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# Perennial rhizomatous grasses: Can they really increase species richness and abundance in arable land?—A meta-analysis

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**Abstract**

Perennial rhizomatous grasses (PRG), such as miscanthus and switchgrass, are considered promising lignocellulosic feedstocks. Their cultivation is expected to experience a significant increase in the near future, as it offers a wide range of benefits. For instance, when PRG replace typical annual crops, positive biodiversity impacts are usually anticipated. However, to date, there is no solid, statistically strong evidence for this hypothesis. This study aims to evaluate its validity through a meta-analysis based on an extensive systematic literature review of research comparing biodiversity attributes in PRG and common annual crops. Dynamics of species richness and abundance in response to PRG cultivation were quantitatively evaluated drawing on 220 paired comparisons from 25 studies. This includes data on five taxonomic groups—arthropods, birds, earthworms, mammals and plants—and three PRG—miscanthus, switchgrass and reed canary grass. The results indicate that biodiversity tends to be higher in PRG cultivations relative to the reference crops, but the initial hypothesis of significantly beneficial impacts could not be confirmed. Trends were specific to the individual taxonomic groups: significantly higher biodiversity was found for plants and small mammals. Positive but insignificant trends were observed for arthropods and birds, while earthworm response was neutral and insignificant. More substantial conclusions could not be drawn, which is mainly due to the low number of studies conducting biodiversity assessments in PRG cultivations that included a comparison with annual crops. In addition, a detailed analysis of the observed responses was impaired by poor reporting of the parameters influencing biodiversity in the studies reviewed, such as planting and crop density, as well as yields. For this reason, we conclude with a call for improved data reporting in biodiversity assessments of PRG cultivations and detail requirements for future biodiversity research.

**KEYWORDS**

abundance, biodiversity, meta-analysis, miscanthus, perennial biomass crop, reed canary grass, species richness, switchgrass

Jan Lask and Elena Magenau should be considered joint first author.

# 1 | INTRODUCTION

Perennial biomass crops are considered a promising resource to meet the growing demand for biomass in a developing global bioeconomy. Perennial rhizomatous grasses (PRG) such as miscanthus and switchgrass (*Panicum virgatum* L.) are receiving increasing attention from industry due to their versatile applications and high-yield potentials. The cultivation of these crops is expected to experience a significant increase in the near future, as they have numerous benefits. For instance, they can provide rewarding yields in a wide range of climatic and soil conditions, including marginal agricultural land (Clifton-Brown et al., 2017; Lewandowski et al., 2016). Their fertilizer and pesticide demand is low compared to annual crops due to efficient nutrient recycling and the absence of major pests (Kiesel, Wagner, & Lewandowski, 2017; van der Weijde et al., 2013). Previous research has demonstrated economic and ecological advantages of PRG cultivation (Kiesel et al., 2017; McCalmont et al., 2017; Wagner et al., 2018), in particular when integrated along field margins and on marginal lands (Ferrarini, Serra, Almagro, Trevisan, & Amaducci, 2017; Manning, Taylor, & Hanley, 2015). It is concluded that these crops could be produced sustainably without affecting global food supply and even decrease pressure on planetary boundaries such as climate change and other biogeochemical processes of the Earth system (Steffen et al., 2015).

