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RESEARCH ARTICLE

People's appreciation of colorful field margins in intensively used arable landscapes and the conservation of plants and invertebrates

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Abstract
Sown field margins can improve the conservation of biodiversity in rural areas and can contribute to the aesthetics of rural landscapes, thereby potentially increasing public support for agri-environmental measures. However, these two functions do not necessarily coincide. This raises the question whether field margins that are appreciated for their contribution to landscape aesthetics also deliver on the conservation of biodiversity. We conducted choice experiments with different groups of citizens and collected biodiversity data in the Netherlands, to investigate if the number of colors and vegetation cover in field margins increased respondents' appreciation for them, and how these visual cues correlated with taxonomic diversity and abundance of plants and invertebrates in those field margins. Using manipulated photos, we also assessed whether the presence of colorful field margins in a range of different rural landscapes increased respondents' appreciation of those landscapes. Respondents preferred colorful margins with high vegetation cover and showed a preference for green rural landscapes with colorful field margins. The presence of colorful field margins increased landscape aesthetics most in the least appreciated landscapes. The number of colors correlated positively with the diversity of sown and spontaneous plant species, and overall invertebrate abundance and abundance of predatory invertebrates, but was not related to invertebrate diversity. Our results show for the first time that colorful field margins support both public appreciation and diversity of plants and abundance of ground-dwelling invertebrates, with potential advantages to farmers in terms of natural pest control, at least in intensively used agricultural landscapes. However, management practices to maintain a high number of colors over time may be detrimental for invertebrate diversity. To optimize the different functions, we recommend that field margin layouts should consist of a perennial part that is allowed to develop over time, in combination with a part that is managed for its colorfulness.

Keywords Field margins · Arable landscape · Citizens appreciation · Vegetation colors · Vegetation cover · Biodiversity

1 Introduction

In response to the negative impact of current farming practices on biodiversity (Stoate et al. 2009; Geiger et al. 2010; Dudley and Alexander 2017), agri-environmental measures that are supposed to reduce the environmental impact of agriculture have been implemented at a large scale within the European Union since the mid-1980s (Batáry et al. 2015).

A widely applied option in these agri-environmental schemes in European countries is the creation of flower or grass strips along the margins of production fields by setting aside part of the productive area, and either sowing wildflower and/or grass seed mixtures or allowing natural regeneration of the vegetation (Haaland et al. 2011; Uyttenbroeck et al. 2016; Fig. 1). Field margins provide a number of functions, including the reduction of emissions of agro-chemicals to adjacent habitats, stimulating natural pest control, and enhancing biodiversity. Positive effects have been documented for plants, insects, and birds (Marshall and Moonen 2002; Buner et al. 2005; Marshall 2009; Vickery et al. 2009; Haaland et al. 2011; Kuiper et al. 2013; Zollinger et al. 2013; Ouvrard and Jacquemart 2018; Albrecht et al. 2021), but reviews of their effects, also compared with conservation

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Fig. 1 A field margin sown with a wildflower seed mixture in the province Zeeland, The Netherlands (photo Vincent van Beusekom).

efforts in nature areas (for example Batáry et al. 2011; 2015), show that the overall outcome for biodiversity depends on type of vegetation of the margin (e.g., sown vs non-sown; grasses vs wildflowers), sown seed mixture, age of the margin, location on the farm, connectivity with surrounding habitats, the landscape complexity (e.g., simple vs complex), and their management (e.g., timing of management; with vs without annual cultivation; with vs without leaving mowing rests) (Musters et al. 2009; Vickery et al. 2009; Noordijk et al. 2010; Haaland et al. 2011; Zollinger et al. 2013; Batáry et al. 2011; 2015; Kuiper et al. 2015; Evans et al. 2016a; 2016b; Sybertz et al. 2017; Krimmer et al. 2019; Threadgill et al. 2020; Albrecht et al. 2021; Schmidt et al. 2020; Mei et al. 2021; Boetzl et al. 2022; Schutz et al. 2022; Brittain et al. 2022; Cirujeda et al. 2023). Studies of the economic or psycho-social effects of flower strips for farmers are relatively rare (Uyttenbroeck et al. 2016)

Apart from their benefits for the environment, ecosystem services, and biodiversity, field margins can also contribute to the aesthetics of agricultural landscapes. Land use intensification in agriculture has led to rationalized landscapes with large monoculture fields and an enormous loss of semi-natural landscape elements. Research has shown that people have preferences for heterogeneous agricultural landscapes with a variety of crops and a considerable proportion of non-crop landscape elements (Junge et al. 2011).

The aesthetic appreciation of a landscape is probably affected by a large number of sensory impressions, such as smell, sound, movement, or visual clues, and the expectations that these sensations generate. The presence of field margins may increase appreciation, for example, by increasing bird song, the smell of flowers, or possibilities for hunting. Here we concentrate on changing landscape aesthetics by creating colorful field margins, which may increase public support for agri-environmental measures (Tahvavainen et al. 2002; Soga et al. 2021) and agriculture in general. It has been shown that public support is a strong motivating factor for farmers to participate in agri-environmental schemes (Wilson and Hart 2000; De Krom 2017). For the sustainable conservation of farmland biodiversity, we should aim to place farmland biodiversity "in the hands and minds of farmers," cf. De Snoo et al. (2013).

Scenic beauty, however, is in the eye of the beholder, and it is therefore not surprising that different rural landscape configurations are valued differently by different stakeholders (Van den Berg et al. 1998, but see also Soga et al. 2021). Junge et al. (2011), for instance, showed that although farmers appreciated a large diversity in crops in agricultural landscapes as much as the general public, they preferred a much lower number of non-crop elements to be present. Furthermore, studies of the appreciation of the general public of natural areas, green spaces, and semi-natural landscape elements showed that the public appreciation is guided more by visual cues, such as the diversity of flower colors, than by the actual presence of wildlife and flora, or the delivery of related ecosystem services (Folmer et al. 2016; Kütt et al. 2016). However, there is some evidence that public appreciation may coincide with high species diversity, because there can be a direct relation between visual cues and biodiversity, e.g., in the case of plant species diversity in grasslands (Lindemann-Matthies et al. 2010; Kütt et al. 2016).

