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REVIEW AND SYNTHESIS PAPER

Vegetation survey methodology in arable weeds is reported with less detail from vegetation science than weed science

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Abstract

Aims: Understand and illustrate differences and common methods in surveys of arable weed vegetation from the two scientific disciplines *Vegetation science* and *Weed science*; analyse the relationship between study aims and the employed methodology; assess in how much detail methodologies are reported and whether this changed over time. **Study area:** Europe. **Methods:** Literature review, classification of studies according to their reported aims and according to the journal scope. **Results:** Survey methods were reported in greater detail in studies aiming to describe management effects on weed vegetation compared to phytosociological studies. Methods employed in vegetation science and weed science differ in plot sizes, surveyed field parts and the seasonal timing of the survey. **Conclusions:** We recommend for future weed surveys to record and report on plot size and position relative to field limits, recording date, abundance scale, as well as the crop grown in a field. This information should also be retained when digitising published data and compiling large databases. A data standard should be developed in an interdisciplinary process.

Keywords

arable, agriculture, field edge, phytosociology, plot size, segetal, vegetation survey, weed, weed survey

Introduction

A recent analysis of arable weed surveys revealed strong differences in species richness between observations originating from two different scientific disciplines (Bürger et al. 2022). *Weed science*, sometimes also called *Herbology*, is traditionally more focussed on agronomic questions regarding weed species ecology and weed management whereas *Vegetation science*, and more specifically the subfield of phytosociology are traditionally more concerned with (weed) community ecology, composition, classification and the synsystematics of plant communities. In the abovementioned analysis, we used two datasets of vegetation surveys in arable fields that were compiled from independent source databases. One dataset contained > 30.000 plot observations originating in weed science, the other approx. 14.000 observations originating in vegetation science. We found a much lower species number in observations from a weed science background compared to observations from vegetation science.

We assumed the difference was most likely caused by differing survey methodology. For example, species richness is likely to be higher when margins or field edges are surveyed compared to field centres (Romero et al. 2008; Fried et al. 2009). We could not conclude on the impact of methodology in our analysis because for the vegetation science dataset we had only very little information on methodology. It had either not been recorded in the field

or not been digitised into the databases. Subsequently, we aimed to understand whether and how methods differ between the two disciplines which is a prerequisite for interdisciplinary research towards more sustainable agriculture (Neve et al. 2018). To our knowledge, no such comparison has been undertaken before. We now present a literature review on weed surveys in and around arable fields published in national and international journals or as theses.

No formal guideline exists on how to survey weed vegetation in agricultural fields although there is a wealth of studies on methodology of vegetation survey in general, including seminal papers regarding the Braun-Blanquet approach (which is one of the most widely used in Europe, see Braun-Blanquet 1964; Dengler et al. 2008; Guarino et al. 2018), studies on aspects like plot sizes and shapes (Otýpková and Chytrý 2006; Wietzke and Leuschner 2020), plant species cover measure (Dengler and Dembicz 2023), and reviews on study design (Hanzlik and Gerowitt 2016; Krähmer 2016). As an example, plot sizes have been proposed from below 16 to 100 m^2 in weed communities in vegetation science (Westhoff and van der Maarel 1978; Dierschke 1994; Chytrý and Otýpková 2003), but Chauvel et al. (1998) suggested a minimum sampling area of 1,000 to 2,000 m^2 for arable weed communities. The plot sizes used in practise in weed science vary between 0.1 m^2 or 0.25 m^2 (often repeated for a number of times in the same field) and 20,000 m^2 (Bürger et al. 2022).

The overall goal of our analysis was to understand and illustrate differences and common methods between both disciplines. More specifically, we 1) explored the variety of the employed methods in weed vegetation research, 2) determined differences between studies from vegetation science and weed science, 3) analysed the relationship between specific study aims and the methodology employed and reported, and 4) assessed whether the number and variety of methodological details that were reported in a study changed over the course of time.

We present our findings in this paper because in times of increasing interdisciplinary research and increasing reuse of primary research data they can be useful to other researchers in order to understand each other and interpret their results in meaningful ways.

Material and methods

Data collection

We conducted a literature search from various sources between February 2021 and January 2023: source publications of three vegetation databases which contain weed records (Chytrý et al. 2016; Bürger et al. 2020; Küzmič et al. 2020), the literature database Scopus, papers from reference lists of other publications, and a research inquiry mailed to colleagues in September 2021. We included only studies that were reportedly based on plot observations (full list in Suppl. material 1).

