and shrubby formations like willow strips, brambles and different Mediterranean understory and forest communities that provide structural heterogeneity and additional food resources for birds [82].

Within native plant associations, Mediterranean riparian galleries as habitats 92A0 and 92D0 are key biodiversity hotspots on a regional scale, since they often represent the only well-structured habitat available for bird breeding and foraging within intensively developed landscapes [76]. Moreover, specialist birds strongly tied to riparian areas share these habitats with forest generalists and ubiquitous species typical of surrounding shrublands and agricultural landscapes [75]. The concept of riparian-obligate and riparian-dependent species [83] is useful since different restoration strategies (local vs landscape-oriented) would deliver improvements in each subset of species [84]. While some riparian-dependent species can be favoured in the initial stages after restoration, recovering the full set of riparian-obligate ones probably needs more time to rebuild the structural complexity they require. Although we did not detect meaningful changes in the more frequent species, there was a negative trend in pioneer species inhabiting open habitats (e.g. *Muscicapa striata*), and an increase of riparian and facultative birds with seed dispersal potential (e.g. *Turdus viscivorus*), which could benefit passive restoration in the long term (as previously demonstrated in burned areas [85]).

Overall, it seems that planted riparian vegetation has not fully developed yet to modify associated bird communities substantially. Nevertheless, mowing campaigns and restoration actions could have enhanced bird diversity through the creation of transient spots of open habitat with animal and plant resources that can be exploited by bird community inhabiting in the remaining tree stratum and adjacent shrubland patches. Tree canopies, which can persist even in river sections partially invaded by *A. donax.*, are the habitat most used by many riparian bird species. Most riparian trees are deciduous, a type of forest limited in the study area to riparian zones due to the climatic restrictions of semi-arid Mediterranean areas. This type of forests hosts particular bird communities [86] that may complement the species typical from conifers and Mediterranean evergreen sclerophyllous forests, enhancing diversity at landscape and regional scale. Moreover, given the greater diversity and abundance of insects in deciduous broadleaf forests [87], these riparian species could result particularly important for birds, especially insectivorous ones. However, despite the importance of these tree canopies, the presence of native understory strata seems also necessary to reach a really diverse community [88]. It suggests that the plantation of native trees supplemented by shrub and herbs, as done in this project, could promote synergies with existing vegetation and enhance longitudinal, lateral and vertical landscape connectivity with beneficial effects on riparian bird community in the mid-term.

4.4 Management implications

Human-driven environmental changes (e.g. land use intensification) disturb native riparian communities adapted to previous local conditions, arising niche opportunities for alien species which can show positive rates of increase from low densities [89]. Given the advanced state of *A. donax* invasion in the Segura River, the complete removal of this invasive species and successful recovery of native riparian communities are not feasible without reversing or, at least, mitigating the negative effect of the human activities that originally enabled the invasion. In this context, it should be stressed that the project LIFE+ RIPISILVANATURA has attempted, albeit partially, to face these other human pressures through the implementation of complementary actions to restoration measures, such as the removal of unnecessary river embankments, demarcation of public waters and riparian areas, creation of a land stewardship network, fire prevention as well as supporting and promoting sustainable agricultural practices.

The restoration actions performed, based on repeated mowing in combination with native species plantation, are specifically recommended on river reaches not fully invaded by *A. donax* and with specific ecological interest (e.g. habitats of European interest, protected areas, threatened species, etc.). Otherwise, there are promising strategies that could be successfully applied in riparian areas dominated by monospecific stands of *A. donax*, such as plastic layering, a cost-effective, clean and sustainable technique that consists of covering the area recently mowed with an opaque reusable material (preferentially of polyethylene) during several months. This technique can increase temperature above 60 °C, intercepts sunlight (exhausting the reserves of the rhizome) and produces the massive death of *A. donax* [90]. Regarding the methodological approach used here, increasing mowing effort right before the plantation of native species could have weaken *A. donax* to a greater extent and, subsequently, increase the survival rate of native saplings [38].