This raises the question whether field margins that are appreciated for their contribution to landscape aesthetics also deliver on the conservation of biodiversity in rural landscapes. To answer this question, we investigated perceived attractiveness of the margins in different landscape settings by different groups of citizens using a preference study based on manipulated photographs of rural landscapes. We collected field data in these landscapes to be able to examine the relationship between the colorfulness and the vegetation cover of field margins and the abundance of plants and invertebrates as proxies of biodiversity. With this survey, we aimed to answer the following research questions:

– What makes field margins attractive to different groups of citizens, in terms of color, vegetation cover, and the landscape setting?
– How are different visual indicators, that is, color and vegetation cover of field margins, correlated with the abundance of plants and invertebrates?

2 Materials and methods

2.1 General setup

Field work was carried out in Zeeland in 2006, a province in the southwest of the Netherlands, which is dominated by intensive arable agriculture on marine clay soils. The province is made up by five areas of open, flat landscapes in the marine clay district separated by strands of the Scheldt River estuary. By selecting farms only in this province, the influence of differences in soil or landscape context was minimized (Noordijk et al. 2010). Main crops in the rotation are winter wheat, potatoes, onions, and sugar beet (Lokhorst et al. 2009). An arable farm had on average an area of 0.32 km^2 crop land in 2006 (CBS 2022). Parcels have no natural boundaries, but are typically bounded by ditches, roads, hedges, or dykes.

In the Netherlands, subsidized schemes for promoting agri-environmental management have been in place since 1975 (De Snoo et al. 2016). Non-crop field margins became part of those schemes later (around 2000) and were a popular option in Zeeland. The field margins in our research were targeted at fauna conservation, specifically focusing on birds and insects. Subsidy prescriptions require that these margins are 6–12 m wide, at least 50 long, and border cropland (LNV 2006). All margins were sown with either grasses, wildflowers, or a mixture of these when they were created, but sowing was not annually. The use of synthetic pesticides and fertilizer is not allowed, and mowing is permitted once a year between July 15th and September 14th. Exceptions are made for locally combating very persistent weeds. All farmers involved in field margin management were member of a local agri-environmental farmer collective (De Snoo et al. 2016). For our research, we randomly selected 36 arable farms with field margins throughout the whole province. On these farms, 54 field margins were visited in July 2006 to collect data about plants and insects. During these visits, digital pictures of the field margins were taken, one with a landscape perspective and one close-up, showing a representative part of the margin vegetation from above. Pictures were standardized as much as possible in terms of distance and angle and were taken at least 10 m away from field corners and disturbances such as field access or machinery tracks. To standardize the number of colors, all colors observed on the 54 pictures couples were assigned to the closest matching color in the 40 colors standard MS Office 2003 color chart. To avoid variation in interpretation of colors by different people, this was done by the same person (WV).

A complete overview of all the variables that were available on the field margins in the study is given in the Supplementary Material, Table S1. All plant species and groups of invertebrates found are in Table S1 and S2. None of the farms was organic. The amount of semi-natural area on the farm did not correlate to the number of colors, cover, or the biodiversity variables (results not shown). Distance of margins to semi-natural area was not assessed.

2.2 Aesthetic appreciation of field margins

We tested the effect of two visual indicators on the aesthetic perception of field margins by the respondents: the number of colors and the vegetation cover. To assess the influence of the two visual indicators on the aesthetic appreciation of respondents, we assigned all close-up pictures of the field margins to one of three color classes (high: ≥ 7 colors, medium: 4–6 colors, and low: between 2 and 3 colors) and one of two vegetation cover classes (high: > 90% cover and low: 40–90% cover) based on the actual distribution of the number of colors and vegetation cover (Fig. S1a and b in Supplementary Material). Field margin photos were then combined in a series of six photos that provided a full factorial representation of color and vegetation cover. To account for potential effects of variability between photos within classes, we created two such "margin photo series" to present to the respondents (Fig. S2).

To assess which type of field margin added the most to landscape aesthetics as perceived by the respondents, artificial landscape pictures were created with Adobe Photoshop by combining a picture of one of our field margins with three types of rural landscape contexts, the "landscape series": a landscape with only green elements present, a landscape with both green elements and buildings (houses and farmhouses) present, and a landscape with green elements and the presence of a larger road with traffic. These landscape contexts were all photographed in the same province as where the field margin study was conducted. To limit the number of pictures the respondents had to classify, we only used two color classes (high or low) and only used pictures of margins with full vegetation cover. The photo of the crop next to the field margin that was used to create the images was kept constant in each picture. Again, we created full factorial combinations of these three types of landscape context and the two-color classes of the field margin, resulting in a series of six pictures. Again, to account for potential effects of variability between pictures within classes, we created two photo series to present to the respondents (Fig. S3).

To assess the aesthetic appreciation of the field margins, a total of 108 respondents ranked the six pictures in each series from the highest to the lowest attractiveness. We asked three citizen groups of respondents, i.e., urban inhabitants, inhabitants of rural villages, and farmers, to rank the same 4 series of pictures to assess differences in appreciation between the three groups. We conducted the study in different provinces (the Dutch provinces of *Noord-Holland* and *Zuid-Holland*) than where the pictures were taken to avoid local bias. Urban inhabitants were interviewed in the main shopping street in the city of *Leiden* (*Zuid-Holland*); rural inhabitants were interviewed outside a mall in the rural village of *Nieuw-Vennep* (*Noord-Holland*). Farmers were interviewed in the *Haarlemmermeerpolder* (*Noord-Holland*), an area with arable farms that are generally comparable with those in the province of Zeeland in terms of soil type, size, farming intensity, and crops grown. Farmers were first contacted by phone and later visited on their farms to do the ranking.

