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Gabrielle Rudi, Jean-Stéphane Bailly, Yves Caraglio, Jeanne Dollinger, Fabrice Vinatier

Vinatier Fabrice (Orcid ID: 0000-0003-3693-4422)

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Gabrielle Rudi[1,2], Jean-Stéphane Bailly[1,3], Yves Caraglio[4], Jeanne Dollinger[1], and Fabrice Vinatier[1]

1 LISAH, Univ Montpellier, INRAE, IRD, l'Institut Agro Montpellier, Montpellier, France

2 G-Eau, Univ Montpellier, AgroParisTech, BRGM, CIRAD, INRAE, IRD, l'Institut Agro Montpellier, Montpellier, France

3 AgroParisTech, Paris, France

4 AMAP, Univ Montpellier, CIRAD, CNRS, INRAE, IRD, Montpellier, France

Correspondence : Fabrice Vinatier, LISAH, INRAE, 2 place Pierre Viala, 34060 Montpellier, France. Email : fabrice.vinatier@inrae.fr

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ABSTRACT

Maintenance practices in agricultural ditches influence their abiotic and biotic functioning in the short and medium term, leading to modifications of plant communities. These modifications might in turn affect the water transport regulation and seed retention functions of ditches. The effects of maintenance practices on ditch plant communities have been poorly studied in terms of (i) functional response traits to maintenance practices (ii) functional effect traits driving ecosystem functioning. We designed an experiment to compare the effects of different maintenance practices (mowing, burning, chemical weeding and dredging) in an agricultural Mediterranean ditch. We measured the plant species richness (i.e. alpha diversity or number of species), stem densities, and plant traits/community functional parameters affecting water transport and seed retention (height, blockage factor and surface vegetation ratio), every year during two years before and after applying contrasting maintenance practices. All the plants growing in the bottom and on the banks of the studied ditch were identified. We characterized the differences between treatments using linear mixed-effects models. Maintenance practices differently affected plant communities and resulting ecosystem functions. After two years, burning was the poorest practice regarding seed retention and the best practice regarding hydraulic transport capacity, on the basis of a water-depth of 60 cm in the ditch. Mowing was the poorest practice regarding water transport and was an averaged practice for seed retention. Mowing was also the practice favoring the highest richness. Chemical weeding did not really differ from the control in terms of studied traits and parameters, although a slight decrease in water conveyance ability and increase in seed retention was assessed after two years. The results pave the way to developing easy to implement maintenance solutions with the potential to

optimize ecosystem functions, relying both on historical agricultural practices for farmers (involving no new know-how) and on non-introduced plant species.

Keywords: drainage networks; agricultural channel; management practices; Mediterranean agrosystem; response-and-effect trait framework; ecosystem function ; ditch plant communities

1. INTRODUCTION

Ditch networks are seminatural landscape features located at field, path, or road boundaries. In rural areas, these ditches are soil excavations that have mainly been established for drainage, runoff collection or erosion mitigation purposes (Levavasseur et al. 2016). Ditches' morphology and layout make them prone to collecting sediments, nutrients, phytosanitary products and plant propagules from other landscape objects. As interfaces between terrestrial and aquatic bodies, ditches support a high level of plant biodiversity (Herzon and Helenius 2008; Le Coeur et al. 2002 ; Milsom et al. 2004; Pierce et al. 2012 ; Twisk et al. 2003). In northern Europe, this vegetation is mostly aquatic (Shaw et al. 2015; Twisk et al. 2003), whereas it is generally terrestrial or semiaquatic in Mediterranean areas (Levavasseur et al. 2014; Rudi et al. 2018b). This vegetation has traditionally been removed to restore the hydraulic transport capacity in agricultural ditches. However, it is now recognized that vegetation plays a role in other ecosystem functions such as water transport regulation ; water table recharge ; bank strengthening ; and sediment, plant propagule and contaminant retention (Dollinger et al. 2015, 2017;

Rudi et al. 2018a, Rudi et al. 2020 in press, Soomers et al. 2010; van Dijk et al. 2014).

The plant community composition in ditches depends on several factors. In addition to endogenous factors such as dispersal abilities (Favre-Bac et al. 2016; Van Dijk et al. 2014) or competitive strategies (Blomqvist et al. 2003), several exogenous factors shape the plant communities. At the local scale, soil properties (Maheu-Giroux and De Blois 2007; Shaw et al. 2015 ; van Strien et al. 1991), sun exposure (Shaw et al. 2015 ; van Strien et al. 1991) and the water regime (Shaw et al. 2015 ; Twisk et al. 2003) can affect the distribution of plants. Plant community composition is also explained by landscape scale factors such as geomorphology and drainage area (Rudi et al. 2018b), the distance to natural areas and plant source populations (Maheu-Giroux and De Blois 2007; Van Dijk et al. 2014), and landscape configuration (Favre-Bac et al. 2014; Bassa et al. 2012). Moreover, plant communities are highly dynamic because they are also shaped by seasonality and interannual variation in climatic conditions. Especially in Mediterranean landscapes, climatic variability and intermittent rainfall affect the flow regime in ditches and the related succession of plant communities.

The last important factors explaining the composition of plant communities in ditches are the type and timing of maintenance practices performed in adjacent fields or in the ditches themselves (Blomqvist et al. 2009; Chaudron et al. 2016b; Le Coeur et al. 2002; Leng et al. 2011b; Manhoudt et al. 2007; Shaw et al. 2015; van Strien et al. 1991; Twisk et al. 2003). Most studies on the effects of ditch maintenance practices have been performed in northern Europe (Blomqvist et al. 2009; Leng et al. 2011b; Manhoudt et al. 2007; Shaw et al. 2015; van Strien et al. 1991; Twisk et al. 2003). Many of these studies focused on understanding whether practices conducted by farmers in ditches or adjacent fields modified the plant species richness/abundance of ditch communities. A reduction in competition for light (Shaw et al. 2015; van Strien et al. 1991) and high levels of water (Shaw et al. 2015; Twisk et al. 2003) induced by the practices reportedly have a positive effect on plant species richness. Other studies focused on determining the timings of practices that might be optimal for seed dispersal (Chaudron et al. 2016a; Leng et al. 2011a). Alignier et al. (2013), in a study focused on in-field weed composition, also showed that past practices were an important factor explaining present plant communities. In Mediterranean rural areas, four types of maintenance strategies, i.e., mowing, burning, chemical weeding and dredging (Dollinger et al. 2015; Levavasseur et al. 2014) are usually used to restore the hydraulic capacity of ditches. Mowing, burning and chemical weeding are used to clear vegetation and are generally applied annually or twice per year (Levavasseur et al. 2014). In contrast, dredging is performed every 5 to 10 years (Dollinger et al. 2015; Levavasseur et al. 2014). The effects of dredging on diversity largely depend on the nature of the seeds established after the removal of the superficial layer of soil. In vineyard fields, chemical weeding has a significant filtering effect, favoring therophytes or perennials with deep root systems (Fried et al. 2019), although mowing generally allowed greater plant diversity (Kazakou et al. 2016 ; Fried et al. 2019). However, the effect of maintenance practices on ditch species surrounding vineyards has rarely been studied (see Bassa et al. 2012 for the only examples to our knowledge).

Therefore, maintenance practices are significant "filters" (Lavorel and Garnier 2002) explaining plant community composition in agroecosystems (Bengtsson et al. 2005 ; Fried et al. 2019 ; Winter et al. 2018). As illustrated above, more extensive maintenance practices generally present a less filtering effect. Trait responses generally associated with agricultural practices (especially tillage and chemical weeding) are traits relating to seed persistence and dormancy, germination period, seedling shoot morphology, Raunkiaer type, root system depth and width, leaf dry matter content, number of seeds produced (Gaba et al. 2017) or even pollination syndrome (Pakeman & Stockan 2013 ; Tarifa et al. 2021). As highlighted in Rudi et al. (2020), many studies used the trait framework to study the modification of ecosystem functions following disturbances due to agricultural practices, however, to our knowledge no trait-based study focused on ditch plant vegetation and associated ecosystem functions. Consequently, in this study, rather than focusing only on the ability of these maintenance operations to affect the plant species richness and abundance of species in ditches, we investigated the effect of maintenance on the selection of traits influencing water transport, the main driver of ditch functioning, and influencing seed retention, involved in ditch restoration capacity (these two ecosystem functions being described in detail and quantitatively related to parameters and densities of plant communities and ditch hydraulic characteristics in Vinatier et al. 2017 and Rudi et al. 2021). Following the definitions provided by Violle et al. (2007), a trait in this study is a morphological feature that can be measured at the individual level. A community functional parameter is a feature measured on each individual (example: plant height) and aggregated at the community level (example: mean plant height). In the present study, we aimed to clarify how maintenance modifies community composition and traits, and how this modification in turn affects the functioning of the ecosystem.