The observed ecological trends in response to *A. donax* control and restoration actions can be strengthened by longer evaluation periods, which would allow for extracting more robust conclusions to be considered in further riparian restoration projects. Although plant species early established after restoration could be informative on the long-term success of vegetation outcomes [91], further evaluation after the end of the project (2019 and following years) will provide a deeper insight into the identification of the key factors behind success or failure (treatments, planted species combination, initial status, etc.). Moreover, long-term (6-10 years) biomonitoring is highly recommended to have a complete view of the processes, effects and durability of the applied measures [91,92]. The cross-taxon biomonitoring scheme performed here considers the multi-dimensional nature of rivers and expands the assessment to river segment scale, which is not common in riparian restoration projects (usually focused on the effects on riparian vegetation patterns at meander scale [91]). This approach is of great help when incorporating adaptive management to restoration projects, which enables to extrapolate successful actions and discard failed ones, therefore improving the cost-benefit ratio of further management actions. If biomonitoring is maintained in the long term, further hot research topics could include how riparian restoration actions modulate the functional features of aquatic and terrestrial species and how these traits interact within and between associated biological communities (e.g. insectivorous birds and aquatic emergent insects).

Supplementary Materials: The following information is available online at www.mdpi.com/xxx/s1, Table S1: Taxa checklist of riparian vegetation, aquatic macroinvertebrates and birds recorded, Table S2: Table summarizing the mean values and standard deviation of riparian vegetation, birds and aquatic invertebrate indexes through time and between treatments, Figure S1: Boxplots showing the temporal evolution of bird density, abundance and species richness.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used conceptualization, D.B., V.Z. F.R., and J.V.; methodology, D.B., F.R., J.V., A.M., V.Z., E.D., S.G., F.P and J.C. ; formal analysis, D.B.; data curation, V.Z., S.G., F.P., A.M., F.R. and D.B.; writing—original draft preparation, D.B.; writing—review and editing, D.B., F.R., J.V., A.M., V.Z., E.D., S.G., F.P and J.C.; project administration, F.R.;

Funding: This research was funded by European Commission through LIFE+ RIPISILVANATURA LIFE13 BIO/ES/1407. DB was supported by a "Juan de la Cierva" research contract (Spanish MINECO FJCI-2016-29856) at Instituto Pirenaico de Ecología (IPE-CSIC, Spain). SG was partially supported by a Royal Society-Newton International Fellowship (NIF\R1\180346) at Loughborough University (UK).

Acknowledgments: The authors are very grateful to Alberto Conesa, Antonio J. García-Meseguer, Aram Vilar, Carlota Vilar and José Manuel Ayala for their support in fieldwork during the different phases of the project. We also want to thank to Jaime Fraile and Adolfo Mérida (Confederación Hidrográfica del Segura) as main coordinators of LIFE+ RIPISILVANATURA.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Table S1. Taxa checklist of riparian vegetation, aquatic macroinvertebrates and birds recorded between 2015 and 2018 in the study area.