The 108 respondents were distributed over the three citizen groups as follows: 40 urban inhabitants, 38 rural inhabitants, and 30 farmers. For each respondent, we also registered gender, age (in years), and highest level of education (primary school, preparatory vocational secondary education, senior general secondary and university preparatory education, vocational education and training, and higher education). Interviews took place in May and July 2007.

2.3 Biodiversity assessment of field margins

In the 54 field margins with seeded species, we measured richness and abundance of plant species and invertebrate groups. All biodiversity assessments were made at the locations in the field margin where the pictures were taken.

Vegetation composition, relative cover of each plant species, and total cover were recorded in 25-m-long and 1-m-wide transects in the middle of each margin in June and July 2006, using an adapted Braun-Blanquet method (Barkman et al. 1964). For assessing the number of plant species, native species were identified using the local flora of Van der Meijden (1990). Plants that could not be identified in the field were collected and compared with herbarium material or identified by experts from the Dutch Foundation for Floristic Research (FLORON). Sown cultivars were identified using Brickell (1999). Vegetation data were processed using Turboveg (Hennekens and Schaminée 2001). All plant species that were found, but of which no seeds were sown during the establishment of the field margins, are indicated as "spontaneous plant species" in the rest of this paper. For studying the relationship between the number of colors and the abundance of plants, we added the cover of each individual plant species to a total sum per margin as a proxy for the total abundance of plants in the margins. This was also done with the spontaneous plant species.

As mentioned above, the field margins in our research were targeted at fauna conservation. Their agricultural function was the stimulation of natural pest control. Pollination was not of interest for farmers given their cropping systems. For this reason, we only studied the taxonomic richness and abundance of soil-dwelling invertebrates. These were sampled at the end of June and the beginning of July 2006 (weeks 26–27) using 4 pitfalls traps in each field margin (fixation liquid: 50% ethylene glycol) placed 10 m apart. The traps had a diameter of 11 cm, were 7 cm deep, had an elevated plastic cover to keep out rainwater, and were open for 7 days. Catches of the 4 traps were pooled to represent one sample for each field margin. Invertebrates were classified to family level if possible and otherwise to order level by J. Noordijk (Noordijk et al. 2010). Invertebrates were classified into four functional groups based on their main food source. Chilopoda, Araneae, Coccinellidae (including their larvae), carnivorous Carabidae, and Staphylinidae were considered to be predators. Isopoda, Diplopoda, and Collembola were considered as detritivores. Gastropoda, Curculionidae, Orthoptera, Cicadellidae, Heteroptera, and Aphidoidea were considered to be herbivores. And all other species groups were classified as omnivores.

2.4 Data analysis

All statistical analyses were performed in R software version 4.0.3 (R Core Team 2020).

We used conjoint analysis (Green et al. 2001) to assess the preference of respondents for the pictures in each series. The two series of pictures of margins, as well as the two series of landscapes, represent two observations within a single test and, therefore, cannot be considered independent observations. Rankings of pictures with the same combination of color class and vegetation cover class of the margin series were averaged for each respondent before analysis, as was done with the rankings of the landscape series. The full factorial setup of each photo series allowed us to assess the contribution of each variable (the color and vegetation cover classes in the margin series and colorfulness of the margin and landscape context classes in landscape series) to the appreciation of the respondents of each photograph. All these analyses were performed using the *conjoint* package in R (Bak and Bartlomowicz 2012).

For testing the differences between the three groups of citizens (urban inhabitants, rural inhabitants, farmers) and the effect of gender, age, and level of education on their preferences, we applied the method of Lee and Yu (2013) for testing the difference between marginal matrices, but used Fisher exact probability, the function *fisher.test()* of R, instead of the chi-square test.

Spatial autocorrelation in the number of colors in the margins and the main biodiversity response variables was checked by calculation of Moran's *I* with the function *moranI()* of the package *lctools* of R, using a weight that selects the 5 nearest margins, which usually includes the second margin of the same farm, as well as the margins of two neighboring farms (Kalogirou 2020). In the results, we have given the *P*-values of the randomized *z*-score, which in all cases were almost equal to the *P*-values of the resampling.

We used linear mixed models (LMMs) to test whether the various measures of biodiversity of the field margins were related to the color and cover classes, as well as to age of the field margin, i.e., the time since sowing. These analyses were performed using the *lmer()* function of the *lme4* package in R (Bates et al. 2015). The different measures of biodiversity were the response variables, with either color or cover as fixed effect variable and farm as random effect variable. For testing the confounding effect of age on the relationship between the measure of biodiversity and color, we used the LMMs for color, but extended them by including age, as well as the interaction between age and color as fixed effect variables. Residuals were checked in all cases. Graphs were made with the *scatterplot()* function of the *car* package in R (Fox and Weisberg 2019).

3 Results

3.1 Aesthetic appreciation

3.1.1 Attractiveness of field margins for different groups of citizens

When arranging pictures of field margins on their attractiveness, respondents showed a preference for pictures that were colorful and had a high vegetation cover, but the difference in preference for colorful pictures with low coverage or medium-colored pictures with high coverage was small (Fig. 2a).

The attractiveness of a margin picture was highly significantly predicted by the conjoint model based on color and cover ($F_{[3,644]} = 188.8$; $P < 0.001$; $R^2 = 0.468$; Table S4 in Supplementary Material), strongest by colorfulness, and less so by its coverage (Fig. 2a–d).

The attractiveness of the pictures was not affected by the difference in gender (Fisher exact probability test: $P = 0.571$), age ($P = 0.163$), education ($P = 0.795$), or citizen group ($P = 0.376$) of the respondent.