The functioning of ecosystems and the provision of related services depends strongly on biodiversity and is endangered by species losses at local and wider scales (Gamfeldt & Roger, 2017). In general, intensive agricultural production is associated with negative effects on biodiversity (Ceballos et al., 2015; Flohre et al., 2011). Lower impacts are usually reported for lignocellulosic second-generation than for first-generation bioenergy crops. Research commonly indicates that PRG cultivation substantially improves agro-biodiversity at the field scale, if replacing typical annual crops such as maize and wheat (Dauber, Jones, & Stout, 2010; Dauber & Miyake, 2016; Immerzeel, Verweij, van der Hilst, & Faaij, 2014). Cultivation periods of up to 20 years which ensure extended soil rest, harvest in late winter or early spring as well as low input requirements are considered conducive to species richness and abundance, features commonly regarded as biodiversity attributes (Dauber et al., 2010). This assumption is usually based on studies which focus on single taxonomic groups (e.g. plants, mammals) and species (e.g. hares, butterflies; Haughton et al., 2016; Petrovan, Dixie, Yapp, & Wheeler, 2017; Semere & Slater, 2007a) and a small number of reviews which qualitatively examined effects of PRG cultivation on species richness and abundance (Dauber et al., 2010; Immerzeel et al., 2014). However, a few studies also indicate neutral (Bellamy et al., 2009; Clapham & Slater, 2008; Felten & Emmerling, 2011; Semere & Slater, 2007a; Stanley & Stout, 2013) or even negative effects on individual taxa (Briones, Elias, Grant, & McNamara, 2019; van der Hilst et al., 2012; Williams & Feest, 2019). The literature commonly suggests and expects positive biodiversity effects for the replacement of annual cropping systems with PRG cultivation. However, solid, statistically strong evidence for this is still lacking. The present study aims to evaluate the validity of this hypothesis through a meta-analysis of available data. The dynamics of species richness and abundance in response to PRG cultivation were quantitatively assessed as this provides an objective mean of testing the potential effects of PRG cultivation on biodiversity. This aids a better understanding of the biodiversity changes associated with a switch from classic arable crops to PRG cultivation and improves the interpretation of existing biodiversity assessments.

A meta-analysis was conducted based on an extensive systematic literature review of studies comparing biodiversity components in PRG and common annual crops. It drew on 220 paired comparisons from 25 publications analysing the response of species richness, abundance and diversity indices. This was done for five taxonomic groups—arthropods, birds, earthworms, mammals and plants—which have a predominant role in biodiversity assessments globally. Based on the assumptions from previous research, in particular the qualitative syntheses, we hypothesized significantly increased biodiversity for PRG cultivation when replacing annual arable crops.

# 2 | MATERIALS AND METHODS

## 2.1 | Data collection

Data were collected using the literature databases, Google Scholar (https://scholar.google.de/) and Scopus (https://www.scopus.com/). We identified potentially relevant journal articles, dissertations and master theses using 10 search terms, which combined keywords for common PRG crops with biodiversity key terms and five taxonomic groups. The search terms are given in Appendix 1. For the analysis, we selected only data from studies which were based on field experiments (not, e.g., pot experiments), compared PRG and annual arable crops in similar environments and investigated at least one of the biodiversity attributes 'species richness' (number of different species), 'abundance' (number of individuals) and 'diversity indices' (combination of species number and evenness of their abundance e.g. Shannon-Wiener and Simpson).

In total, 25 studies were selected from the initial set of 1,874 studies (2,259 prior to duplicate removal), which resulted from the search-term-based literature research. These are presented in Table 1. From the selected studies, we collected data on means, standard errors/deviation, and sample size for the biodiversity attributes species richness, abundance and diversity indices. If available, information on site and plantation characteristics was also considered and coded

**TABLE 1** Studies included in meta-analysis

| No. | Study | Arthropods | Birds | Earthworms | Mammals | Plants |
|---|---|---|---|---|---|---|
| 1 | Bellamy et al. (2009) | x | x | x | | x |
| 2 | Berkley et al. (2018) | x | | | | x |
| 3 | Blank et al. (2014) | | x | | | |
| 4 | Bourke et al. (2014) | x | | | | x |
| 5 | Bright et al. (2013) | | x | | | |
| 6 | Briones et al. (2019) | | | x | | |
| 7 | Chauvat, Perez, Hedde, and Lamy (2014) | x | | | | |
| 8 | Clapham (2011) and Clapham and Slater (2008) | | x | | x | |
| 9 | Emmerling (2014) | | | x | | |
| 10 | Feledyn-Szewczyk, Matyka, et al. (2019) and Feledyn-Szewczyk, Radzikowski, et al. (2019) | | | x | | x |
| 11 | Felten and Emmerling (2011) | | | x | | |
| 12 | Harrison and Berenbaum (2013) | x | | | | |
| 13 | Hedde, van Oort, Renouf, Thénard, and Lamy (2013) and Hedde, van Oort, Boudon, Abonnel, and Lamy (2013) | x | | x | | |
| 14 | Helms, Ijelu, Wills, Landis, & Haddad (2020) | x | | | | |
| 15 | Heyer, Deter, Eckstädt, and Reinicke (2018) | x | | | | |
| 16 | Kaczmarek et al. (2018) | | x | | | |
| 17 | Kempski (2013) | x | | | | |
| 18 | Korpela, Hyvönen, Lindgren, and Kuussaari (2013) | x | | | | |
| 19 | Sage et al. (2010) | | x | | | |
| 20 | Schwer (2011) | | | | x | |
| 21 | Stanley and Stout (2013) | x | | | | x |
| 22 | Vepsäläinen (2010) | | x | | | |
| 23 | Ward and Ward (2001) | x | | | | |
| 24 | Werling et al. (2014) | x | x | | | x |
| 25 | Williams and Feest (2019) | x | | | | |
| | Total per taxonomic group | 14 | 8 | 6 | 2 | 6 |