Geographically, we limited the scope of studies to Europe. Europe has a long and rich history of vegetation survey, also in and around agricultural fields (e.g. Meyer et al. 2013; Šilc 2015; Salonen et al. 2023; for more comprehensive overviews see also Hanzlik and Gerowitt 2016; Krähmer et al. 2020). In opposition to other continents, there is also a recognition of the value of a diverse weed vegetation and an interest in preserving rare and endangered weed species (Neve et al. 2018; Meyer et al. 2021).

We selected only papers with a primary focus on the vegetation of arable land, not considering studies on vegetation of ruderal plant communities or those describing various vegetation types of a certain study region, even if they included vegetation of arable land. This could be signalled by either of the keywords *weed*, *arable*, *segetal*, *agriculture*, *agricultural*, or *field* in the title. We left out all papers which analysed only vegetation data from databases without reporting details on the survey methodology. We aimed to balance the sources to cover a wide time span and diverse geographic locations. For this, we also searched specifically for older studies and less represented regions, including a number of studies which are not available online but only by request.

From each publication we retrieved aims and goals, details of the study design (i.e. field and plot selection), details of the practical execution (i.e. plot position and size, repetitions and the method of cover or abundance estimation), meta data like survey location and time spans, and which additional information was collected for further analysis (i.e. environmental variables or information on field management). For a full overview of the retrieved details see Suppl. material 2. We counted how many methodological details were reported in each study, looking at four major and three minor variables which influence the outcome of a weed survey: plot position in the field, surveying season, plot size, abundance measure, distance to field limit, plot choice and field crop.

A major challenge of our review was to categorise to which discipline a study belongs. Probably, researchers could specify whether they consider themselves part of the vegetation science or weed science community. In contrast, studies do not wear such a label. We therefore took two approaches to assign papers into categories, once through the scope of the journal where a paper was published and once through the aims stated in the paper. Overall, the categorisations show more of a gradient between vegetation science and weed science than a strict division, with considerable overlap and some common aims (see also figure 1 in Bürger et al. 2022).

For the classification via journal scopes, we retrieved the fields of interest from journals' *Aims and Scope*. Then we sorted the journals along a gradient starting on one end with the specialised *Phytosociology & vegetation science*, followed by the plant-focused category *Botany*, the least specialised category *General biology & ecology*, a category concerned with *General agricultural and agroecological research*, and finally on the other end the specialised *Weed science*. Four similar categories (Ecology, Biology, Agronomy and Weed Science) were used by Jordan et al. (2016) in their description of disciplines engaged in transdisciplinary weed research.

For our second approach of categorisation, we copied the aims of each study to our data table. We used the provided information to assign the study to one (or more) of three main thematical categories. These were 1) *Phytosociology* - aiming at classification and description of plant communities, 2) *Inventory or flora* - aiming to record the species or weed communities present in a study region, or to describe their diversity, and 3) *Analysis of the influencing factors*. The last category was additionally divided in two sub-categories: either a study analysed 3A) *Only environmental factors* like soil, landscape complexity or climate, or 3B) a *Combination of management and environmental factors* like cropping system (organic, extensive, conventional), crops, rotations, including generalised phenomena such as "agricultural intensification". With this approach, studies from a vegetation science background can more often be found in categories 1, 2 and 3A but weed science studies more often in 2 and 3B.

For the subsequent analyses, we used a subset of all retrieved studies to avoid biases when the same data or method was used in repeated studies. In our collection we had a number of papers that were based on the same dataset, but analysed different aspects or ecological questions, for example for the French weed data collection Biovigilance (Fried et al. 2008), or the FSE dataset (Firbank et al. 2003). In each case we chose the earliest publication of our list which gave details on survey methodology, but we left out re-analyses. Also, when an author or research group used the same study methodology repeatedly, i.e. in subsequent surveys of different crops, we only used their first publication with this methodology. Finally, only one paper was chosen from series of repeated weed surveys in different decades, like in Finland (Salonen et al. 2023).

Results

General overview

We collected 226 studies of which we included 172 studies in our analysis. These were published between 1927 and 2022 (Figure 1A). All studies were journal articles, except three PhD theses. Up to the year 2000, studies were mostly published in a general botany or biology context. In the years after 2000, the number of studies increased sharply, just like the proportion that was published in agro-ecological or weed science context. The majority of phytosociological works was published in botanical journals (Figure 1B) while inventories and studies on environmental influences on weed flora were published evenly over all journal categories. Studies on the influence of management measures on weed communities were published mostly in agronomic and agro-ecological journals.