3.1.2 Attractiveness of landscapes for different groups of citizens

When arranging pictures of landscapes on their attractiveness, respondents showed a clear preference for pictures that were colorful without any other elements (Fig. 2e). Landscapes with traffic were the least appreciated.

The attractiveness of a landscape picture was highly significantly predicted by the conjoint model based on color and landscape type ($F_{[3,644]} = 184.7$; $P < 0.001$; $R^2 = 0.463$; Table S5), strongest by the landscape type, and less so by its color (Fig. 2e–h).

Again, the attractiveness of the pictures was not affected by the difference in gender (Fisher exact probability test: $P = 0.987$), age ($P = 0.450$), education ($P = 0.710$), or citizen group ($P = 0.632$) of the respondents.

3.2 Biodiversity

3.2.1 Spatial autocorrelation

The measurements of the main variables showed no spatial autocorrelations: number of colors ($I = 0.013$; $I_{exp} = -0.018$; *P*-value = 0.678), number of plants ($I = -0.023$; $I_{exp} = -0.018$; *P*-value = 0.945), sum of the cover of all plants ($I = 0.079$; $I_{exp} = -0.019$; *P*-value = 0.187), number of invertebrate groups ($I = -0.052$; $I_{exp} = -0.020$; *P*-value = 0.688), and number of invertebrates ($I = 0.007$; $I_{exp} = -0.020$; *P*-value = 0.718). However, in some cases, the farmers collective had a significant effect on the number of colors or the response variables (results not shown). Corrections for the confounding effect of collective could be made by including the farmers collective as random effect variables in the LMMs. When this was done, the factor showed singularity with the random effect variable farm (results not shown), which means that the effect of the factors was already included in the effect of farm, so that no inclusion in the LMMs was needed.

3.2.2 Relationship between the number of colors, vegetation cover, and age

The vegetation of the 54 tested field margins had 2–9 colors (mean = 4.3; median = 4) and most of the field margins were completely covered with vegetation (mean = 89.8; median = 100; Fig. S1a and b). The number of colors dropped in the years after sowing (Fig. S1c), and the vegetation cover increased after the first year (Fig. S1d). The number of colors was not significantly different between cover classes, but tended to be higher for margins with lower cover (Fig. S1e).

A previous study using the same data showed a decrease of the number of plant species with age after sowing, but no such decrease in the number of spontaneous plant species (Noordijk et al. 2011; Tables S9 and S10). The sum of cover

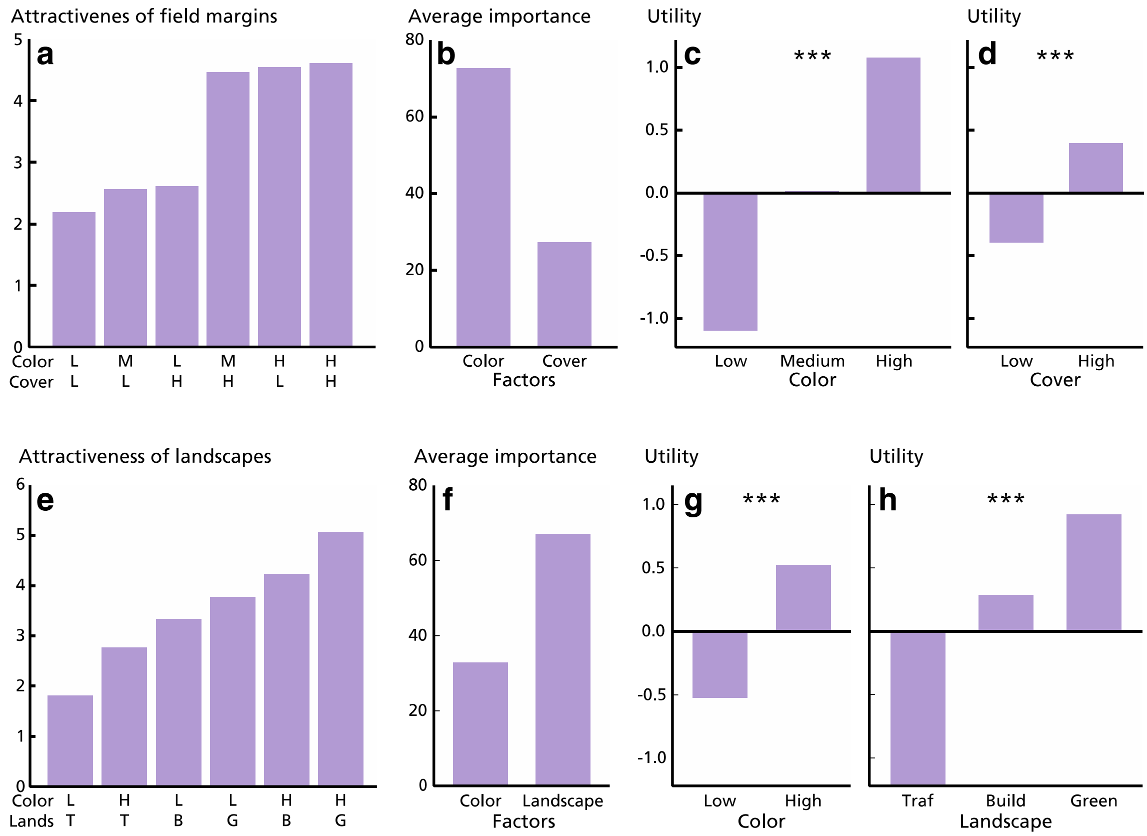

Fig. 2 **a** Average score of attractiveness per picture of field margin averaged over two series of pictures. Scores are from 1 to 6. Upper part of subscript indicates colorfulness: Color Low, Color Medium, or Color High; Lower part vegetation cover: Cover Low or Cover High. **b** Relative importance in attractiveness of field margins of color and cover and **c**, **d** the utility, i.e., the estimates of the conjoint model parameters predicting attractiveness, of the color and cover classes. **e** Average score of attractiveness per picture of landscapes averaged over two series of pictures. Scores are from 1 to 6. Upper part of subscript indicates colorfulness: Color Low or Color High; lower part the landscape (Lands): Landscape Green (Green), Landscape with Buildings (Build), or Landscape with Traffic (Traf). **f** Relative importance in attractiveness of landscapes of color and landscape type and **g**, **h** the utility, i.e., the estimates of the conjoint model parameters predicting attractiveness, of the color and landscape classes. ***P<0.001.

of the individual plant species, a proxy for plant abundance, did not change with age for either all plants or spontaneous plants (Tables S11 and S12).