Many studies conducted in natural and experimental open channels have highlighted the fact that plant heights, in relation to the density of stems and architecture of their aerial parts, influence hydraulic resistance (Baptist et al. 2007; Busari and Li 2015; Cheng 2011; Green 2005; James et al. 2004; Luhar and Nepf 2011; Nepf 2011; Nikora et al. 2008) and permeability to floating and non-floating seeds (Chambert & James, 2009; Cornacchia et al., 2019; Defina & Peruzzo, 2010; Rudi et al. 2021). By projecting plant aerial parts to the channel section, we access good indicators of hydraulic resistance and difference in permeability of the cover to different particles such as seeds (Nepf et al. 2012 ; Vinatier et al. 2017; Rudi et al 2020, 2021). Therefore, the modification of plant traits and density by maintenance practices in ditches can have consequences for water transport regulation and seed retention. If these effects are significant, then such modifications might have implications for the design of ditch maintenance strategies.

Selecting, through maintenance practices, plant communities with functional parameters that can regulate water transport and seed retention is a first step toward designing nature-based solutions (Nesshöver et al. 2017). By considering common maintenance practices in the Mediterranean area and non-introduced plant species, it would be easier to reach the desired goal (here the regulation of water transport and seed retention), because we could limit the cost/risk of introducing exogenous species and favor the acceptance of innovative management practices by farmers (Rey et al. 2015b). The selection of communities with a high or low-conveyance ability should be performed at the landscape scale, depending on the upstream-downstream location of the ditch section in the watershed. Low-conveyance plant communities should be favored upstream to slow peak flow and increase infiltration, whereas high-conveyance communities would be more desirable downstream to limit ditch overflows (Rudi, 2019). As well as that, the selection of communities with the ability to retain floating seeds is a lever to limit weed dispersal through the ditch network (Rudi et al., 2018a) (non-floating seeds have less ability to be transported far from their deposition place through water flows). However, in some cases of rehabilitation purposes, the dispersal of seeds through the network is desired to enhance intra and inter specific diversity. Moreover, as ditches often represent the only places in Mediterranean agricultural landscapes where aquatic and semiaquatic species can be found, a trade-off between hydraulic transport regulation, biodiversity preservation and limitation of weed dispersal must be found.

We make here the hypothesis that the trait-based response-and-effect-framework (Suding et al. 2008) is useful for predicting the effects of the disturbances caused by management practices on the dynamics of spontaneous plant communities in agroecosystems. As described by the authors, this framework involves the study of how the community responds to the disturbance and how the modification of the parameters of the community will affect functions provided by this community. Given the functions considered in the study, we hypothesize that the chosen response and effect traits are correlated, and that this correlation is the basis for the indirect control of studied ecosystem functions (regulation of water flow and seed dispersal) of this ecosystem. The objectives of this study were to: (i) characterize the influence of ditch maintenance practices (mowing, chemical weeding, burning and dredging) on the composition of plant communities and response traits after two years (the medium term) and (ii) identify the consequences of these modifications on community functional parameters affecting water transport regulation and seed retention, in order to identify practices optimizing the trade-off between these two functions. The experiment presented in this paper focused on a small agricultural ditch in a Mediterranean region of southern France.

2. MATERIAL AND METHODS

2.1. Study area

The study area is located in a small agricultural catchment in southern France, in the territory of the Alignan-du-Vent township of the Hérault department. Rainfed vineyards are the major land use type in the area. The area is characterized by a Mediterranean climate. Precipitation totals approximately 650 mm per year on average with high interannual variations (data issued by the Observatoire Méditerranéen de l'Environnement Rural et de l'Eau (OMERE), http://www.obs-omere.org) and two rainy seasons in spring and autumn. These rainy periods correspond to the major periods of vegetation growth. The rainfall from January to the end of April in 2015 and 2017 totaled 107 and 231 mm, respectively, although both hydrological years (2014-2015 and 2016-2017) were intermediate in terms of measured rainfall compared with the past 25 years. The maximum and minimum temperatures registered from January to the end of April were -3.7°C and 26.7°C in 2015, and -7.3°C and 26.3°C in 2017, respectively.

The landscape is characterized by an extended ditch network dug to facilitate the collection of runoff and the discharge of water (Levavasseur et al. 2016; Moussa et al. 2002). The network density in the region was characterized by Levavasseur et al. (2015) and found to be approximately 200 m/ha. Four types of maintenance are currently performed in the area to restore the hydraulic capacity of ditches: mowing, burning, chemical weeding and dredging (Dollinger et al. 2015; Levavasseur et al. 2014).

The ditch that was studied is 120 meters long. We chose a limited area of study instead of multiple areas across the watershed network for two main reasons: (i) to control the schedule of practices during the study period, as the timing and types of practices are uncertain over the whole network (Levavasseur et al., 2014), and (ii) to ensure a homogeneous area in terms of abiotic factors (pedology, hygrometry, morphology and nutrient level), as the ditch plant communities are highly dependent on these factors across the network (Manhoudt et al. 2007; Rudi et al. 2018b). The ditch is directly surrounded by vineyards without field strip margins or trees. The ditch has a trapezoidal shape and is approximately 1.5 meters wide at the top and 0.6 meters wide at the bottom (Figure 1), with an elbow located approximately 40 meters from upstream. The first part of the ditch has a northwest/southeast orientation, and the second part has a west/east orientation. The water flows from northwest to east. The outlet of the ditch is located 10 meters from the end of the experimental area. The ditch has intermittent exfiltration behavior when the groundwater table is shallow and infiltration behavior when the groundwater table is deep. The vegetation observed in this ditch ranges from terrestrial (herbaceous) to semiaquatic, but no aquatic species have been reported (based on yearly observations) due to the intermittent nature of the water flows. The capacity sensor with centimetric precision monitoring the water level in the ditch, registered several rainy events during which the water depth in the ditch reached 60 cm.

2.2. Experimental setup

The experimental ditch was divided into four sections, each of which was divided into five quadrats managed in various ways (**Figure 1**). Four different maintenance practices, i.e., mowing, burning, chemical weeding, and dredging, and a control treatment with no maintenance and thus representing the other exogenous effects (especially climatic conditions), were implemented between 2015 and 2017. The 20 resulting quadrats were approximately four meters long. In order to reduce the impacts of downstream treatments due to water flow, we separated each treatment by a two-meter-long non-managed buffer zone. The locations of the quadrats in the ditch were indicated by markers positioned every meter on both sides of the ditch. Before the start of the experiment, all the quadrats of the ditch were managed in the same way.

According to Levavasseur et al. (2014), in this agricultural area, mowing is generally conducted during summer. Chemical weeding is generally conducted during spring using nonselective herbicides. Burning occurs from mid-October to mid-March, coinciding with the legal authorizations for burning enforced in the area (burning is not allowed during dry periods to limit the risk of fire spreading). The experimental setup was developed in accordance with these field constraints and surveys. The completion dates for the maintenance operations are presented in **Table 1**.

The timing of maintenance practices differed between years because they resulted from a combination of criteria that explain the spread of treatment periods over several weeks.

2.3. Vegetation surveys

Three vegetation surveys were conducted in April 2015 (before the application of treatments), April 2016 and April 2017 (the best period for identifying the plant species). We chose a time span of two years between the surveys to allow significant evolution of plant community composition between treatments. An exhaustive list of surveyed species is presented in Appendix A. With the help of botanists, the visual cover of each species in the bottom and on the banks of the ditch was carefully assessed across the study area, which was divided into 1-meter-long rectangular sampling units using markers. The choice of a rectangular shape is suitable for long and narrow communities occurring in ditches (Gage and Cooper, 2010). Visual inspections of the plant species were realized by walking from both sides of the ditch in a buffer zone around the quadrat to avoid disturbance. The observer determined the footprint positions of each species according to the markers, ditch bottom, banks and sides. The specific areas of each species were calculated relative to the quadrat area across treatments and replicates. We calculated plant species richness (i.e. alpha diversity) as the total number of species in a quadrat.