Riparian vegetation	**Birds**	**Aquatic macroinvertebrates (families)**

Agave americana	*Acrocephalus scirpaceus*	*Aeshnidae*
Agrostis stolonifera	*Aegithalos caudatus*	*Ancylidae*
Anthyllis cytisoides	*Alcedo atthis*	*Anthomyiidae*
Apium graveolens	*Anas platyrrynchos*	*Athericidae*
Apium nodiflorum	*Ardea cinerea*	*Atyidae*
Arbutus unedo	*Caprimulgus ruficollis*	*Baetidae*
Arundo donax	*Carduelis cannabina*	*Brachycentridae*
Artemisia campestris	*Carduelis carduelis*	*Caenidae*
Asparagus acutifolius	*Carduelis chloris*	*Calopterygidae*
Asparagus albus	*Certhia brachydactyla*	*Cambaridae*
Asparagus horridus	*Cettia cetti*	*Ceratopogonidae*
Asparagus officinalis	*Cisticola juncidis*	*Chironomidae*
Atriplex halimus	*Columba livia domestica*	*Coenagrionidae*
Ballota hirsuta	*Columba palumbus*	*Corbiculidae*
Brachypodium retusum	*Cuculus canorus*	*Corduliidae*
Bryonia dioica	*Cyanistes caeruleus*	*Corixidae*
Carpobrotus edulis	*Dendrocopos major*	*Culicidae*
Carex pendula	*Emberiza cia*	*Curculionidae*
Celtis australis	*Emberiza cirlus*	*Dixidae*
Cistus albidus	*Erithacus rubecula*	*Dolychopodidae*
Cistus clusii	*Falco tinnunculus*	*Dryopidae*
Cistus monspeliensis	*Ficedula hypoleuca*	*Dugesiidae*
Cladium mariscus	*Fringilla coelebs*	*Dytiscidae*
Clematis vitalba	*Galerida cristata*	*Elmidae*
Coriaria myrtifolia	*Gallinula chloropus*	*Empididae*
Crataegus monogyna	*Hippolais opaca*	*Ephemerellidae*
Cyperus fuscus	*Hippolais polyglotta*	*Ephemeridae*
Cyperus longus	*Jynx torquilla*	*Ephydridae*
Cynanchum acutum	*Lanius senator*	*Erpobdellidae*
Daphne gnidium	*Lophophanes cristatus*	*Gammaridae*
Desmazeria rigida	*Loxia curvirostra*	*Gerridae*
Digitalis obscura	*Luscinia megarhynchos*	*Glossiphoniidae*
Dittrichia viscosa	*Merops apiaster*	*Glossosomatidae*
Dorycnium pentaphyllum	*Motacilla alba*	*Gomphidae*
Dorycnium rectum	*Motacilla cinerea*	*Gyrinidae*
Equisetum ramosissimum	*Muscicapa striata*	*Haliplidae*
Eleagnos angustifolia	*Nycticorax nycticorax*	*Helophoridae*
Elymus hispidus	*Oenanthe leucura*	*Heptagenidae*
Ficus carica	*Oriolus oriolus*	*Hydracarina*
Riparian vegetation	**Birds**	**Aquatic macroinvertebrates (families)**

Fraxinus angustifolia	*Parus major*	*Hydraenidae*
Fraxinus excelsior	*Passer domesticus*	*Hydrobiidae*
Genista_scorpius	*Passer montanus*	*Hydrometridae*
Genista spartioides	*Periparus ater*	*Hydrophilidae*
Hedera helix	*Petronia petronia*	*Hydropsychidae*
Helychrisum stoechas	*Phalacrocorax carbo*	*Hydroptilidae*
Imperata cylindrica	*Phylloscopus collybita*	*Leptoceridae*
Iris pseudacorus	*Phylloscopus trochilus*	*Leptophlebiidae*
Juglans regia	*Pica pica*	*Leuctridae*
Juncus acutus	*Picus viridis*	*Libellulidae*
Juncus articulatus	*Regulus ignicapilla*	*Limnephilidae*
Juncus inflexus	*Remiz pendulinus*	*Limoniidae*
Juncus maritimus	*Saxicola rubicola*	*Lymnaeidae*
Juniperus oxycedrus	*Serinus serinus*	*Melanopsidae*
Juniperus phoenicea	*Streptopelia decaocto*	*Nepidae*
Laurus nobilis	*Streptopelia turtur*	*Neritidae*
Lonicera biflora	*Sturnus unicolor*	*Notonectidae*
Lonicera_implexa	*Sylvia atricapilla*	*Oligochaeta*
Lonicera sp	*Sylvia borin*	*Oligoneuriidae*
Lygeum spartum	*Sylvia hortensis*	*Ostracoda*
Lysimachia ephemerum	*Sylvia melanocephala*	*Perlodidae*
Marrubium vulgare	*Troglodytes troglodytes*	*Philopotamidae*
Mentha suaveolens	*Turdus merula*	*Physidae*
Mespilus germanica	*Turdus viscivorus*	*Planariidae*
Morus alba	*Upupa epops*	*Planorbidae*
Nasturtium officinale		*Platycnemididae*
Nerium oleander		*Polycentropodidae*
Nicotiana glauca		*Polymitarcidae*
Olea europaea		*Potamanthidae*
Opuntia maxima		*Prosopistomatidae*
Osyris lanceolata		*Psychomyiidae*
Osyris quadripartira		*Rhyacophilidae*
Phlomys_lychnitis		*Scirtidae*
Phyllirea angustifolia		*Simuliidae*
Phragmites australis		*Sphaeriidae*
Pinus halepensis		*Tabanidae*
Pinus pinea		*Tipulidae*
Pistacia lentiscus		*Veliidae*
Platanus_hyspanica		
Populus alba		
Riparian vegetation	**Birds**	**Aquatic macroinvertebrates (Coleoptera)**