3.2.3 Color and cover of field margins related to plant species and abundance

The vegetation of the field margins was composed of 3–47 plant species (mean = 14.1; median = 10), of which 1–18 were spontaneous, i.e., not sown (mean = 6.6; median = 6) (see Table S2 in Supplementary Information for a complete species list). A clear relationship was found between the number of colors and the number of plant species (positive, Fig. 3a scatterplot), as well as between the cover of the vegetation and the number of plant species (negative, Fig. 3a boxplot). Such clear relationships were also found for the number of spontaneous plant species (Fig. 3b). When testing the effect of both the number of colors and age on the number of plants, the effect of age was no longer significant so that we can ignore age as a confounding variable in the relationship between number of colors and plant species (Table S13). So, the positive correlation between the number of colors and plant species remains.

The number of colors was positively related to the sum of the cover of all plants, a proxy for the abundance of all plants in the field margin, but not to that of the spontaneous plants (Fig. 3c and d scatterplots).

3.2.4 Color and cover of field margins related to invertebrates

In the pitfalls, 13–24 different ground-dwelling invertebrate groups were caught (mean = 19.1; median = 19, see Table S1 for a complete list of invertebrate groups). There was no significant relationship between the number of colors

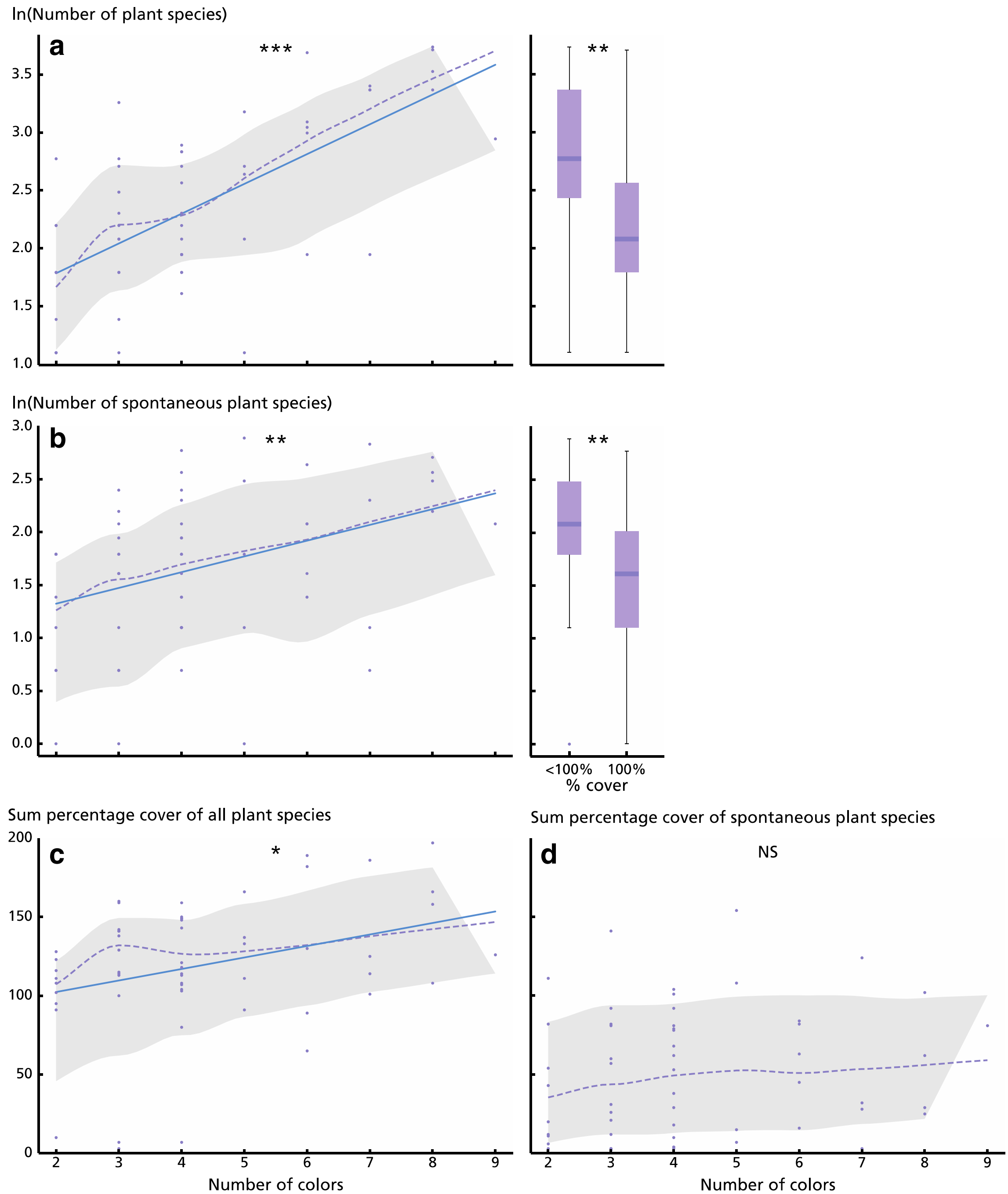

Fig. 3 Relationship between the number of colors and **a** number of plant species; **b** number of spontaneous plant species; **c** percentage cover of all plant species; and **d** percentage cover of spontaneous species. The right-hand panels in **a** and **b**, the boxplots, indicate the difference between vegetation cover classes in the total number of plant species and spontaneous plant species, respectively. Solid blue line in the scatterplots is the regression line; broken line is the smoothed, non-linear LOESS line drawn by *scatterplot()*. Regression coefficients, *P*-values, and number of cases are given in supplementary tables S13-17. NS, not significant; $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

and the number of invertebrate groups (Fig. 4a scatterplot), nor between the cover of the vegetation and the number of invertebrate groups either (Fig. 4a boxplot).