as moderators to consider differences between studies. Data were taken from text and tables in the main manuscript or supplementary material. Additionally, values were extracted from figures using the GetData Graph Digitizer version 2.26 (http://getdata-graph-digitizer.com/).

## 2.2 | Data description

Overall, 25 studies published between 2001 and 2020 were considered. All of them assessed biodiversity attributes in Europe and the United States and focused mainly on the perennials miscanthus and switchgrass. While miscanthus was mostly studied in Europe, switchgrass was the predominant research object in the United States. Reed canary grass featured in only three studies. Maize and wheat were the annual crops mainly used as reference, irrespective of the location.

The studies assessed five taxonomic groups—arthropods, birds, earthworms, mammals and plants. Comparisons of arthropod abundance in PRG and annual arable crops were contained in 14 of the studies, making this the most widely investigated taxonomic group under consideration. More than half of the selected studies were published in 2013 and 2014.

The PRG cultivation data consisted mainly of miscanthus (75%) and switchgrass (22%), with the remaining data relating to reed canary grass. Substantial differences in collection approaches were found between studies. Two groups were distinguished: First, the collection of non-ground-dwelling arthropods, which were trapped by sweep net sampling, pan traps, bucket traps and sticky cards. Second, the collection of ground-dwelling arthropods, trapped by pitfall traps and soil cores.

Abundance and richness of birds was reported in eight studies published between 2006 and 2015. Four studies alone were conducted in the United Kingdom. The remaining include one from Finland and Poland and two from the United States. Due to the predominantly European focus, most of the comparisons included had miscanthus (69%) as PRG. Similarly, earthworm biodiversity was assessed in six studies from Germany, France, the United Kingdom and Poland. Despite all being European, these studies, which were published between 2009 and 2019, included data on both miscanthus and switchgrass. Small mammal populations in PRG and annual crops were compared in only two studies, one from the United Kingdom comparing miscanthus and reed canary grass (Clapham, 2011) and the other from the United States focusing on switchgrass (Schwer, 2011). Data on plant species richness and abundance were reported in six studies, mainly with miscanthus as PRG. These studies were published between 2009 and 2019 and were located in Ireland, Poland, the United Kingdom and the United States.

## 2.3 | Data analysis

The effect of PRG cultivation on the biodiversity attributes 'species richness', 'abundance' and 'diversity indices' was quantitatively evaluated in accordance with Fletcher et al. (2011) and Hedges, Gurevitch, and Curtis (1999). We calculated response ratios (RR) for each comparison pair using Equation (1):

$$\mathrm{RR} = \ln\left(\frac{\bar{x}_{\mathrm{PRG}}}{\bar{x}_{\mathrm{ara}}}\right), \quad (1)$$

where $\bar{x}_{\mathrm{PRG}}$ and $\bar{x}_{\mathrm{ara}}$ denote means for each biodiversity attribute for PRG and annual arable crops respectively. The five taxonomic, as well as different sampling methods and years within a study, were each treated as separate comparison pairs.