2.4. Measurement of plant functional traits and density, assessment of community parameters

We measured density, as well as plant heights, to assess the response of the plant community to disturbance caused by maintenance practices. More specifically, for each type of species, we estimated the mean plant density by measuring the spacing between 10 nearby plants of the same species in a given patch. The number of stems for each specimen was counted. The measured heights were the natural heights reached by the main stem of the plants in the field, according to Perez-Harguindeguy et al. (2013). We considered the standard indice community-weighted mean (CWM) to aggregate the measured individual traits, considering the relative abundance of each species by calculating the covered area multiplied by the stem density per area of a species (Lavorel et al, 2008). We also informed the Raunkiaer type of each species. Information on species Raunkiaer types (Raunkiaer, 1934) was collected from Tela Botanica (<https ://www.tela-botanica.org, license CC BY-SA 4.0>). Note that the Raunkiaer system is used to classify plants according to their life form.

Two effect traits associated with the two studied hydraulic ecosystem functions (water transport regulation and seed retention) were measured at a specific water depth (60 cm), representative of the water depth encountered in ditches during an intense rainfall : (i) the blockage factor as the proportion of the wetted cross section occupied by plant stands (Vinatier et al, 2017), and (ii) the surface vegetation ratio as the area of the plant cover at the free surface of the water (Rudi et al, 2021). These two indicators depend on the height and specific architecture of individual plants (the specific architecture is in this study taken in consideration through the frontal area), as well as on the density of the community. We therefore collected 10 specimens of each plant species, and we took a lateral picture of each individual against a white background to measure the frontal area. We calculated the related blockage factor and the surface vegetation ratio based on the formulas provided in Vinatier et al. (2017) and Rudi et al. (2021).

These two effect traits were used to assess the studied ecosystem functions (water transport and seed retention). On the basis of the relation between the blockage factor (Bf) and the water friction expressed with the manning coefficient (n) (Vinatier et al 2017), and surface vegetation ratio (SVr) and water permeability to seed expressed at the percentage of retained seeds (Rr) (Rudi et al 2021), we calculated the gain in each indicator by the formulas presented in Equations 1 and 2. Note that the Manning coefficient (n) is an empirical coefficient, widely used in hydraulics, accounting for the roughness of the surface in contact with the water flow (and therefore largely depending on vegetation characteristics). The surface vegetation ratio (SVr) is a metric developed in Rudi et al. (2021) to account for the capacity of the plant community to trap floating seeds.

$$\Delta n(\%) = \frac{a_1 \times (1-Bf_{2017})^{-b} \times H^{\frac{1}{6}}}{a_1 \times (1-Bf_{2015})^{-b} \times H^{\frac{1}{6}}} - 1 = \frac{(1-Bf_{2017})^{-b}}{(1-Bf_{2015})^{-b}} - 1 \qquad \text{Equation 1}$$

$$\Delta Rr(\%) = \frac{1-e^{\left(\frac{-SVr_{2017}}{a_2 \times R \times 10^{-5}}\right)}}{1-e^{\left(\frac{-SVr_{2015}}{a_2 \times R \times 10^{-5}}\right)}} - 1 \simeq \frac{SVr_{2017}}{SVr_{2015}} - 1 \qquad \text{Equation 2}$$

The relationships between disturbances (maintenance practices), response trait (vegetation height) and the stem density, and effect traits (the blockage factor and the surface vegetation ratio), were tested following Suding et al (2008) and Larsen et al (2005). We first identified the relationships between maintenance practices (ordered in terms of increasing disturbance level considering our knowledge on their filtering effect on species) and resulting response trait (height). Maintenance practices were ordered from the most disturbing to least disturbing practice : dredging, burning, chemical weeding, mowing and control. Secondly, we tested whether response traits were correlated to effect traits following Suding et al (2008). All relationships were tested using Spearman's Rho correlation test.

2.5. Statistical analysis

As quadrats are spatially distributed along the same ditch with a possible influence of upstream quadrats to the downstream ones, and quadrats are not randomized within repetitions, we considered a linear mixed-effects model assigning a random effect for each quadrat between each repetition to take into account the spatial correlation between quadrats and a fixed effect for maintenance practices. The influence of quadrat's location on each explained variable was tested using a Spearman's correlation test. As both climatic environmental variables and maintenance applications were different for the three years of study, we cannot consider the year variable as a temporal pseudoreplicate and we considered to realize one linear mixed-effects model per year. We tested the association between treatments and explained variables using Tukey's all-pair comparisons, on the basis of a one way anova for continuous explained variables (e.g. density of stems) and a two-way anova for categorical variables (Raunkiaer types). The tests were considered interpretable if the effects of treatments in 2015 were nonsignificant, because before 2015 all the quadrats were managed in the same way.

All analyses were conducted using R (R Development Core Team 2018) using the package “lme4” for linear mixed-effects model, and the packages “emmeans” and “multcomp” for Tukey all-pair comparisons. All plots were realized using the package “ggplot2”.

3. RESULTS

3.1. Changes in plant species richness between 2015 and 2017

The vegetation surveys established that the ditch hosted 59 species from 22 plant families (**Appendix A**). The most abundant species, i.e. covering more than 90% of the ditch bottom surface, were 7 in 2015 and 20 in 2017, with *Equisetum ramosissimum, Diplotaxis erucoides, Elytrigia repens*, and *Lythrum hyssopifolia* present in both surveys. In 2015 and 2016, the median plant species richness (alpha-diversity) was between 8 and 13 in all treatments, and there were no significant differences between treatments (p>0.05, Tukey contrasts), except for the dredged treatment in 2016. In 2017, the plant species richness had increased in all quadrats, reaching a median of 15 to 25 species according to treatment (**Figure 2**). Mowing differed significantly from the control, with a plant species richness 50% higher than that in the control (p=0.03, Tukey contrasts). Three species present in 2015 had disappeared in 2017: *Taraxacum sp*, *Valerianella locusta* and *Calendula officinalis*. We observed a semiaquatic species, *Veronica anagallis-aquatica*, among the species surveyed only in 2017. Plant species richness was not correlated to quadrat’s position along the studied ditch (Pearson cross product correlation: cor=0.11).

As shown in Figure 3, the analysis of Raunkiaer type distributions according to treatment and year revealed predominance of the geophyte type in all treatments for the first survey (*p<0.0001*, Tukey contrasts). These proportions differed significantly between the first and last surveys (*p<0.001*, two-way ANOVA), and also across treatments (*p<0.001*, two-way ANOVA), with increases in the hemicryptophyte and therophyte proportions in all treatments in 2016 and 2017.

3.2. Plant community response to maintenance practices, and correlation between response and effect traits

Vegetation height (Spearman's Rho=-0.57, df=14, P=0.02) and stem density (Spearman's Rho=0.64, df=14, P=0.03) were correlated to the disturbance level caused by the maintenance practices (burning, chemical weeding, mowing and control were considered) (Figure 4). A gradient of response trait is observed : community height increases from one of the most disturbing practices (burning) to the least disturbing practice (mowing). Density increases from the least disturbing practice (mowing) to one of the most disturbing practices (burning). The status of dredging is undefined : the level of disturbance of this practice is maximal because it removes all the community in place. The resulting community is therefore more associated to dispersal processes rather than to the response of the community in place.

Response trait (height) and density were correlated to effect traits (see Material and Methods). The correlation between these traits are presented in Appendix B.

3.3. Influence of maintenance practices on water transport and seed retention

There were no significant differences between treatments for any of the tested variables (stem density, mean height, blockage factor, surface area ratio) in 2015 (*p>0.05*, Tukey contrast), validating the homogeneity of the studied zone in terms of studied traits and plant functional community parameters before the two years of the experiment.

Furthermore, none of the explained variables (stem density, mean height, blockage factor and surface area ratio) were related to quadrat's position along the studied ditch (Spearman's cross product correlation: Rho <0.2, df=57, P>0.05).

The four studied variables were affected differently by treatments (Figures 5-8). Mowing presented a high blockage factor (Figure 7), but did not significantly differ from control regarding density, mean height and surface area ratio (Figure 5, 6 and 8), although surface area ratio was high. Chemical weeding never differed significantly from control (Figure 5-8). Burning led to significantly higher values of stem density (*p=0.006, Tukey contrast*) and lower values of blockage factor (Bf) (*p=0.02, Tukey contrast)* than the control, especially for year 2017. Burning also led to the lowest mean height and surface area ratio in 2017 (Figure 6 and 8). Dredging did not differ significantly from control regarding density (Figure 5), height (Figure 6), blockage factor and surface area ratio (Figures 7 and 8), although the surface area ratio and blockage factors were high in 2017 compared to burning (Figure 8).