The studies in our review cover all parts of Europe (Figure 2A), with the main body (82) coming from Central Europe, 14 studies from Northern, 28 from Western, 28 from Southern, 10 from South-Eastern and eight from Eastern Europe. Two studies covered countries from all over Europe or a north-south transect. The relatively lower number of studies from Southern Europe corresponds to the lower distribution of arable cropping there, with a higher proportion of agricultural land used for permanent crops in vineyards, orchards and olive groves (Eurostat 2023).

Twenty-three studies explored vegetation change retrospectively either as a resurvey, or as a qualitative comparison of recent plot data with a description of a certain area from an earlier time (Figure 2B). The papers were based

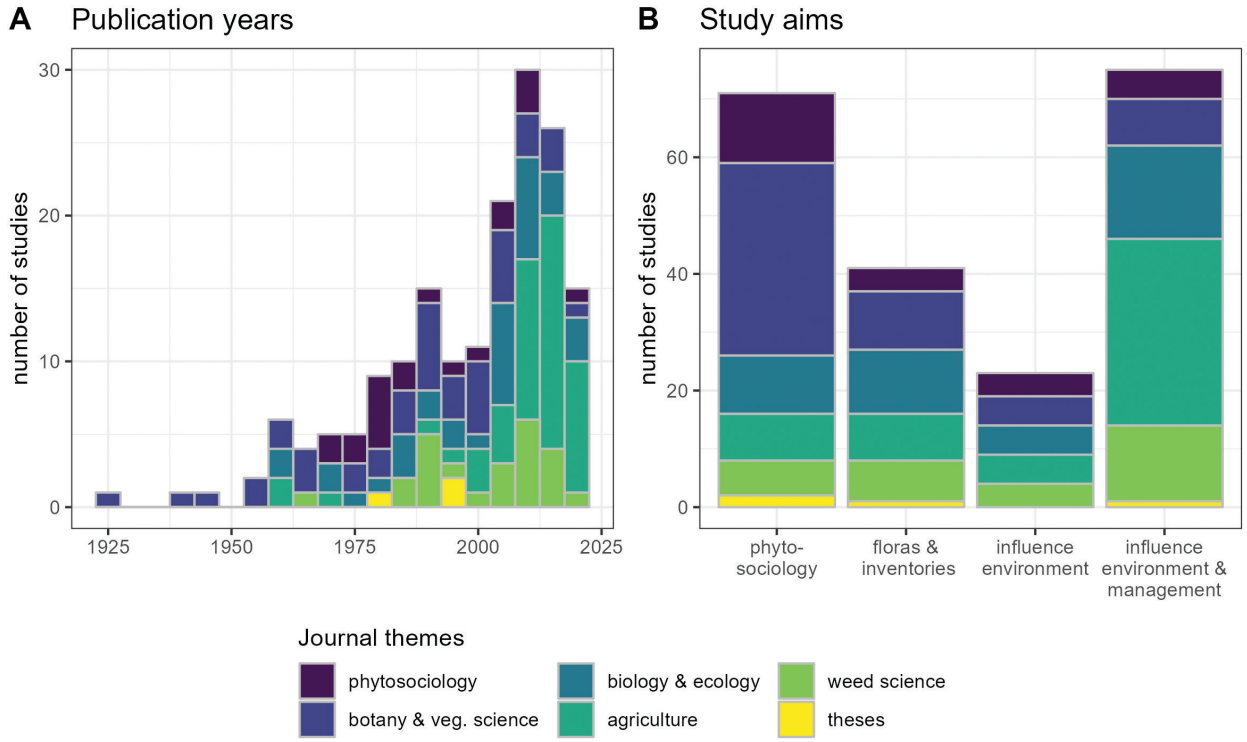

Figure 1. Publication time (A) and study aims (B) of 172 weed vegetation studies, classified by the theme of journal in which they were published. Publications partly mentioned multiple study aims.