Not all studies indicated standard errors and deviations. For this reason, the variance and weighting factors of the study-specific RRs were based on the number of locations (Hamman, Pappalardo, Bence, Peacor, & Osenberg, 2018; Núñez-Regueiro, Siddiqui, & Fletcher, 2019). The weighting factor $W$ was calculated by Equation (2):

$$W = \left[\frac{(N_{\mathrm{PRG}} * N_{\mathrm{ara}})}{(N_{\mathrm{PRG}} + N_{\mathrm{ara}})}\right], \quad (2)$$

where $N_{\mathrm{PRG}}$ and $N_{\mathrm{ara}}$ are the number of locations with PRG cultivation and annual arable crops respectively (Núñez-Regueiro et al., 2019). The mean weighted response ratio ($\mathrm{RR}_{++}$) was calculated from the RRs of individual pairwise comparisons between PRG and the reference, as given in Equation (3):

$$\mathrm{RR}_{++} = \frac{\int_{i=1}^{m}\int_{j=1}^{k} W_{ij}\mathrm{RR}_{ij}}{\int_{i=1}^{m}\int_{j=1}^{k} W_{ij}} \quad (3)$$

The standard error of $\mathrm{RR}_{++}$ was estimated according to Equation (4):

$$SE\left(\mathrm{RR}_{++}\right) = \sqrt{\frac{1}{\int_{i=1}^{m}\int_{j=1}^{k} W_{ij}}}. \quad (4)$$

The meta-analysis was conducted on two levels. First, for all data and second, separately for each taxonomic group. A multilevel random-effects model was fitted to account for the nonindependence of effect sizes due to the nested data structure (Bender, Contreras, & Fahrig, 1998; Konstantopoulos, 2011; Viechtbauer, 2010). The random-effects model assumes that studies are using distinct research methods and differ in their characteristics of response. $Z$-tests with a significance level of $p \leq .05$ were conducted to test the significance of the differences between PRG and annual crops. Heterogeneity of variance was analysed with the $I^2$ statistic, which describes the deviation between study results (Higgins & Thompson, 2002). We then tested the effect of different moderators including year, country, PRG type, annual arable crop type, and age group of PRG. Data were analysed by the metafor package (Viechtbauer, 2010) in the program R (R Core Team, 2019). The resulting data were displayed using the R package ggplot2 (Wickham, 2016).

# 3 | RESULTS

The following section presents the results for the responses of the biodiversity attributes species richness, abundance and diversity indices on PRG production. A positive response was found for the pooled taxonomic groups ($\mathrm{RR}_{++} = 0.31$; $SE = 0.18$; $p = .08$), indicating beneficial biodiversity impacts of PRG in comparison with annual arable crops (Figure 2). The response strength varied significantly with the type of biodiversity attributes. A significant response ($\mathrm{RR}_{++} = 0.40$; $SE = 0.20$; $p = .05$) was observed for abundance while richness and diversity indices showed positive, but nonsignificant, trends (Figure 1). Tendencies and significant responses are presented per taxonomic group and biodiversity attribute below.

For arthropods, the analysis presented a clear trend (Figure 1). Species richness, abundance and diversity indices showed higher figures in PRG than in annual arable crops. Although figures for non-ground-dwelling arthropods were lower than for ground-dwelling arthropods, RR were still positive, but differences between the groups were insignificant. For this reason, the results for arthropods are presented as a single value in Figure 1.

No significant responses were observed for birds. RR for abundance and diversity indices were close to zero (Figure 1), indicating similar biodiversity figures for PRG and annual crop cultivation. Only the RR of species richness was slightly higher than zero, but still insignificant. Earthworm abundance and species richness showed no significant difference between PRG cultivation and annual crops. The RR of species richness was close to zero across all studies. Abundance, including earthworm biomass and number of individuals, was slightly below zero with a decrease in biomass and an increase in number of individuals. Due to lack of data, no response was calculated for diversity indices. All RR for small mammals and plants, except plants indices, were consistently higher for PRG cultivation than for annual crops.

Data were heterogeneous for arthropods abundance and plant indices. When data of all taxonomic groups were pooled, positive $RR_{++}$ were observed for the individual PRG. Only for switchgrass a significant positive response was observed. In contrast, reference crop type (e.g. wheat, maize) had no effect. For plant diversity indices, only three comparison pairs were analysed. The age of the PRG cultivation