Changes in community traits and parameters according to practices affected differently the Manning coefficient and seed retention indicator, representative of the two studied ecosystem functions (ditch water transport and seed retention) (Table 1). Between year 2015 and 2017, there was only a slight or null difference in Manning (n) and seed retention (Rr) for the control. However, the burning practice decreased by 33% seed retention with a limited effect on Manning. The other management practices (chemical weeding, dredging and mowing) have a positive effect on both Manning, with a gain ranging between 24% and 63%, the major effect being related to mowing practice on Manning coefficient. Chemical weeding increased seed retention by 41%.

4. DISCUSSION

4.1 Effects of maintenance practices on plant species richness and the appearance/loss of species

The more abundant species encountered in ditches were consistent with those observed in ranks and inter-ranks of vineyards in basic soils of Languedoc-Roussillon (Fried et al. 2019), which shows that except for some hygrophilous species (for example, *Lythrum hyssopifolia* and *Veronica anagallis-aquatica*), the species found in ditches are very similar to those that can be found in adjacent fields. These results call for further studies specifically devoted to the comparison of plant community composition between ditches and adjacent crops in Mediterranean agricultural areas for conservation purposes.

The only practice significantly different from the control in terms of plant species richness was mowing, in accordance with the findings of previous studies on crop border maintenance strategies (Chaudron et al. 2016b; Milsom et al. 2004). This practice resulted in the smallest number of species losses between 2015 and 2017. Mowing was in this study the least disturbing practice because it is the only practice which is “non-destructive” because it lets the plant community in place, while increasing light availability, allowing less competitive species to establish (Schippers and Joenje 2002). This practice also contributes to nitrogen enrichment (Collins et al. 1998) because in this study area, when the practice is performed, litter is generally left on site, and organic matter decomposition is accelerated. Therefore, mowing seems to be the practice favoring the best cohabitation of plant species. Note, however, that mowing also favored annual weeds such as *Galium aparine* which has been reported to grow preferentially in frequently disturbed habitats (Fried et al. 2019).

4.2. Can maintenance practices influence water transport and seed retention through the modification of plant communities ?

The different maintenance practices led to the selection of plant communities with contrasting parameters and therefore had consequences for water transport and seed retention functions. Mowing favored communities with a high blockage factor, leading to increased Manning coefficient after two years (+63%), which means a decreased water conveyance ability after two years. This is explained by medium values of stem densities and quite high values of heights, and probably by an increased presence of plants with extended frontal areas compared to other practices in the studied ecosystem. However, for this practice, seed retention was medium (+31%) and did not differ significantly from the control, probably due to average stem densities. Burning favored communities with a low blockage factor (calculated at a depth of 60 cm). This is due to a low mean height of the community, although stem density was important, which makes burning a favorable practice for the conveyance of water (when the depth of water in the ditch is important). Burning led to low seed retention (due to the low mean height of the community again), and makes this practice unsuitable for weed dispersal limitation. In contrast, dredging and chemical weeding favored plants with the same functional traits as those in the control, and had generally no significant effects on the studied functions, although chemical weeding increased seed retention by 41% in 2017.

Except for the practice of dredging, the practices (mowing, chemical weeding and dredging) could be classified from the least disturbing practice (mowing) to the most disturbing practice (burning), with chemical weeding representing an intermediate disturbance between the two, based on the gradient of resulting mean height of the communities (CWM). The level of competition for light might have been higher in the mowed and chemically weeded quadrats than in burned quadrats. The level of disturbance caused by dredging in the study was difficult to assess. Indeed, this practice completely removes the plant community in place (Levasseur et al. 2014 ; Dollinger et al. 2015), as well as the seed bank, and was therefore considered in the first place as the most disturbing practice. However, results regarding this practice were difficult to interpret. Indeed, due to the removal of all the vegetation material in place, it seems that the variability of the resulting community is really important between quadrats, compared to other practices. The resulting plant community is probably largely explained by factors such as the dispersal of seed through water, wind, machinery and animals, rather than by the practice itself. We therefore conclude that the results regarding the effect of this specific practice of dredging can't be extended to other networks of Mediterranean ditches.

Another interesting aspect of this study is the focus on plant height that is both a response and effect trait (because it is used in the calculation of blockage factor and surface area ratio). The mean height in the plant communities is affected by the degree of disturbance caused by the different practices. In turn, height influences the ecosystem by modifying hydraulic transport capacity and seed retention in the medium term (two years). Therefore, response-effect linkages (Lavorel and Garnier 2002) can be observed in the present study as traits involved in response to disturbances such as maintenance practices (plant height) are also involved in water transport regulation and seed retention functions. This linkage might indicate the existence of medium-term retroactive loops between the type and frequency of maintenance practices, the response of the plant community, and the effects on ecosystem processes, which could ultimately influence the frequency of maintenance operations subsequently performed in the ditch. In this sense, burning favors a plant community composition allowing good water conveyance (when high water depths are present in the ditch), and may therefore decrease the frequency of subsequent maintenance operations. This linkage was especially observable in the study for burning, because the mean height of the community was the key factor explaining the level of resulting indicators of hydraulic functions (we remind that the blockage factor and surface area ratio depend mainly on heights, densities, and frontal areas) ; however, it seemed less clear for mowing and chemical weeding.

4.3. Homogenization effects between quadrats : Interannual climatic variability, duration of the experiment and fluxes of matter from adjacent landscape objects

In this study, in which we aimed to characterize the effect of maintenance strategies on plant community composition, the “year” effect appeared to be as significant as the “treatment” effect. This year effect was especially clear for plant species richness. Spring 2017 was far rainier than spring 2015, with the appearance of semiaquatic species such as *Veronica anagallis-aquatica* in all treatments in 2017. Such year effects are commonly observed for weed richness and abundance in vineyards (see Fried et al. 2019).

This study was conducted for only two years (the medium term) but still highlighted significant differences in community composition among maintenance practices. Continuing the experiment over longer periods of time would most likely further promote the shift in plant community composition. Performing studies over a longer period of time would eliminate the persistent effects of past maintenance strategies that were not controlled. Such effects on plant community composition can persist for many years (Alignier et al. 2013).

However, in some Dutch studies, applying one type of maintenance practice over a longer period of time did not lead to increased differences in plant richness (Blomqvist et al. 2009; Kleijn et al. 2001; van Dijk et al. 2013). Indeed, some limiting factors have been reported, such as soil nutrient status or limited recruitment from the seed bank. In our study, a source of relative homogeneity between quadrats may have been fluxes of agricultural inputs coming from the adjacent vineyard as was observed in Manhoudt et al. (2007). Moreover, in this experiment, we decided to arrange the 20 quadrats in succession in the same ditch to guarantee homogeneous environmental conditions. Although the quadrats were surrounded by unmanaged buffers, this successive arrangement may have facilitated fluxes of matter (for example, seeds) towards downstream quadrats, enhancing the homogeneity between quadrats.

4.4. Consequences for maintenance strategies

Currently, farmers, the main managers of agricultural ditches, are required to promote practices allowing good management of water transport (to limit erosion and overflows),the conservation of biodiversity (Blomqvist et al. 2003, 2009) and the limitation of weed dispersal (Rudi et al., 2018a). The results of this study provide insights into how to manage ditches at the catchment level.

At the catchment level, mowing seems to be a good practice for managing the upstream ditch network, where the hydraulic resistance engendered by plant communities is important for slowing water velocity and limiting erosion (ditch bank erosion is generally higher in headwater catchments than downstream of the network due to steeper slopes). Burning, as it favors an optimal water conveyance with high depths of water can be used in the downstream catchment where levels of water are usually higher due to lower slopes and concentration of the catchment waters at the level of the outlet. In terms of limitation of weed dispersal, mowing promotes a medium seed retention (+31% between 2015 and 2017). It also enhances biodiversity in the specific place where this practice has been applied, due to this good retention of floating seeds, and promotes high richness. However, it does not favor plant material circulation through the network.

We thus conclude that trade-offs between functions must be found, according to the location and desired goal on the ditch network (Dollinger et al. 2017; Vinatier et al. 2018). Future studies should focus on assessing these associations of maintenance operations in time and in space (considering higher levels of organization such as the ditch network) in order to confirm their potential relevance for the optimization of different ecosystem functions provided by ditches.

Furthermore, the data collected on maintenance practices effects on water transport regulation and seed retention could be of interest for revegetation procedures led in the field of ecological engineering. For example, Rey et al. (2019) expressed the need to fill plant species databases with information about species suitable for regulating water and soil resources.