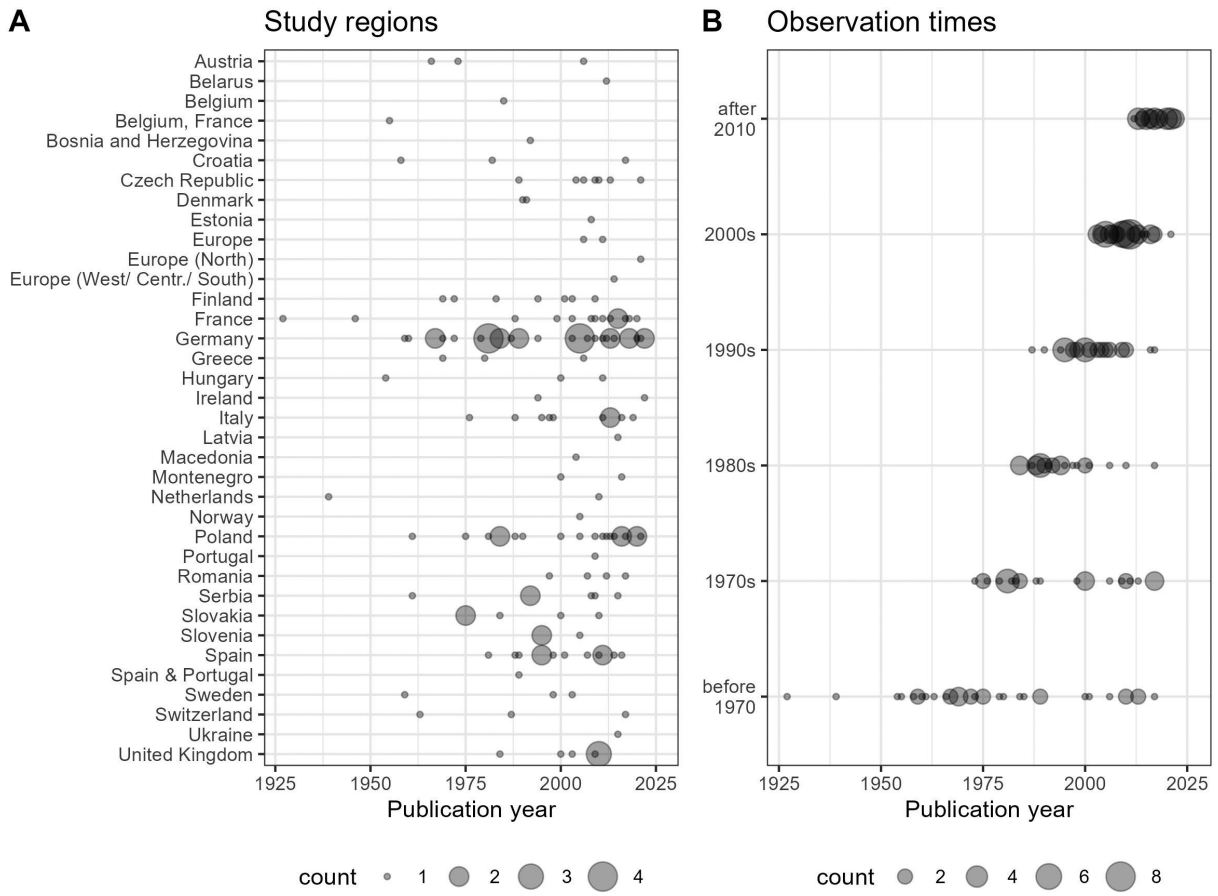

Figure 2. Study region (A) and observation periods (B) of 172 weed vegetation studies, ordered by publication years. Some studies included survey data from more than one decade.

on 4 to 26,020 plot observations, with a median of 211 and a mean of 949 observations. Sixteen papers (9%) did not include any information on the number of plot observations they were based on.

Details on study methodology

We analysed in how much detail the survey methodology was reported in each study. We present an overview for four main methodological aspects (Figure 3) showing the proportion of studies reporting on each aspect, separately for the categories of aims and the journal themes. After that we counted how many details each study reported altogether.

It differs between the four main methodological aspects how often they were reported: abundance scale was reported in 93% of all studies, plot sizes in 82%, survey season in 67% and plot position in field (field part) in 49% of the studies. When detailing these results for the four categories of study aims, there are clear differences. Abundance measure is reported equally in all categories (Figure 3D), but the other three aspects are most often reported in studies on the influence of environment and management and least often for the phytosociological studies. This is especially apparent for the distinction of the studied field part (Figure 3A).

In our second approach to categorising studies via journal scopes, the differences are less pronounced. Here, the proportion of studies that reported on abundance measure, plot size and surveyed field part is similar, only the survey timing is reported more often in agricultural journals compared to the other journal themes, and least often in phytosociological journals.