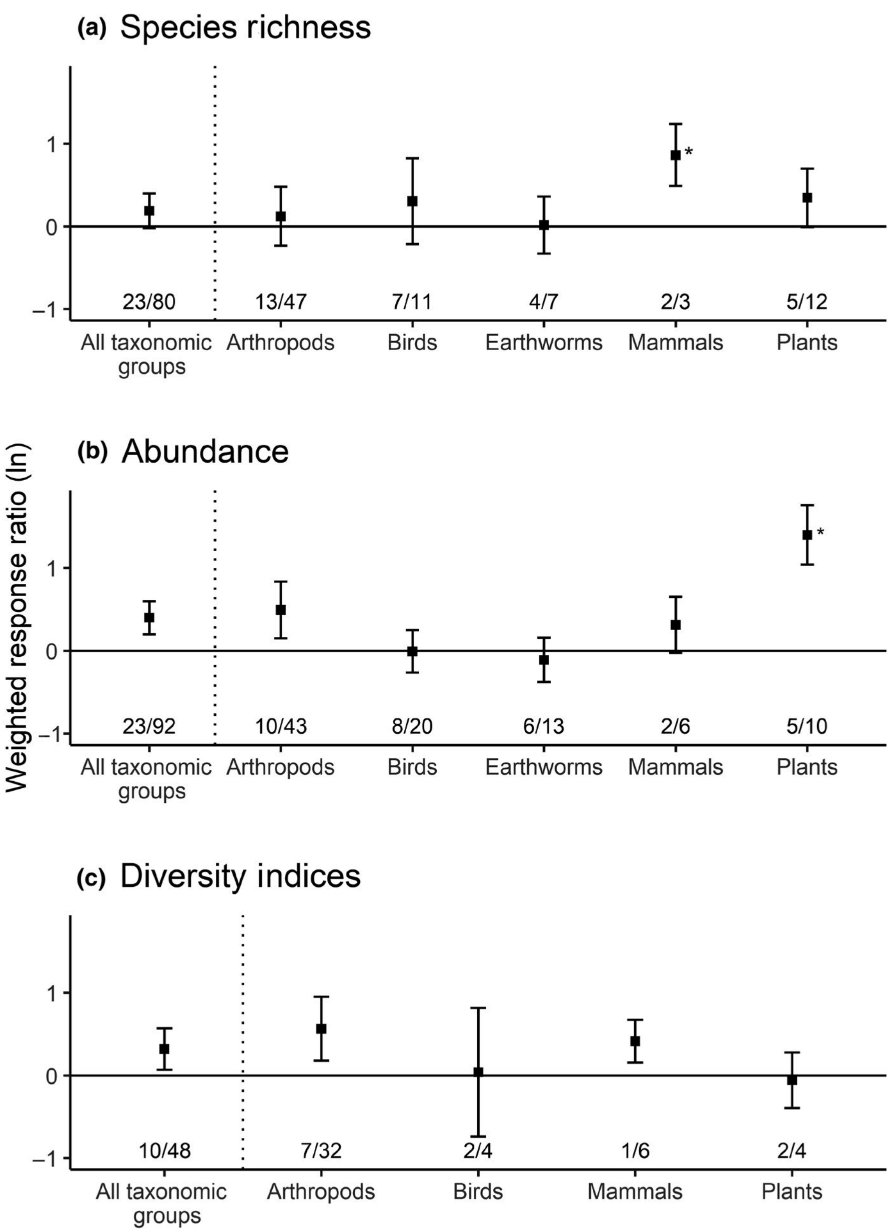


**FIGURE 1** Weighted response ratio of biodiversity attributes: (a) species richness, (b) abundance and (c) diversity indices for the comparison of perennial rhizomatous grasses (PRG) and annual arable crops. A response ratio above zero indicates a positive response to PRG cultivation. Bars indicate standard errors, *statistically significant ($p \leq .05$) response. Number of studies and paired comparisons considered given below

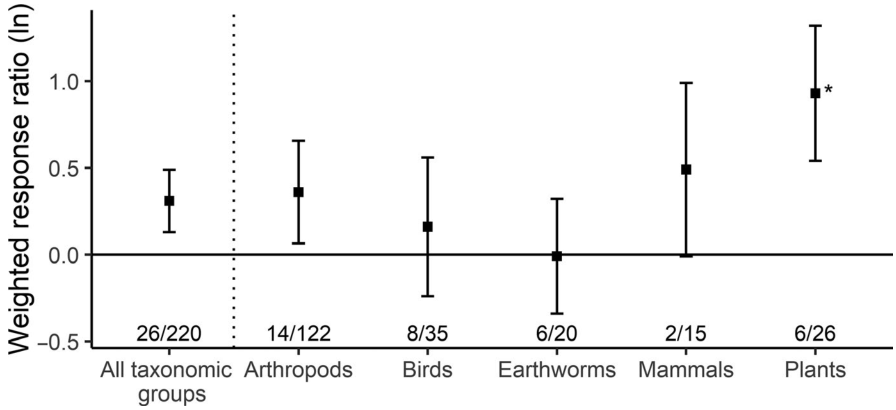


**FIGURE 2** Cumulated response of biodiversity impacts to cultivation of perennial rhizomatous grasses (PRG). A response ratio above zero indicates a positive response associated with PRG cultivation. Bars indicate standard errors, *statistically significant ($p \leq .05$) response. Number of studies and paired comparisons considered given below