5. Conclusion

Our study highlighted the influence of maintenance practices on ditch plant community composition in the medium term (two years between 2015 and 2017), and especially focused on the associated modifications of plant traits and resulting community functional parameters associated with water transport regulation and seed retention. Burning resulted in vegetation communities associated with high water conveyance (when the water depth is 60 cm) and low seed retention (-33% in seed retention between 2015 and 2017), and a medium resulting plant species richness (approximately 19 in 2017). Mowing resulted in a low water conveyance ability of the plant community (+63% in Manning coefficient), and a medium seed retention ability (+31%), and had a clear effect on the species richness of the plant communities after two years of experiment (approximately 25 in 2017). Chemical weeding did not differ significantly from the control in terms of studied traits and parameters, but presented an increased seed retention ability of 41% after two years. Except for dredging, the studied practices could be classified from the least disturbing practice (mowing) to the most disturbing practice (burning), with chemical weeding representing an intermediate disturbance between the two, based on the resulting mean height of the communities (CWM), decreasing from mowing to burning. The results obtained for dredging were considered as non-interpretable, because this practice removes all the community and seed bank in place, and the resulting community after two years was probably mainly the result of dispersal processes, rather than the result of this specific maintenance practice. This study paves the way for optimal management of ditches based on the identification of ditch ecosystem functions affected by the different maintenance practices in the medium-term.

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Appendix A : List of plant species collected in april 2015 and april 2017 in the ditch of Alignan-du-Vent (34). The table presents the ratio of ditch surface covered by each species according to the maintenance practice.

	2015					2016					2017				
	control	burned	chemically weeded	dredged	mowed	control	burned	chemically weeded	dredged	mowed	control	burned	chemically weeded	dredged	mowed
Althea cannabina	-	-	-	-	-	-	0,006	-	-	-	-	-	-	-	-
Anagallis arvensis	-	-	-	-	-	-	-	-	-	-	-	-	0,004	-	-
Avena sterilis	0,03	0,037	0,043	0,013	0,016	0,018	0,01	0,006	0,004	0,063	-	0,005	0,004	0,003	0,007
Borago officinalis	-	-	-	-	-	-	-	-	-	-	-	0,002	-	-	-
Bromus arvensis	-	-	-	-	-	-	0,003	-	0,004	0,024	-	-	-	-	-
Calendula officinalis	-	0,005	-	-	-	-	-	-	-	-	-	-	-	-	-
Cardamine hirsuta	-	-	-	-	-	-	-	-	-	-	0,018	0,002	0,051	-	0,011
Carduus pycnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	0,001	0,003	0,001
Carduus sp	-	-	-	-	-	-	-	-	-	-	-	-	0,001	-	0,004
Cirsium vulgare	-	-	-	-	-	-	-	0,012	-	-	-	-	0,009	-	-
Convolvulus arvensis	-	-	-	-	-	0,003	0,193	0,561	0,04	0,056	0,002	-	-	-	-
Conyza canadensis	-	-	-	-	-	-	-	-	-	-	-	0,002	-	-	-
Crepis capillaris	0,025	0,005	0,014	0,009	0,012	-	-	-	-	-	0,005	0,002	0,028	0,016	0,037
Crepis sancta	-	-	-	-	-	-	-	-	-	-	0,009	0,008	0,035	0,014	0,01
Daucus carota	0,106	0,069	0,072	0,093	0,098	-	-	-	0,018	0,004	0,007	0,006	-	0,003	0,014
Diplotaxis erucoides	0,02	0,032	0,029	0,018	0,027	-	0,016	0,071	0,004	-	0,007	0,029	0,061	0,011	0,022
Diplotaxis tenuifolia	-	-	-	-	-	-	0,019	-	0,004	0,004	-	0,005	-	-	-
Dipsacus sylvestris	-	-	-	-	-	-	-	0,006	0,033	-	-	-	0,001	-	-
Elytrigia repens	0,477	0,405	0,489	0,367	0,37	0,19	0,193	0,071	0,176	0,04	0,06	0,018	0,019	-	0,018
Equisetum ramosissimum	0,08	0,165	0,092	0,199	0,183	0,046	0,032	0,048	-	0,239	0,526	0,463	0,435	0,599	0,351
Erodium malacoides	0,005	-	0,01	0,004	0,004	-	-	-	-	-	0,005	0,01	0,013	0,014	0,016
Euphorbia helioscopia	-	0,005	0,005	-	0,004	-	-	-	-	-	0,002	-	0,004	0,005	0,003
Fumaria officinalis	-	-	-	-	-	-	-	-	-	-	-	-	0,003	-	-
Galium aparine	0,01	0,016	0,048	0,004	0,019	-	-	-	-	-	0,007	-	-	-	0,034
Galium mollugo	-	-	0,019	-	0,004	-	0,013	0,024	-	-	-	-	0,013	-	-
Galium verum	-	-	-	-	-	0,024	0,189	0,036	0,04	0,088	0,011	0,096	0,016	0,019	0,005
Geranium molle	-	-	-	-	-	-	-	-	-	-	-	-	-	0,005	0,003
Hordeum murinum	0,015	0,011	0,014	-	-	-	-	-	-	-	-	-	-	0,005	0,001
Hypericum perforatum	-	-	-	-	-	-	-	-	0,011	-	-	-	-	-	-
Knautia arvensis	-	-	-	-	-	0,037	-	-	0,015	0,024	-	0,006	-	0,005	0,012
Lactuca serriola	-	-	-	-	-	-	-	-	-	-	0,005	0,003	0,028	0,005	0,007
Lamium amplexicaule	-	-	-	-	-	-	-	-	-	-	-	-	0,015	0,005	0,001
Lamium purpureum	-	-	-	-	-	-	-	-	-	-	-	0,002	0,003	-	0,004
Lathyrus cicera	-	-	0,005	-	-	-	-	-	-	-	-	0,002	-	-	-
Lolium multiflorum	-	-	-	-	-	-	-	-	-	-	0,014	-	-	0,008	0,007
Lythrum hyssopifolia	0,186	0,186	0,077	0,186	0,218	0,12	0,006	0,107	0,194	0,059	0,043	0,005	0,017	0,052	0,005
Lythrum salicaria	-	-	-	-	-	0,003	-	-	0,011	0,016	0,005	-	-	0,011	-
Malva sylvestris	-	-	-	-	-	-	0,022	0,018	-	0,032	-	-	-	0,014	0,01
Medicago sativa	-	-	-	-	-	-	-	-	-	-	-	0,01	-	-	0,027
Mentha suaveolens	-	-	-	-	-	0,065	-	-	0,15	0,063	0,161	0,003	-	0,025	0,04
Mercurialis annua	0,005	0,037	0,019	0,022	0,008	-	-	-	-	-	0,002	-	0,02	0,003	0,001
Picris echioides	-	-	-	-	-	-	0,032	0,012	0,007	-	0,005	0,206	0,058	0,055	0,157
Picris hieracioides	-	-	-	-	-	-	0,122	-	0,004	-	0,009	0,006	-	0,003	0,001
Plantago lanceolata	-	-	-	-	-	0,037	0,071	-	0,051	0,108	0,005	0,034	-	0,014	0,03
Potentilla reptans	-	-	-	-	-	-	-	-	-	-	0,011	0,027	-	0,019	-
Rubus fruticosus	-	-	-	-	-	0,006	-	-	-	-	0,005	-	0,001	-	-
Rumex crispus	-	-	-	-	-	-	-	-	-	-	0,002	0,002	-	-	0,001
Senecio vulgaris	-	-	-	-	-	-	-	-	-	-	-	0,005	0,031	0,008	0,03
Setaria viridis	-	-	-	-	-	-	-	-	-	-	-	-	0,07	-	-
Silene pratensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,005
Sonchus asper	0,02	0,011	0,01	0,026	0,004	-	-	-	-	-	0,002	-	0,006	-	0,012
Sonchus oleraceus	-	-	-	-	-	0,015	0,068	0,006	0,081	0,08	0,002	0,002	0,017	0,003	0,003
Stellaria media	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,001
Taraxacum sp	-	0,005	0,01	0,004	-	-	-	-	-	-	-	-	-	-	-
Torilis arvensis	-	-	-	-	-	0,43	-	0,024	0,15	0,1	0,051	0,018	0,01	0,005	0,015
Trifolium dubium	-	-	-	-	-	-	-	-	-	-	-	0,005	0,004	-	0,063
Trifolium pratense	-	-	-	-	-	-	-	-	-	-	-	0,002	-	-	-
Valerianella locusta	0,01	0,005	0,01	0,026	0,016	-	-	-	-	-	-	-	-	-	-
Verbascum blattaria	-	-	-	-	-	-	-	-	0,004	-	-	-	-	-	-
Veronica anagallis aquatica	-	-	-	-	-	-	-	-	-	-	0,009	0,006	0,015	0,022	0,007
Veronica persica	0,005	-	0,024	0,026	0,016	-	-	-	-	-	-	-	0,001	-	0,004
Vicia lutea	-	-	-	-	-	-	-	-	-	-	0,009	0,002	0,001	0,025	0,018
Vicia sativa	0,005	0,005	0,01	-	0,004	0,006	0,003	-	-	-	0,002	0,008	-	0,019	-