When the field part is reported, there are not many differences in which field part was surveyed. Most studies that explicitly stated their field part of interest surveyed field centres, often in comparison to the field edge. This is similar in all categories of aims and journal scope (Figure 3A). Surveys are timed rather later in the (cropping) year for phytosociological studies, with a large part covering the whole vegetation period from spring to summer (Figure 3B). Studies on the influence of external factors were carried out in larger parts in spring and summer. Only three studies were carried out in autumn. Two of these were interested in the influence of management factors. Clear differences can be found for plot sizes (Figure 3C). While studies on phytosociology reported plot sizes starting from 10 m², the other three study aims were partly pursued with much smaller plot sizes. This is reflected within the journal categories these studies were published in: in phytosociology, vegetation science and botany journals, the studies with larger plot sizes prevail. In agricultural

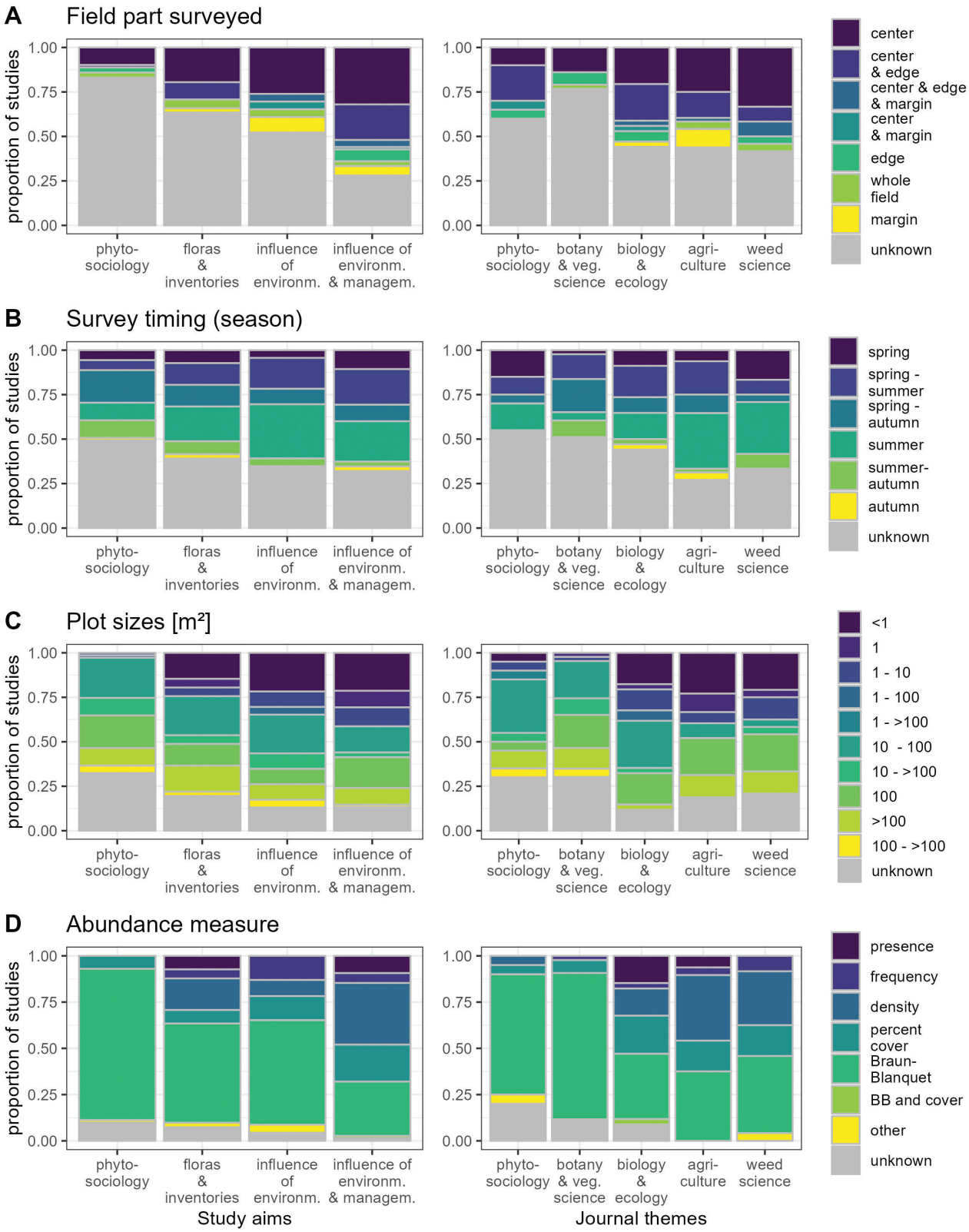

Figure 3. Details of survey methodology (A–D) as reported in 172 studies of weed vegetation, categorised by study aims (on the left) and journal scope (on the right). Number of studies in each category of study aims: phytosociology: 71, floras & inventories: 41, influence of environment: 23, influence of environment & management: 75. Publications partly mentioned multiple study aims. Number of studies in each category of journal scope: phytosociology: 20, botany & vegetation science: 43, biology & ecology: 34, agriculture: 48, weed science: 24.