under consideration also influenced the RR, significant higher biodiversity was found for cultivation ages between 3 and 6 years. For older stands, results indicated negative, but insignificant impacts. In addition, RR varied significantly with the taxonomic group, as shown in Figure 1.

Overall, RR varied slightly between the three biodiversity attributes. Abundance of PRG crops showed a positive trend compared to annual crops, while the response patterns of species richness and diversity indices were less clear. Differences between the biodiversity attributes were however insignificant except for small mammals and plants. With the attribute data pooled, significantly positive responses were observed for plants (Figure 2).

## 4 | DISCUSSION

This study collates quantitative data from a range of publications reporting on the comparison of biodiversity in PRG cultivation and common annual arable crops. It was hypothesized that PRG cultivation promotes a higher level of biodiversity, which can be quantified through the attributes 'species richness', 'abundance' and their combination in 'diversity indices'.

This initial hypothesis could not be confirmed. However, the results of the meta-analysis indicated that biodiversity tends to be higher (without statistical significance) in PRG cultivations relative to the reference situation. These trends are in line with results from previous research qualitatively assessing biodiversity impacts of PRG cultivation (Dauber et al., 2015; Immerzeel et al., 2014). The strength of the trends also varies between the taxonomic groups (partially significantly). For instance, abundance and species richness in small mammals and plants clearly benefitted from PRG cultivation, while earthworm biodiversity attributes showed no or even negative effects. Although the detected trends were consistent across the taxonomic groups, only a few of them were significant. Effects on species richness and abundance did not differ significantly between the considered PRGs (mainly miscanthus and switchgrass).

Unfortunately, it was not possible to draw more substantial conclusions due to the generally low number of studies conducting biodiversity assessments in PRG cultivations. In addition, such studies often do not provide information on the biodiversity status in annual crops which could be used as a reference (e.g. Robertson, Landis, Sillett, Loomis, & Rice, 2013; Semere & Slater, 2007b). Due to the site-specific nature of biodiversity, this information is however imperative to be able to assess and compare the actual impact of PRG cultivation. For this reason, 42 studies were rejected and only 25 studies were finally found eligible in accordance with the selection criteria.

In addition to site-specific aspects, biodiversity attributes are influenced by numerous factors related to the crop and its management (e.g. plant age, planting density, etc.). It was not possible to assess the impact of these factors on the response of the biodiversity attributes to PRG cultivation on arable land using the selected studies. Essential information for response interpretation is often absent or given in non-standardized form. This is a general concern in the biodiversity assessment of agricultural systems and has been previously criticized (Brown & Matthews, 2016; Gotelli & Colwell, 2001). The following section presents factors that can potentially influence biodiversity attributes in PRG cultivation but are not systematically reported in assessments, thus impeding a thorough analysis of studies on biodiversity in PRGs. We have classified these into three categories:

1. biomass yield, crop density and phenotype
2. landscape context
3. temporal issues.