A positive correlation between the number of colors and the abundance of invertebrates could be found (Fig. 4b scatterplot), but no correlation between the vegetation cover of the field margins and the abundance of invertebrates (Fig. 4b boxplot). When we included age as a confounding variable in our analysis, the effect of age diminished (Table S21).

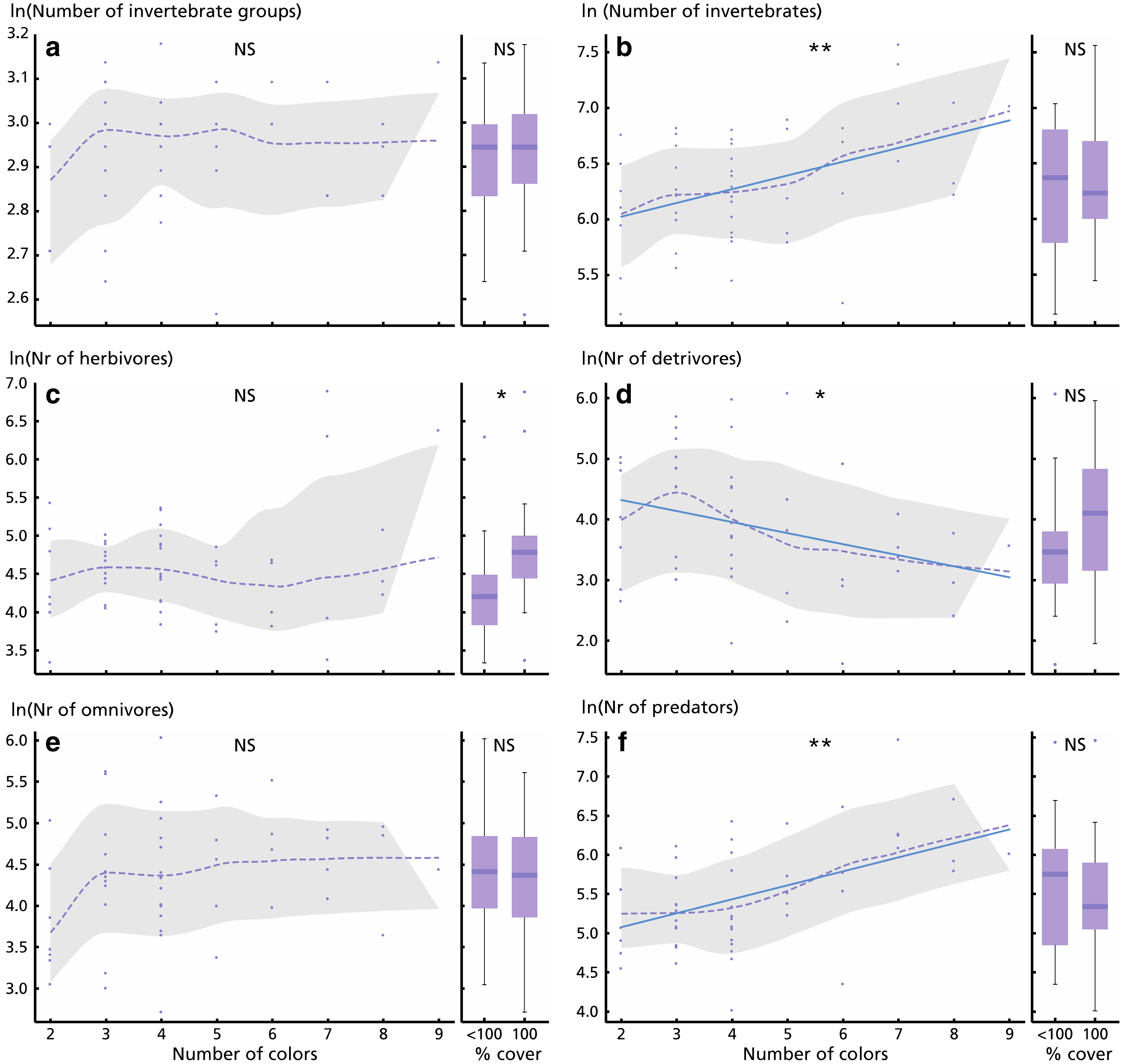

Fig. 4 Relationship between the number of colors and the number of **a** taxonomic invertebrate groups; **b** total invertebrates; **c** herbivores; **d** detritivores; **e** omnivores; and **f** predators (left-hand panels; scatterplots) and differences in the same groups between high and low vegetation cover (right-hand panels; boxplots). Solid blue line in the scatterplots is the regression line; broken line is the smoothed, non-linear LOESS line drawn by *scatterplot()*. Regression coefficients, *P*-values, and number of cases are given in supplementary tables S19-30. NS, not significant; $*P < 0.05$; $**P < 0.01$.