Appendix B. Relationships between vegetation effect traits (blockage factor and surface vegetation area) and response trait (vegetation height) and stem density in the 20 quadrats managed with 5 different treatments (control, mowing, chemical weeding, burning and dredging)

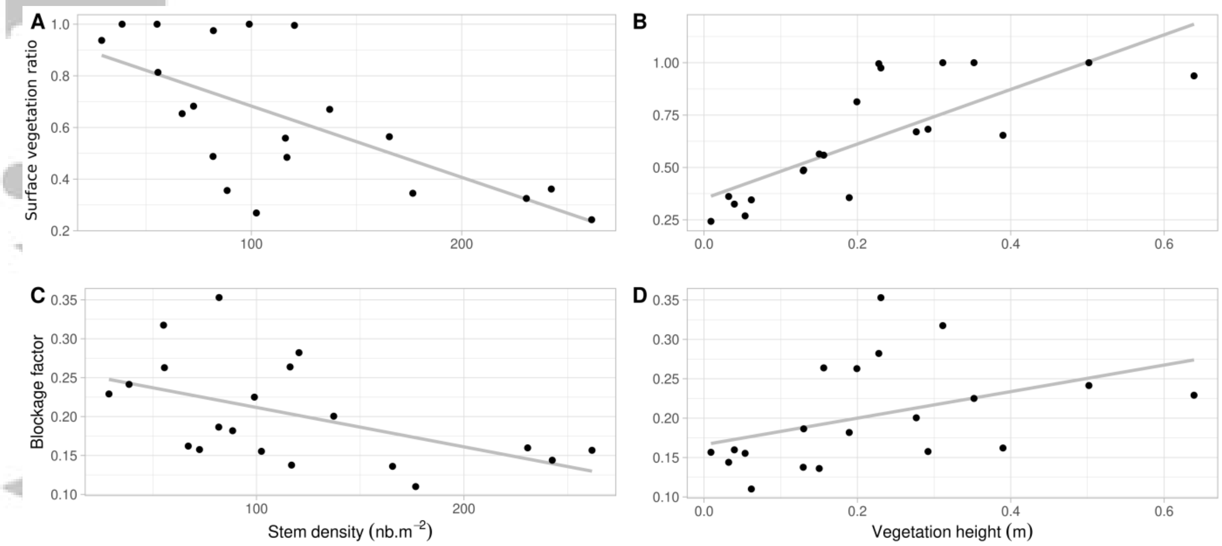


Figure B1: Response and effects traits for the 20 quadrats. All relationships were significant using Spearman's correlation coefficient (A: Rho = -0.67, d.f.= 18, P=0.001; B: Rho=0.77, d.f.=18, P<0.001; C: Rho=-0.56, d.f.=18, P=0.01; D: Rho=0.6, d.f.=18, P=0.006)

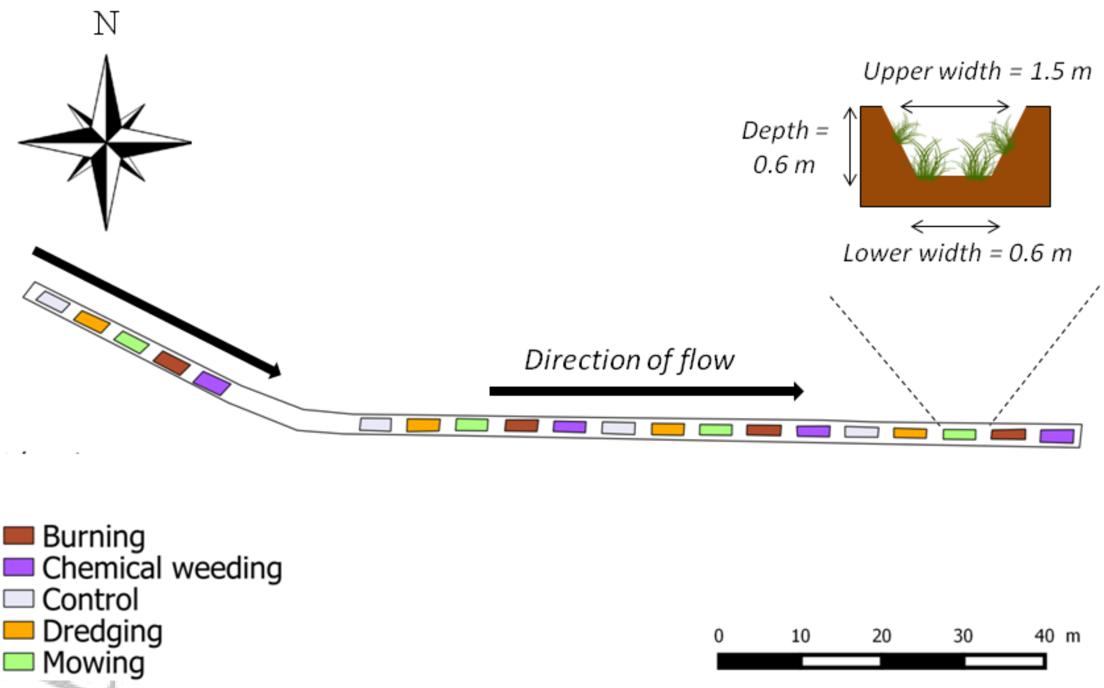


Figure 1: Schematic illustration of the experimental setup. Five treatments were applied to the studied ditch : mowing, burning, chemical weeding, dredging, and a control. Each of these treatments was replicated four times.

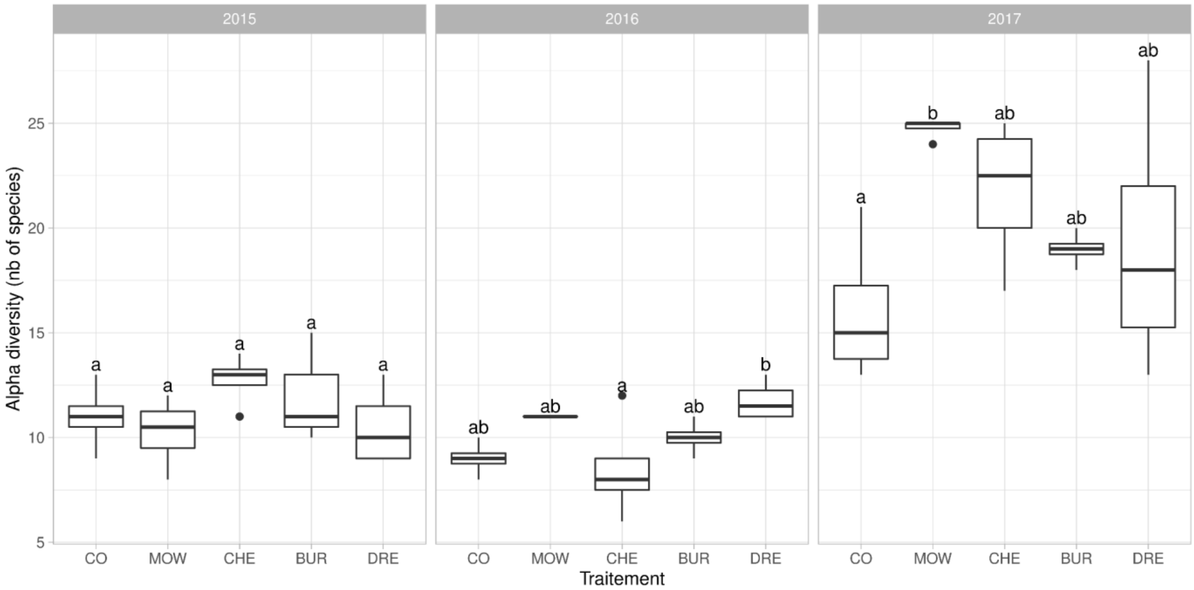


Figure 2 : Box-and-whisker plot of the plant species richness (alpha-diversity) for each year of the experiment and for each treatment (CO: control, MOW: mowing, CHE: chemical weeding, BUR: burning, DRE: dredging). Horizontal line: median. Box margins: 25th and 75th percentiles. Outliers are plotted individually. Letters represent the results of Tukey's all-pair comparisons between treatments.