The first category is related to information on biomass yield, which predominantly depends on climate and soil conditions but also on factors including planting density, crop establishment status, plant age and genotypic variation. As has been previously shown, these attributes strongly influence biodiversity potential in second-generation biomass crops and PRGs in particular (Dauber et al., 2015; Núñez-Regueiro et al., 2019). Biomass productivity is directly related to crop/canopy cover and the associated light interception. These factors are, however, negatively correlated with the abundance and richness of plant species in PRG cultivations (Bekewe, Castillo, & Rivera, 2019). As the canopy/crop cover increases over the years after establishment, plant species richness and abundance usually also decrease (Holguin et al., 2010). This highlights the importance of considering the entire life cycle of PRG cultivation when assessing species richness and abundance of plants. The majority of studies included in our assessment evaluated established PRG cultivations, potentially resulting in an underestimation of the benefits of PRG cultivation for plant biodiversity. In addition, planting density and crop establishment status should be assessed in order to enable comparisons of plant biodiversity in PRG cultivation. This is of particular importance, as noncrop vegetation in plantations can indirectly affect other organisms by serving as a food source and/or habitat. For instance, arthropod biodiversity is commonly interrelated with plant abundance and species richness. It has been found that species richness and abundance of ground beetles, butterflies and spiders are negatively correlated with yields and reduction of the noncrop vegetation (Dauber et al., 2015; Semere & Slater, 2007a). This emphasizes the importance of reporting data on PRG cultivation status, including phenotype and genotype (crop density/canopy cover) and could explain variation in values given in studies on arthropods in PRG cultivation, at least to a certain extent. In addition, it should be emphasized that most of the approaches for the quantification of biodiversity rely purely on species richness and abundance, while aspects such as rarity and endangerment are rarely considered.

Similar to arthropod and plant biodiversity, bird abundance appears to be related to the PRG phenotype, in particular plant height. It has been reported that, due to the provision of shelter and nesting sites, birds benefit from PRG cultivation in the first years after establishment in intensive farmland (Bellamy et al., 2009). However, for switchgrass, it has also been reported that bird abundance reaches a maximum at a crop height of 0.5–0.6 m (and a biomass yield of 3–4 t/ha, Blank, Sample, Williams, & Turner, 2014) and then decreases with increasing crop height. A negative correlation between bird abundance and miscanthus crop height was also reported by Bellamy et al. (2009). In contrast, Bright et al. (2013) did not find a significant correlation. Bird species richness is also affected by the PRG cultivation status. Typical field species such as corn bunting, skylark and starling generally prefer younger, poorly established PRG cultivations and avoid older, dense and well-established plantations. The latter are however, usually a preferred habitat for woodland species (Bellamy et al., 2009; Clapham, 2011; Kaczmarek, Mizera, & Tryjanowski, 2018). In the United Kingdom, PRG are preferred by woodland species (Bellamy et al., 2009; Clapham, 2011). However, in summer, more farmland bird were identified in PRG than in annuals crops by Bellamy et al. (2009) and in Poland, farmland species dominated in PRG (Kaczmarek et al., 2018). These aspects are often not addressed in enough detail in biodiversity assessments, and this can result in a change in species composition being overseen. Small mammals constitute the only group which clearly profit from denser biomass stands. It has been previously reported that vegetative cover is an important characteristic of habitat quality for small mammals. This is mainly due to its functions of predator protection and provision of nesting opportunities (Clapham and Slater, 2008).

When summarizing these first aspects, it should be emphasized that biodiversity assessments of PRG cultivations require more detailed information on the specific PRG setup in order to give clear indications. While the age of plants is reported in most studies, crop establishment success and crop/canopy density as well as yields are only rarely reported, despite their importance in evaluating the biodiversity attributes measured.

The second category of factors is mainly determined by aspects relating to the surrounding environment and the integration of PRG cultivation into the landscape. Biodiversity potentials vary depending on landscape, and this is also one reason why not all the five taxonomic groups assessed respond in a consistent way across locations and studies. For instance, it has been previously shown that the probability of observing grassland bird species declines with an increasing share of forest land cover (Robertson, Doran, Loomis, Robertson, & Schemske, 2011; Werling et al., 2014). In addition, the way in which PRG cultivation is integrated into the landscape affects habitat quality. Field size is an important parameter influencing biodiversity attributes in PRG cultivation. For example, the number of grassland birds has been found to be negatively correlated with field size, as dense PRG monocultures do not constitute a suitable habitat (Norment, Ardizzone, & Hartman, 1999). Similarly, miscanthus is not a food source for small mammals and these cannot thrive in areas densely planted with miscanthus. However, as a well-dosed complement to an agricultural landscape, miscanthus cultivation may provide biodiversity benefits by increasing refuge areas for mammals such as brown hares (Petrovan et al., 2017). Switchgrass seeds in comparison could also provide a food source for small mammals (Briones, Homyack, Miller, & Kalcounis-Rueppell, 2013). The integration of PRG as landscape elements, for example, the cultivation along field margins, could provide habitat and forage for birds and small mammals, resulting in high species richness in field edges (Clapham, 2011). These beyond-field impacts are commonly overseen in typical biodiversity assessments of PRG cultivation. The typical focus on species number often results in neglect of habitat specialists and endangered species in biodiversity evaluation. Taken together, this puts the focus on the concept of landscape moderation with the major goal of increasing crop heterogeneity in agricultural landscapes (Landis, 2017; Sirami et al., 2019; Tscharntke et al., 2012).