Populus deltoides		*Agabus biguttatus* (Olivier, 1795)
Populus nigra		*Agabus ramblae* Millán & Ribera, 2001
Potentilla reptans		*Aulonogyrus striatus* (Fabricius, 1792)
Prunus domestica		*Coelostoma hispanicum* Küster, 1848
Prunus dulcis		*Cyphon* sp.
Prunus persica		*Dryops gracilis* (Karsch, 1881)
Punica granatum		*Elmis maugetii* Latreille, 1798
Pyrus communis		*Enochrus ater* Kuwert, 1888
Quercus coccifera		*Esolus pygmaeus* Müller, P.W.J., 1806
Quercus rotundifolia		*Gyrinus distinctus* aubé, 1836
Retama sphaerocarpa		*Helochares lividus* (Forster, 1771)
Rhamnus alaternus		*Helophorus* sp.
Rhamnus lycioides		*Hydraena* cf *hernandoi* Fresneda & Lagar, 1990
Robinia pesudoacacia		*Hydroglyphus geminus* (Fabricius, 1792)
Rosa canina		*Hydrophylus pistaceus* Laporte de Castelnau, 1840
Rosmarinus officinalis		*Laccophilus hyalinus* (De Geer, 1774)
Rubia peregrina		*Limnius intermedius* Fairmaire, 1881
Rubus caesius		*Normandia nitens* (Erichson, 1847)
Rubus ulmifolius		*Ochthebius viridis fallaciosus* Ganglbauer, 1901
Ruscus aculeatus		*Orectochilus villosus* (Müller, 1776)
Saccharum ravennae		*Oulimnius troglodytes* (Gyllenhal, 1827)
Salix alba		*Pomatinus substriatus* (Muller, 1806)
Salix atrocinerea		*Potamophylus acuminatus* (Fabricius, 1792)
Salix eleagnos		*Ranthus suturalis* (MacLeay, 1825)
Salix fragilis		
Salix neotricha		
Salix purpurea		
Sambucus nigra		
Samolus valerandi		
Satureja intricata		
Scirpus holoschoenus		
Scirpus maritimus		
Sedum sediforme		
Smilax aspera		
Sorghum halepense		
Stipa tenacissima		
Suaeda vera		
Tamarix boveana		
Tamarix gallica		
Teucrium capitatum		
Riparian vegetation	**Birds**	**Aquatic macroinvertebrates (Hemiptera)**

Thalictrum speciosissimum	*Aquarius cinereus* (Puton, 1869)
Thymus vulgaris	*Aquarius najas* (De Geer, 1773)
Typha dominguensis	*Gerris argentatus* (Schummel, 1832)
Ulmus minor	*Gerris thoracicus* (Schummel, 1832)
Veronica anagallis-aquatica	*Heliocorisa vermiculata* (Puton, 1874)
Vitex agnus-castus	*Hydrometra stagnorum* (Linnaeus, 1758)
Vitis vinifera	*Micronecta minuscula* Poisson, 1929
Washingtonia robusta	*Micronecta scholtzi* (Fieber, 1851)
Ziziphus_zizyphus	*Velia caprai caprai* (Tamanini, 1947)
Zygophyllum fabago	

Table S2. Table summarizing the mean values and standard deviation of riparian vegetation, birds and aquatic invertebrate indexes through time (2015-2018) and between treatments (intensive-monthly mowing vs extensive- quarterly mowing).