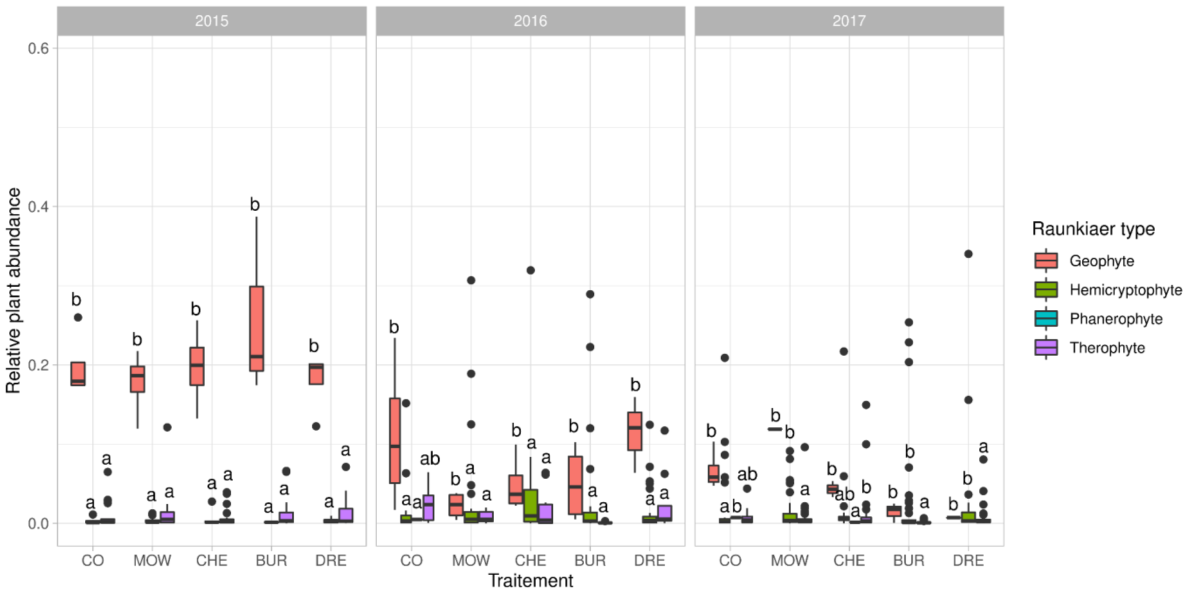
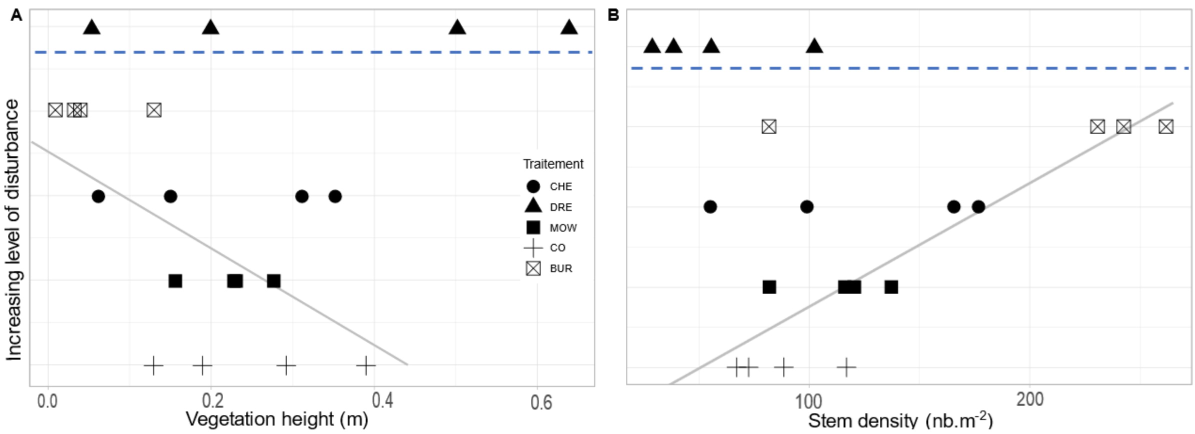


Figure 3. Box-and-whisker of the relative plant abundance per Raunkiaer types for each year of the experiment and for each treatment (CO: control, MOW: mowing, CHE: chemical weeding, BUR: burning, DRE: dredging). Horizontal line: median. Box margins: 25th and 75th percentiles. Outliers are plotted individually. Vertical bars indicate the standard errors. Letters represent the results of Tukey's all-pair comparisons between treatments.



Nb : Dredging has been excluded from the regression analysis and regression line, but results are displayed on the top of the picture (triangles)

Figure 4. Mean vegetation height and stem density according to different levels of disturbance caused by maintenance practices (CO: control, MOW: mowing, CHE: chemical weeding, BUR: burning, DRE: dredging). Note that the values for y-axis have been determined arbitrarily based on our hypotheses of classification of disturbance caused by the different practices.

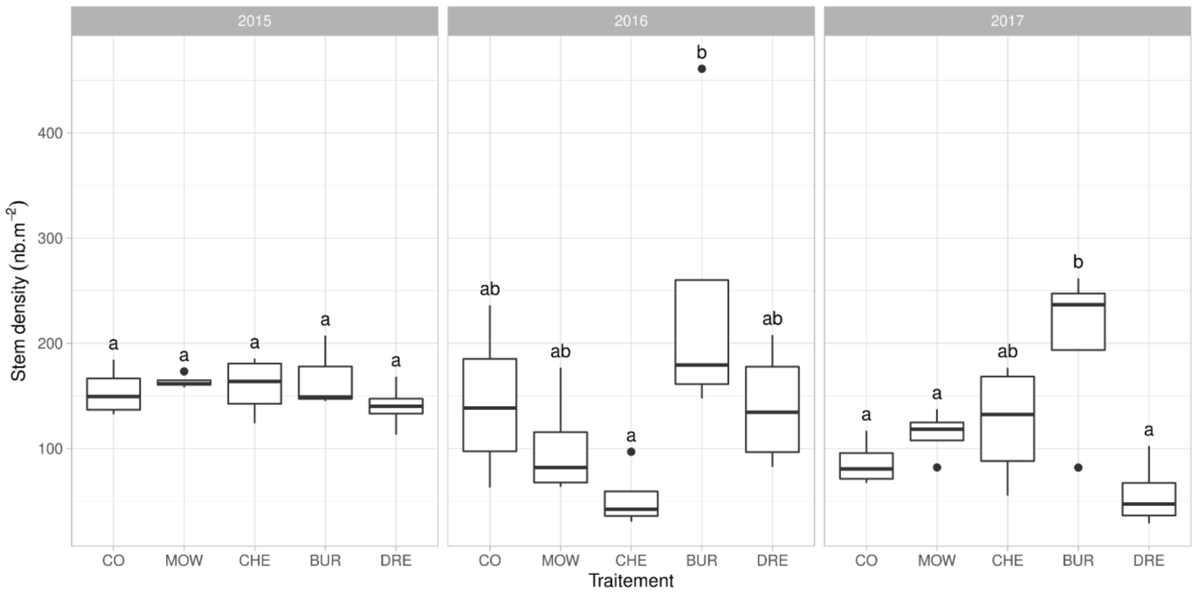


Figure 5: Box-and-whisker plot of the stem densities for each year of the experiment and for each treatment (CO: control, MOW: mowing, CHE: chemical weeding, BUR: burning, DRE: dredging). Horizontal line: median. Box margins: 25th and 75th percentiles. Outliers are plotted individually. Vertical bars indicate the standard errors. Letters represent the results of Tukey's all-pair comparisons between treatments.