In addition to the two categories mentioned above, the influence of temporal issues, for example, seasonality, is commonly neglected in biodiversity reporting. This is despite the fact that evidence for seasonal changes has been observed in assessments on birds. Seen over the year, bird abundance is higher in poorly established than in well-established stands. However, well-established stands reveal higher bird abundance during the winter (Gardiner et al., 2010). Harvest dates can also be responsible for variation in biodiversity impact assessments. Miscanthus can be harvested in autumn or spring. The difference in harvest date has a direct influence on biodiversity, since an autumn harvest completely removes the winter cover for small mammals and birds. An early harvest can also result in a reduction of organic substance recycling and a reduced soil carbon input. It has been hypothesized that performing an autumn harvest over several consecutive years reduces both abundance and biomass of earthworm communities in miscanthus in comparison to a winter/spring harvest (Ruf & Emmerling, 2017).

The previous paragraphs outlined adjustments and further recording requirements for future biodiversity assessments of PRG cultivation. In addition, it should be emphasized that other relevant taxonomic groups are so far underrepresented in PRG biodiversity research. Our work provides a quantitative overview of potential PRG biodiversity impacts. We conclude that biodiversity can, in general, benefit from the replacement of annual crops by PRG, but this could not be proven statistically, due to data gaps in the PRG biodiversity impact assessments. These gaps include the neglect of entire taxonomic groups such as amphibians, but also the fact that management practices and plant-related data are only rarely reported. It should also be noted that biodiversity impacts of PRG cultivation and associated ecosystem services are dependent on the location relative to other habitats. We conclude that, in order to exploit the full potential of biodiversity assessments in PRG cultivation, these need to include a wider range of parameters.

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## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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## APPENDIX 1

### Search strings

1. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (biodiversity OR "species diversity" OR "species abundance" OR "species richness")
2. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (invertebrate OR vertebrate OR arthropods)
3. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Bird OR skylark OR "meadow pipit" OR "lap wing" OR aves)
4. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Insect* OR Pollinat* OR Coleoptera OR Beetle OR Carabidae OR Chrysomelida OR Syrphidae OR Hoverflies OR Diptera OR Lepidoptera OR Butterflies)
5. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Hymenoptera OR Bee OR Apoidea OR Hemiptera OR Thysanoptera OR Dermaptera OR Neuroptera OR Psocoptera OR Orthoptera)
6. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Spider OR Araneida OR Arachnida)
7. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Phytodiversity OR "plant diversity" OR weed OR "segetal flora")
   a. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Phytodiversity OR weed OR "segetal flora")
   b. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND ("plant diversity" OR weed OR "segetal flora")
   c. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Phytodiversity OR "plant diversity" OR "segetal flora")
   d. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND ("segetal flora")
8. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND ("Soil biodiversity" OR "soil diversity" OR Lumbricidae OR earthworm OR "Soil organism" OR "soil microbiology" OR bacteria OR Archaea)
9. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Mammal* OR "Microtus" OR vole OR Rat OR Rattus OR "Micromys" OR mouse OR Lepus OR Hare)
   a. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR phalaris OR "Arundo donax" OR ("Bioenergy crop" AND perennial)) AND (mammal* OR "Microtus" OR vole OR rat OR rattus OR "Micromys" OR mouse OR lepus OR hare))
   b. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR phalaris OR "Arundo donax" OR ("Biomass crop" AND perennial)) AND (mammal* OR "Microtus" OR vole OR rat OR rattus OR "Micromys" OR mouse OR lepus OR hare))
10. (miscanthus OR switchgrass OR "Panicum virgatum" OR "Reed canary grass" OR Phalaris OR "Arundo donax") AND (Amphibia OR Lissamphibia OR Mollusc* OR Gastropoda OR snail)