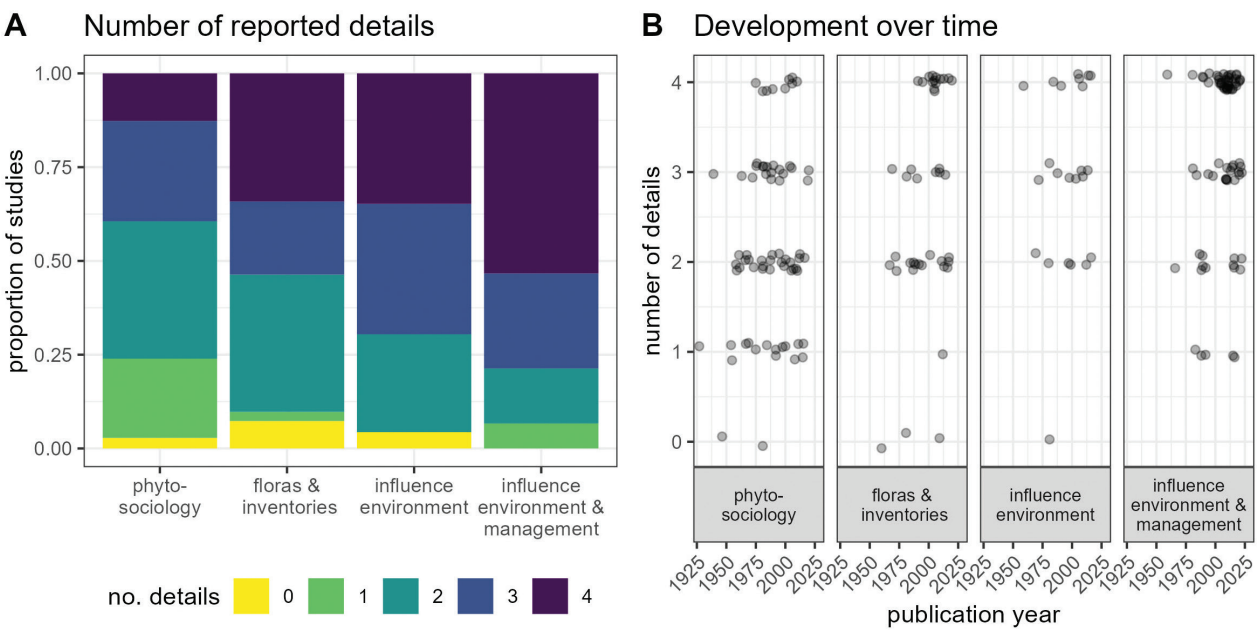

Figure 4. Number of methodological details as reported in 172 studies of weed vegetation, categorised by study aims. (A) Proportions of the studies in each category, (B) in relation to the time of publication. Number of studies in each category of study aims: phytosociology: 71, floras & inventories: 41, influence of environment: 23, influence of environment & management: 75. Publications partly mentioned multiple study aims.

and weed science journals (or general biology and ecology), there is a substantial share of studies on plots below 10 m². The Braun-Blanquet scale and other cover scales were most often used for assessing species abundance, especially when the studies had phytosociological aims. Density was often used when studying the influence of management variables and most often published in agricultural journals.

In sum, the four main methodological aspects shown separately in Figure 3 were reported most often by studies which analysed the influence of environment and management on weed vegetation (Figure 4A). Phytosociological studies reported a lower number of details. There is a slight tendency over time to more detailed reporting (Figure 4B).

Minor methodological aspects

Also the minor methodological details were reported by varying proportions of papers in each field of interest (Table 1): Only half of the phytosociological studies gave information on how they chose survey locations and plot positions within field, compared to over 80% of studies on flora and inventories of a region or studies on the influence of management.

