Agriculture, Ecosystems and Environment 237 (2017) 224–233

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Quantifying the extent to which farmers can influence biodiversity on their farms

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A R T I C L E I N F O

Article history:
Received 22 May 2016
Received in revised form 18 November 2016
Accepted 15 December 2016
Available online xxx

Keywords:
Agri-environment schemes
Birds
Butterflies
Ecological compensation
Farm scale
In-field options
Grasshoppers
Plants
Variance partitioning

A B S T R A C T

Despite the introduction of agri-environmental schemes, no general increase of farmland biodiversity in Europe has been observed. Farmers take decisions about the implementation of agri-environmental schemes at the farm scale, and it is thus highly relevant to assess the relationship between farm management and biodiversity at this scale to increase the effectiveness of agri-environmental schemes. The present study quantifies to what extent and with which practices farmers can influence biodiversity on their farm and to what extent conditions outside farmers' control may mediate biodiversity.

We grouped 27 variables into four variable sets: (1) ecological compensation (mainly semi-natural habitats), (2) in-field options (e.g. no growth regulator, insecticide and herbicide treatment), and (3) farm characteristics, which can be influenced by farmers (e.g. land-use types) as well as (4) farm settings, which cannot be influenced by farmers (e.g. altitude). As biodiversity metrics, plant, grasshopper, butterfly and bird richness and abundance of farmland target species were assessed on 133 farms of the Swiss Central Plateau from 2009 to 2011. Variance partitioning and generalised linear mixed models were used to analyse the impact of each variable set on farmland species diversity.

Our results provide evidence that farmers can indeed positively influence biodiversity by ecological compensation and in-field options. The variables of the ecological compensation set explained the highest proportion in the variation of plant richness and butterfly abundance. We found a significant positive relationship between in-field options and plant abundance. Our study illustrated that the effects of biodiversity-related farming practices differ between species and biodiversity metrics. Conditions outside farmers' control explained a high variation in grasshopper and bird diversity. One variable within the set of farm settings, the degree of consolidation, had a significant negative impact on five out of eight biodiversity metrics (plant, butterfly and bird richness; plant and bird abundance). We demonstrate that farmers can substantially enhance biodiversity on their farms and provide knowledge on how such biodiversity improvements can be achieved by farmers. Further, we highlight the value of new biodiversity-related management practices such as in-field options.

1. Introduction

Major declines in biodiversity in agricultural landscapes have been recorded over the last 100 years in Europe (Donald et al., 2006; Ekroos et al., 2010; EEA, 2013; FOEN, 2014; Ollerton et al., 2014). In Europe agricultural intensification, habitat loss or fragmentation and changes in landscape structure are the main drivers of biodiversity decline (Robinson and Sutherland, 2002; Fischer and Lindenmayer, 2007; Tsiafouli et al., 2015). One response to the declining diversity was the introduction of agri-environment schemes (AES) in many European countries as a policy instrument (EU, 2005; Kleijn et al., 2006). AES reward farmers financially for biodiversity-related farm management. A plethora of evaluation studies have revealed marginal to moderately positive effects of AES on biodiversity at the plot or scheme level (Herzog et al., 2005; Kleijn et al., 2006; Knop et al., 2006; Aviron et al., 2007; Jeanneret et al., 2010; Perkins et al., 2011;

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http://dx.doi.org/10.1016/j.agee.2016.12.029
0167-8809/

Whittingham, 2011; Tscharntke et al., 2012; Batáry et al., 2015; Roesch et al., 2015). Thus, major shortcomings limiting the effectiveness of AES are found in terms of quality, size and connectivity.

Farmers make decisions about the implementation of AES at the farm scale, and it is thus highly relevant to assess the relationship between farm management and biodiversity at this scale to increase the effectiveness of AES (de Snoo et al., 2013; Home et al., 2014). A farmer can influence biodiversity positively by creating semi-natural habitats or managing fields at low intensity ("ecological compensation", e.g. extensively managed meadows, hedges, traditional orchards), using in-field options (e.g. no growth regulator, insecticide and herbicide treatment, undrilled patches or wide-spaced rows) and determining farm characteristics (e.g. number of fields, livestock units) (Kleijn et al., 2006; Aviron et al., 2007). In addition biodiversity on the farm depends on conditions outside farmers' control ("farm setting", e.g. altitude, landscape context) (Tscharntke et al., 2012). To our knowledge, the relative contributions of farmers' actions in influencing biodiversity, and of the farm setting, which the farmer cannot control, have not been quantified so far. Furthermore impacts of ecological compensation, in-field options, farm characteristics and farm settings on biodiversity have rarely been investigated together. Since no single taxonomic group provides an effective indicator of change in all groups in response to AES, we measured responses of different groups simultaneously (Wolters et al., 2006; Billeter et al., 2008; Koch et al., 2013).