Among the functional groups of invertebrates, the detritivores showed a negative and the predators a positive correlation between the number of colors in the vegetation and their abundance (Fig. 4d and f scatterplots). The herbivores showed a positive correlation between the cover of the vegetation and their abundance (Fig. 4c boxplot). Including age as a confounding variable in the relation between the number of colors and the abundance of the functional groups did not result in a significant effect of age, so that we can ignore the effect of the age for these variables, too (Tables S23-S25), except in the case of the detritivores (Table S26), where an interaction between age and number of colors showed that the negative correlation between number of colors and abundance was only true in the young field margins (Fig. 5).

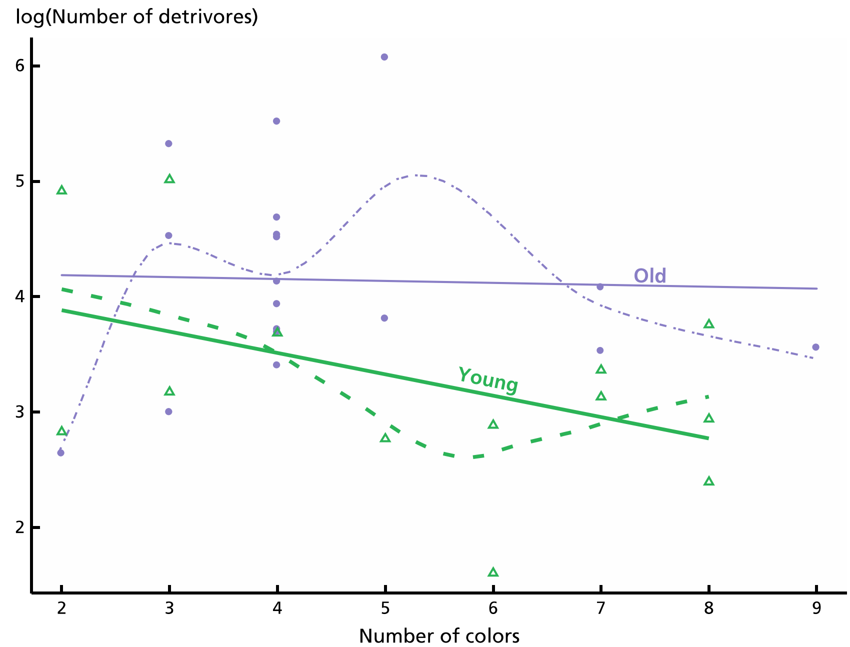

Fig. 5 Difference in the relationship of the number of colors and the abundance of detritivores between young (age < 3 years) and old field margins. The interaction between the number of colors and age is significantly different from zero (LMM; Table S26). Solid lines are regression lines; broken lines the smoothed, and non-linear LOESS lines drawn by *scatterplot()*.

4 Discussion

Our results showed that respondents of different gender, age, education, and citizen groups (urban inhabitants, rural inhabitants, farmers) all found colorful field margins most attractive. The amount of vegetation cover of the margins seemed of less importance for the appreciation of the margins than colorfulness. All respondents preferred rural landscapes without the presence of buildings of traffic, but the presence of colorful field margins in any landscape setting always increased landscape appreciation. Interestingly, the relative increase in appreciation due to the presence of colorful field margins was highest in the least appreciated landscapes, i.e., those with the presence of road infrastructure and traffic. These results indicate that colorful field margins may increase the attractiveness of the countryside in agricultural areas with high population density such as the Netherlands, and may therefore contribute significantly to public support for this type of agri-environmental measures (Lindemann-Matthies et al. 2010; Junge et al. 2011; Soga et al. 2021). Moreover, for safeguarding biodiversity on farmland, the motivation of farmers is crucial (Lokhorst et al. 2011; De Snoo et al. 2013) and the colorfulness of margins can be of help here.

Since the goal of field margins in the study area is to increase biodiversity, we also investigated whether colorful margins supported the highest abundance and diversity of plants and ground-dwelling invertebrate groups. Our results showed that the number of colors in a field margin correlated positively with the number of plant species in these margins, independent of whether these species were sown or not. While the relation between the number of colors and the number of plant species was significant for both sown species and spontaneous species, it was much stronger for the former (almost 1:1) than for the latter (relation of about 1:2). Despite this positive effect on plant species diversity, the spontaneous species in these field margins almost exclusively consisted of common arable plants species with low conservation value (Noordijk et al. 2011), which is generally found in field margin vegetation in open areas with intensive agriculture such as in the Netherlands due to the influence of adjacent farming activities (Kleijn et al. 1997; Walker et al. 2007; Noordijk et al. 2011, but see Cirujeda et al. 2023, who found in Spain that newly established field margins were still different from old field boundaries after 10 years). The number of colors also positively correlated with the abundance of sown plant species, showing that photos can be used to assess the abundance of flowers. Vegetation cover had a negative effect on the number of plant species, again both for the species that were sown and spontaneous species meaning that in the margins with a high vegetation cover a limited number of species dominate.

We also identified a positive correlation between the number of colors and the overall abundance of ground-dwelling invertebrates. The latter effect, however, differed between the different functional groups. This distinction is important to make, because besides the potential contribution to biodiversity conservation in agricultural landscapes, field margins can also have an effect on the adjacent crops, both beneficial and negative (Kleijn et al. 2019; Lowe et al. 2021; Marshall and Moonen 2002; Albrecht et al. 2021; Mei et al. 2021; Toivonen et al. 2023). The groups of herbivores and omnivores, for instance, can contain a number of pest species, while predators can play an important role in natural pest control. Whether or not field margins are a potential source of pests, or can contribute to agricultural production may be an important determinant for the willingness of farmers to establish sown field margins on their land. Our results showed that establishing colorful field margins may make a positive agronomic contribution, since the abundance of predators significantly increased with an increase in the number of colors (an almost threefold increase in predator abundance from margins with only 2 colors to margins with 9 colors). This seemed to support the results of Mei et al. (2021), who found that availability of flowers across wildflower strips and control margins was positively correlated to the abundance of natural enemies of pest organisms in crops. The abundance of herbivores and omnivores did not show a significant correlation with color. Vegetation cover had no effect on the abundance of ground-dwelling invertebrates, except for the herbivores that were more abundant in margins with 100% vegetation cover.