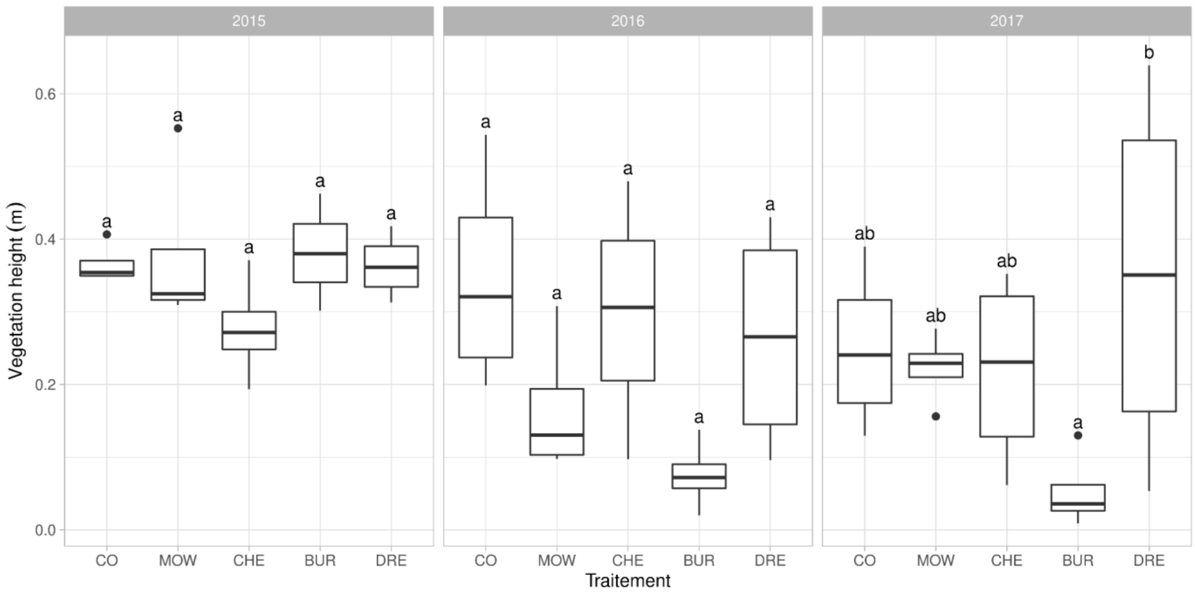


Figure 6: Box-and-whisker plot of the vegetation height (CWM) for each year of the experiment and for each treatment (CO: control, MOW: mowing, CHE: chemical weeding, BUR: burning, DRE: dredging). Horizontal line: median. Box margins: 25th and 75th percentiles. Outliers are plotted individually. Vertical bars indicate the standard errors. Letters represent the results of Tukey’s all-pair comparisons between treatments.

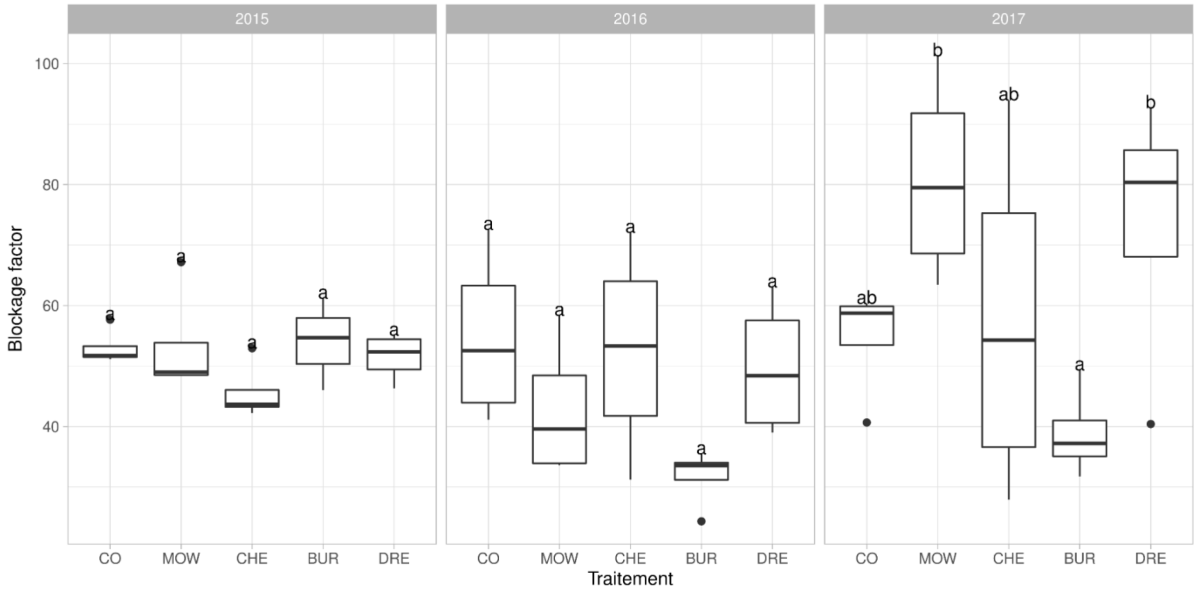


Figure 7**:** Box-and-whisker plot of the blockage factor (CWM) for each year of the experiment and for each treatment (CO: control, MOW: mowing, CHE: chemical weeding, BUR: burning, DRE: dredging). Horizontal line: median. Box margins: 25th and 75th percentiles. Outliers are plotted individually. Vertical bars indicate the standard errors. Letters represent the results of Tukey's all-pair comparisons between treatments.

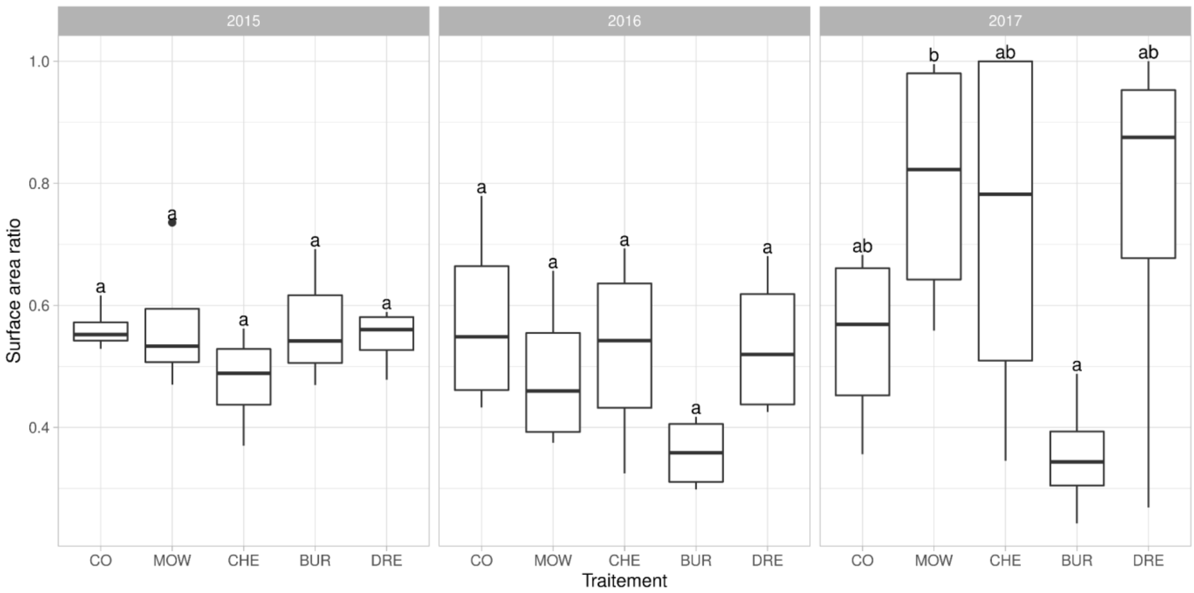


Figure 8: Box-and-whisker plot of the CWM for surface vegetation ratio (SVr) for each year of the experiment and for each treatment (CO: control, MOW: mowing, CHE: chemical weeding, BUR: burning, DRE: dredging). Horizontal line: median. Box margins: 25th and 75th percentiles. Outliers are plotted individually. Vertical bars indicate the standard errors. Letters represent the results of Tukey's all-pair comparisons between treatments.

Table 1: Completion dates for the four maintenance operations : mowing, burning, chemical weeding and dredging. Each of these operations was applied to four of the 20 quadrats. The four remaining quadrats were controls.

Mowing	**Burning**	**Chemical weeding**	**Dredging**
June 2015 September 2015 June 2016	April 2015 February 2016	April 2015 April 2016	April-May 2015

Table 1: Gain in % of two vegetation properties (CWM) and their corresponding hydraulic parameters regarding water transport (Manning n) and seed retention (Rr) between the beginning of study (2015) and after contrasting maintenance practices (2017).

	Blockage factor (Bf) (%)	Manning (n) (%)	Surface vegetation ratio (SVr) (%)	Seed retention (Rr (%)
CO: control	5	3	-3	-3
MOW: mowed	80	63	41	31
CHE: chemically weeded	41	24	52	41
BUR: burned	5	3	-38	-33
DRE: dredged	52	34	38	29