We evaluated the effect of ecological compensation, in-field options, farm characteristics and farm settings on plant, grasshopper, butterfly and bird richness and abundance on 133 Swiss farms. For each organism group, we calculated species richness and abundance. We hypothesised that farmers can enhance biodiversity on their farms and that the measures considered have a positive effect on species richness and abundance. A greater understanding of how these factors interact is important and will be useful to improve the efficacy and success of AES.

2. Materials and methods

2.1. Experimental design and biodiversity metrics

Biodiversity metrics and explanatory variables were assessed on 133 farms of the Swiss Central Plateau between 400 and 800 m a.s.l. from 2009 to 2011. Farms were selected based on a regular distribution along the Swiss Central Plateau, the utilised agricultural area for farming ranged between 20 and 30 ha (corresponding to the national lowland average), mixed production, and a wide spread in the proportion of arable crops. The mean utilised agricultural area per farm was 24.7 ± 0.1 ha (mean $\pm$ se; range: 17.3 ha to 34.0 ha). The average proportion of arable crops was $39.6 \pm 1.5\%$ (12.9%–90.8%), based on utilised agricultural area (= approx. total farm area). On average 19.9 ± 0.4 (10–38) transects were defined on each farm. Each transect was assigned to only one crop type. In total all transects per farm summed up to 2500 m. Based on the irregular field size, transects varied in length (average 126.5 ± 1.3 m, range 10–447 m). If feasible, transects covered the entire field diagonally. The field border (2.5 m) was not considered for transects. Each ecological compensation area (see below) was selected for a transect due to their variability. Furthermore all crop types on a farm were represented by a transect section.

Plant, insect and bird richness and abundance were used as biodiversity metrics. Birds were observed on the entire farm area, while plants and insects were recorded on transects. Each farm was visited once between 2009 and 2011, but plants, insects and birds were assessed during several visits within that year. Transects were walked at a constant pace and not faster than 3 km/h. All individuals found within 2.5 m from the transects (total transect width: 5 m) were determined to species level in the field and the data stored on digital handhelds (© Palm Tungsten E2, insects) or on printed forms (plants). Plants and grasshoppers were recorded during two visits per year meeting a predefined time period (plants: (1) 23 April to10 June, (2) 22 July to 8 September; grasshoppers: (1) 8 July to 11 August, (2) 15 August to18 September). Butterflies were recorded during six visits between 1 May and 8 September (3-week interval with regular distribution of the visits during the season). For grasshoppers and butterflies suitable weather conditions were specified (temperature > 13 °C, wind < 3 Beaufort, sunshine on > 80% of the transect). The time intervals were defined with the aim to record all species during the season. Plants were grouped into three abundance classes (sporadic, recurrent but not ground-covering and ground-covering) and grasshoppers into four abundance classes (1, 2–10, 11–100 and > 100 individuals). Abundance classes were determined per 100 m of transect section. If a transect section was < 100 m the abundance class per 100 m of transect section was estimated by extrapolation. For plants and grasshoppers, the maximum abundance class observed on either the first or second visit was considered as abundance. Butterfly abundance was based on the sum of all observed individuals of a given species over the six surveys per year.

Birds were recorded three times per year between April and July on the entire farm area. All visits took place during suitable weather conditions (minimal wind, no rain) between 6 and 11 a.m. A route was selected that allowed for audio-visual observation of the entire farm area. During the three records the ornithologists followed the same route but with different starting points or walking directions. Each visit spanned 1.5–3 h. All bird species heard or seen were recorded, resulting in presence/absence data. The number of territories per species and farm was assessed. Each visual or acoustic contact or breeding behaviour was recorded on a map and used to define the territories according to the breeding bird census method (Bibby et al., 2000; Birrer et al., 2007). To meet the criteria for assigning a breeding territory, species had to display territorial behaviour or had to be observed at least twice at the same place during different visits.

We calculated species richness and abundance for all four organism groups. For plants, grasshoppers and butterflies the total number of species from all transects per farm was taken as total species richness per farm. The abundance of each species per farm was extrapolated from abundance on transects according to proportions of crop types. First the abundance per field was calculated by multiplying transect section density (abundance divided by transect section area) by field size. For fields without transect sections (24.1% of the fields, $n = 3139$), the average density at transects of the same crop type on the same farm was used. When transect sections of a certain crop type were missing on that farm (2.3% of the fields), the average density of transects of this crop type had to be derived from other farms. To obtain species abundance, the abundance of each species found on all investigated fields per farm were added up.

The Swiss Federal Office for the Environment in collaboration with the Federal Office for Agriculture has prepared a set of Federal Environmental Objectives of the Agricultural Sector (EOAS) (BAFU and BLW, 2008). One objective states "agriculture should promote those native species in their natural range that occur mainly on land used for agricultural purposes or depend on agricultural use" (EOAS species). The list contains 731 plant, 48 grasshopper, 140 butterfly and 47 bird species. These listed farmland species need to have their primary distribution on farmland, which underlines the responsibility of the agricultural sector for those species. The list contains threatened species of conservation concern as well as common indicator species representing the quality of farmland