Table 1. Minor methodological details reported in weed survey studies.

Aim	Proportion of studies reporting on:		
	distance to field limit	field selection and /or plot choice within field	crop
Phytosociology	1%	39%	48%
Flora/Inventory	20%	66%	41%
Influence of environment	17%	57%	48%
Influence of environment and management	45%	72%	41%

Discussion

The idea for this paper was developed when the authors combined weed vegetation survey data from vegetation science and weed science for a joint analysis. Interpreting the differences was inhibited by missing information on the survey methodology, mainly in the dataset originating from vegetation science. We now reviewed original publications on weed surveys to analyse whether survey methodology and reporting practise differ between the two fairly distinct scientific communities.

Differences in reporting

We found that a large proportion of publications does not report certain aspects of the employed methodology. This is more prevalent in studies with phytosociological aims. In contrast, studies that aim to analyse the effect of agricultural management on weed species richness or community composition report the highest number of details on how their surveys were undertaken.

Phytosociological studies and studies from the vegetation science realm most often use the Braun-Blanquet scale as abundance measure. Some of these studies stated they used the "Braun-Blanquet" method or the method of the "Central European school" etc., mostly citing Braun-Blanquet (1964) and it seems the study authors found their methodology sufficiently described with this reference.

Taking plot size as an example, we would like to show that this is not true. Plot size influences the number of species found in a plot. Different recommendations on adequate plot size in agricultural environments exist in

the literature (see Introduction), but not in the original reference. Seventeen of 46 studies that stated only phytosociological aims did not give an indication on the plot size they used, but in the ones that did the plot size varied between 1 and over 100 m². This is a considerable variability, i.e. one cannot conclude on the plot sizes in a study when only "Braun-Blanquet" is given as a general methodological reference.

Naturally, methodological details are connected to the study aim, scientific approach (inductive/ deductive), and the necessary data analysis (Kent 2012). In classic phytosociology, the recorded species composition of a plant stand is sufficient for the typification of the plant community or classification of plant communities in a system (Braun-Blanquet 1964; Dengler et al. 2008). All additional parameters are only useful to find the underlying patterns in variability between plant communities. As species composition is the main data and the additional information is not needed for the original purposes it is often not recorded together with species composition data in the field.

Contrary, studies on the management effects on weed vegetation need to take care of methodological aspects to get sound results and interpret their findings in a meaningful way (Hanzlik and Gerowitt 2016; Colbach et al. 2000). Weed vegetation differs between edges and the centre of a field, both due to spill over effects from outside the field, and due to management differences (Fried et al. 2009; Metcalfe et al. 2019). Tillage, fertiliser and herbicide use intensity are often lower towards the field limits, for example due to regulations for protection of non-target habitats and prevention of run-off or due to technological limitations of the machinery. This may also impact the sowing density and therefore the crop density. Soil compaction on the other hand can be higher in the areas where the machinery is turned. As the centre is often the much larger part of the field compared to the edge, and this is the part where most of the agricultural operations happen, the studies on management effects often explicitly take a certain distance from the field limit to avoid edge effects.

What are the consequences of these different reporting practices?

It is clear from many studies how survey methodology influences what is observed in a vegetation survey. Species composition on a plot is influenced by survey timing, for example when the plant communities which are present on a plot change throughout the year (spring aspect vs. summer aspect vs. autumn aspect, see Kropáč et al. 1971; Pinke et al. 2010). Species richness depends on the plot size and shape (Dengler 2009). In the special case of arable fields, both richness and composition are influenced by a number of management factors, so it makes a difference whether arable weeds are surveyed in the centre, at the edge inside the field or in the margin outside the managed area.

For certain research questions, like taking an inventory of arable communities for a certain region, these aspects may not be important, but the challenges arise as soon as we use the same data for secondary analyses and comparison. If we combine data from different sources and we don't know how they were produced, it may be much harder or impossible to interpret results. In the times of growing databases and large-scale data analysis, many challenges for combined datasets have been discussed and found practicable, like transforming abundance values between different coverage scales (Pätsch et al. 2019) or between abundance measures (Metcalfe et al. 2023). Merging data is possible, sometimes on the cost of precision, but missing data, for example on field part, can pose an actual problem as it is hardly possible to deduce the information from the plot data, or make an informed guess.