Our results therefore suggest that sowing field margins with a flower mixture that maximizes the number of flower colors support both public appreciation and the biodiversity of plants and abundance of ground-dwelling invertebrates, with potential advantages to the farmer in terms of natural pest control. However, the correlations between the number of colors and field margin biodiversity do not give insights into the causal relation between the two, which would be required to substantiate a management advice. We therefore further explored the relation between the number of colors, vegetation cover, biodiversity, and the temporal dynamics of the field margins under study.

Although we identified a relation between the number of colors and the number of sown plant species, it is not a given that the number of colors is constant over time. Previous research indicated that sown species are hardly able to establish themselves in field margins and other herbaceous landscape elements for longer time (Noordijk et al. 2011; Kütt et al. 2016; Mei et al. 2021). In the first year, the margins were dominated by the annual species in the seed mixtures, by biannual species in the second year, after which grasses and arable weeds took over (Noordijk et al. 2011; Schmied et al. 2023). Contrary to Cirujeda et al. (2023), our results also show a reduction in plant species richness over time, which levels off between 4 and 6 years at around 7 species. This would imply that interventions, such as renewing or reseeding the margin, would be needed every 4 to 6 years to maintain the number of colors.

Regarding the ground-dwelling invertebrates, Noordijk et al. (2010) showed that taxonomic diversity of ground-dwelling invertebrates increased with the age of the margins. More recently, it was shown that soil disturbance may negatively affect the survival of populations of overwintering invertebrates (Holland et al. 2016; Ganser et al. 2019). These findings imply that maintaining a high number of colors by annually ploughing and seeding the field margins may be detrimental to their function for biodiversity conservation of invertebrates (Boetzl et al. 2022). It is therefore important to assess whether the relationships between number of colors, vegetation cover, and abundance of invertebrates we identified may be due to a confounding effect of aging. From our study, it is clear that this was not the case, except for the abundance of detritivores that was negatively related to the number of colors only in the first years after sowing. From this, we may conclude that the number of colors, vegetation cover, and age are all factors that correlate independently with the number of plant species and invertebrate groups, and with abundance of plants and ground-dwelling invertebrates, except for detritivores. This means that numbers of colors may be in itself a positive indicator for both the appreciation of field margins by citizens and the number of plant species, the abundance of ground-dwelling invertebrates, and the abundance of ground-dwelling predators, and a negative indicator for detritivores in young field margins.

Colorfulness of field margins is undoubtedly determined by the abundance of flowers in the margins. This makes the relationship between colorfulness and flower-visiting arthropods that could potentially play an important role as pollinators of agricultural crops, an obvious subject of future research.

Since subsidy regulations for sown field margins quite strictly specify only the management of the margins themselves, the agricultural activities on the adjacent field can be a strong determinant of the actual contribution colorful field margins can make to the conservation of arable biodiversity (Geppert et al. 2020; Gallé et al. 2020; Szitár et al. 2022; Schutz et al. 2022; but see Bakker et al. 2021). Fertilizer misplacement and pesticide drift specifically may affect plants and invertebrates in these margins (Kleijn and Snoeijing 1997; Marshall and Moonen 2002). Because of their high mobility and wide range, certain groups of invertebrates may especially be impacted by activities on the field such as pesticide application, but also by the wider landscape context of the margins (Musters et al. 2022).

Our results also suggest a potential trade-off between appreciation by citizens for colorful field margins and their biodiversity conservation value, because management measures to maintain a high number of colors over time in these margins may be detrimental to their long-term conservation value, especially for arthropods (Boetzl et al. 2022; Schmied et al. 2023, but see also Brittain et al. 2022 for pollinators in Hungary). This trade-off could be avoided with a smart layout of the margin, combined with phased timing of management interventions (Schmied et al. 2023). Our results suggest that the optimal field margin in these open and intensively managed areas should consist of a perennial part that is allowed to develop over time, in combination with a part that is managed for its colorfulness, in which more regular interventions are allowed. We suggest installing this part of the margin directly adjacent to the production field, because of its potential contribution to pest control by maximizing the number of predators. The more perennial part of the margin, with a higher number of herbivores, can be best realized adjacent to the field boundary and so connect to more permanent semi-natural areas like hedgerows and ditches banks.

5 Conclusions

This study tried to answer the question whether field margins that are appreciated for their contribution to landscape aesthetics also deliver on the conservation of biodiversity in rural landscapes. We found that colorful field margins can increase the appreciation of arable landscapes by different groups of citizens, including farmers, in intensively managed open areas like those of the Netherlands. We also found that the number of colors in field margins correlated positively with the diversity of sown and spontaneous plant species, and overall invertebrate abundance and abundance of predatory invertebrates, but was not related to invertebrate diversity. Invertebrate diversity is known to increase in field margins that are allowed to develop over time without major management interventions, while colorfulness decreases in those margins. We therefore conclude that management practices to maintain a high number of colors over time might be detrimental for invertebrate diversity. In order to optimize the different functions, we recommend that field margin layouts should consist of a perennial part that is allowed to develop over time, in combination with a part that is managed for its colorfulness. The relationship between colorfulness, the esthetics of the landscape, and the abundance of pollinators is an obvious subject for future research, because they all depend on the abundance of flowers.

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Authors' contributions GdS and JvD contributed to the study conception and design. Material preparation, data collection, and analysis were performed by JvD, WV, and CM. The first draft of the manuscript was written by WV and CM. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets generated during the current study will be made available in Dryad.

Code availability Not applicable

Declarations

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Conflict of interest The authors declare no competing interests.

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