Date	**Treatment**	***A. donax* density (stems/m^2)**	***A. donax* height (m)**	**Riparian plant richness**	**Native cover (%)**	**Exotic cover (%)**	**Riparian Quality (RQI)**	**Bird density (birds/ha)**	**Kilometric abundance (birds/km)**	**Bird species richness**	**Invert. Quality (IBMWP)**	**Invert. Family richness**	**Coleoptera richness**	**Hemiptera richness**
2015	**Intensive**	23.8 ± 7.8	3.7 ± 1.2	11.9 ± 3.4	32.7 ± 22.4	67.9 ± 25.4	44.2 ± 14.3	87.9 ±38.6	138 ±54	15.3 ±4.2	78.8 ±16	17.4 ±2.5	2.2 ±1.6	1.8 ±1.1
2015	**Extensive**	29.2 ± 8.3	3.9 ± 0.5	18.2 ± 5.4	47.3 ± 15.6	56.5 ± 17.7	55.2 ± 9.7	62.3 ±13.4	126.3 ±33.6	16 ±4	85.3 ±12.8	18 ±2.6	2.8 ±1.9	1 ±0.8
2016	**Intensive**	24.3 ± 4	0.9 ± 0.6	18.5 ± 5	28.8 ± 20.2	73.4 ± 19.7	40.9 ± 11.9	82.9 ±37.9	131 ±41	13.9 ±3.8	74.8 ±19.4	16.3 ±3.7	2.3 ±1.6	0.8 ±1
2016	**Extensive**	14.9 ± 6.7	0.6 ± 0.3	19.8 ± 2.6	51.5 ± 14.9	54.9 ± 15.3	51.4 ± 9.1	78.5 ±36.8	157.2 ±69.1	17.2 ±5.7	60 ±20.7	14.3 ±3.2	3.3 ±1.2	0.7 ±0.6
2017	**Intensive**	30.6 ± 11.3	0.9 ± 0.3	24.2 ± 7.5	32.3 ± 12.7	63.4 ± 14.9	48.7 ± 10.6	65.9 ±28.4	104.9 ±27.4	15.1 ±3.4	96.7 ±28.8	20.3 ±6.2	2.5 ±1.9	2.2 ±1.3
2017	**Extensive**	21.5 ± 10.9	1.5 ± 0.6	28.1 ± 5.8	50.6 ± 17.9	55.5 ± 18.8	57.3 ± 10.6	89.2 ±64.1	170.3 ±96.9	18.7 ±4.6	86.3 ±33.1	20.3 ±4.7	3.3 ±2.5	3.3 ±0.6
2018	**Intensive**	20.7 ± 13.7	0.4 ± 0.2	27 ± 7.9	37.1 ± 14.5	48.9 ± 21.1	47.8 ± 14	50.1 ±20	84.7 ±37.7	13.9 ±4.2	112.3 ±26.8	21 ±4.6	2.2 ±1.2	2.7 ±1
2018	**Extensive**	13.8 ± 2.6	0.4 ± 0.1	26.1 ± 5.5	45.8 ± 22.5	44.9 ± 18.6	56 ± 12.2	73.2 ±24.2	146.5 ±44.3	20.3 ±3.6	91.7 ±38.8	20 ±5.6	3.7 ±2.1	1.7 ±1.2

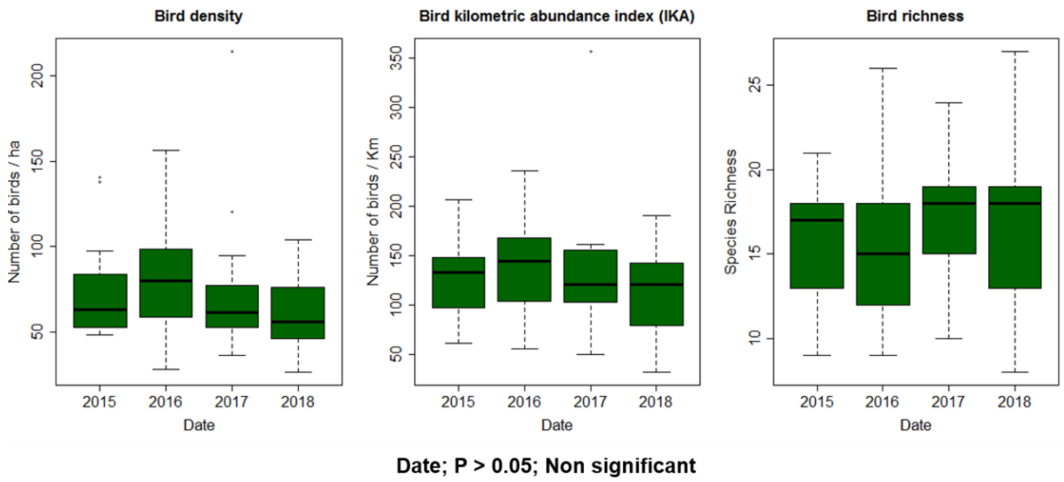

Figure S1. Boxplots showing the temporal evolution of bird density, abundance and species richness.