An overlooked aspect here is the process of field and plot choice. Obviously, an inventory seeking to collect a complete picture of plant communities in a region will have a different sampling strategy than a study interested to compare organic and conventional agriculture or any other environmental or management factor influencing weed community (Kent 2012; Krähmer et al. 2020). For example, to make a complete inventory of weed species and communities in a designated region, several important aspects affecting these variables should be taken into account, e.g. including different crops and seasons (Kropáč et al. 1971; Fried et al. 2008; Šilc 2008; Pinke et al. 2010) while on the other hand a study focusing on one aspect (type of management intensity) will probably select fields with lower number of variables (e.g. few dominating crops) and higher number of repetitions (Heard et al. 2003). Also, preferential sampling will give a different picture than rigorous spatially stratified or randomized approaches (Colbach et al. 2000; Chiarucci 2007). None of these approaches may be better in capturing high-quality data *per se*, but the reporting of the sampling design is important for interpreting the (differing) results.

Differences in employed survey methods

Plot sizes tend to be smaller in weed science. Sampling approaches that survey several smaller plots in a field (and later pool the data) aim to better capture the variability in an area of low weed density.

Surveying annuals in autumn is very hard and only done in an agricultural context. This is surely connected to weed control necessities. Good practice expects farmers to survey their weed vegetation before acting to control, i.e. spraying herbicide. As this happens in autumn for some winter crops, for example winter oil seed rape, a survey is done (of seedling plants) at this unusual time. Phytosociology, in contrary, often cites "at the height of the vegetation period" as the sampling time. Within field centres, it may not be possible to survey in this period, either because the crop stands are too dense, and a surveyor would destroy crop plants, or because crops are harvested before weeds reach advanced growth stages.

Discussion of our categorisation

Categorising by study aims (which were stated in the analysed studies) was useful and showed clear differences for the scientific communities. Categorising journals proved less useful. The diversity of journals has increased over recent decades, probably due to increasing narrowness of research fields (Neve et al. 2018). Connectedness to a certain scientific community is present when journals are the outlet of a scientific association, like *Journal of Vegetation Science* or *Weed Research*. But the higher interdisciplinary cooperation has led to more mixed publication organs. Categorisation is even harder for the rapidly increasing number of open access journals with many specialised titles which are not connected to a specific community of scientists anymore.

Recommendation for the future: A reporting standard is needed

Clear description of methods, which is necessary for data compatibility across studies, is often insufficient in ecological research in general (Belovsky et al. 2004). In phytosociological literature, data standards were proposed to encourage capture of relevant accompanying data for vegetation records across different vegetation types (Dierschke 1994; Mucina et al. 2000). Some of them were deemed obligatory, others optional. To our knowledge, no data standards have been proposed specifically for recording weed vegetation and unfortunately it isn't deemed to be a priority to the scientific community (Neve et al. 2018, but see Chytrý et al. 2019 and Hanzlik and Gerowitt 2016).

Because evidence exists on several parameters which influence species composition and/or richness that are not present in other vegetation types we suggest to develop a new dedicated data standard for recording vegetation in agricultural context. Recording these variables in the field would be fast, without high input of time or money and it would bring good additional value to the vegetation data.

It can be expected that the use of large datasets to find general patterns in vegetation will continue and become increasingly complex in aims, questions, and types of analysis (Chytrý et al. 2019). We therefore encourage future surveyors of weed vegetation to record and publish the following details together with their plot observations: 1) plot size, 2) plot positioning in regard to the field edge, 3) date (or at least month) of the recording, 4) the measure of plant species abundance and 5) the crop or crop category grown on the field.

Furthermore, we encourage digitisers, who put published data into electronic format and compile it into larger databases, to transfer as many variables as possible to the electronic format. To avoid difficulties with translation it would be helpful to use Latin or English expressions, e.g. Latin names of crops.

A data standard should be developed in future in a wider interdisciplinary group of scientists, on the basis of our findings.

Data availability

All data used for the analyses in this article is published in the Supplementary Information (Table with all included studies, the extracted information and the results of data preparation).

Author contributions

J.B. and F.K. planned the research, conducted the literary search and review, and wrote the manuscript together. J.B. performed the statistical analyses.

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Supplementary material

Supplementary material 1
Reference list of all studies collected in the review process
Link: https://doi.org/10.3897/VCS.105300.suppl1

Supplementary material 2
Table of the extracted information from studies used in this article
Link: https://doi.org/10.3897/VCS.105300.suppl2