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Development of the arable vegetation 23 years after conversion from conventional to organic farming – experiences from a farm-scale case study in southern Germany

Entwicklung der Ackerwildkrautvegetation 23 Jahre nach der Umstellung auf ökologischen Landbau – Ergebnisse einer Fallstudie aus Süddeutschland

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Abstract

Recent meta-analyses assessing the impact of organic farming on plant species diversity showed that positive effects mainly occurred at a small scale while benefits at the farm or landscape level were less pronounced. The studies also detected that common species were more favored by organic farming than rare ones. In a farm scale study in southern Bavaria, Germany, we analyzed how the conversion to organic farming changed arable plant communities over a 23-years period and questioned the impact on weed management and species conservation. Vegetation sampling started two years before this conversion. At the end of the study period, crop cover had slightly decreased but yields of winter cereals (5.2 t/ha) still achieved 78% of the pre-organic harvest. Arable plant cover increased from 2 to 40% and the soil seed banks enlarged from 4200 to 33,300 seeds m^{-2}. Total numbers of plant species increased by 46% at the plot level and by 22% at the farm level, plant species characteristic of arable fields increased by 50% and 19%, respectively. Populations of both threatened and problematic plant species clearly profited from the conversion. Our results generally confirm that organic farming benefits plant biodiversity in arable land. Such benefits being more pronounced at the plot scale verifies previous studies, however, these effects were also visible over the whole arable area of the farm. A significant increase in the cover of insect-pollinated plants indicated that organic management can also support ecosystem functions. Our data prove that long-term organic farming can increase nature conservation value of the arable flora with only a moderate setback of crop yields.

Keywords: Arable plants, crop yield, pollinator plants, rare plant species, soil seed bank, species diversity, weeds

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

Intensification of land use during the last decades has caused severe changes in arable plant vegetation (ROBINSON & SUTHERLAND 2002, MEYER et al. 2015). The introduction of herbicides in combination with synthetic fertilizers, more narrow crop rotations, seed

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cleaning and the loss of extensively managed areas are factors which are considered responsible for the decline of plant species diversity in arable land (CIRUJEDA et al. 2011, STORKEY et al. 2012, MEYER et al. 2013).

A management system associated with higher plant species richness in arable fields is organic farming (HALD 1999, BENGTSSON et al. 2005, HOLE et al. 2005, GABRIEL et al. 2006, GIBSON et al. 2007, KOLÁŘOVÁ et al. 2013). Such increased species richness can be achieved by dispensing with synthetic agrochemicals both through ceasing herbicide applications which are the most efficient tool for weed control in conventional farming, and through lower nutrient levels, resulting in reduced crop competition (ALFOELDI et al. 2002). However, release from synthetic agrochemicals does not necessarily increase species richness. As the major objective of organic farming is to produce agricultural goods, many farmers replace herbicides by more frequent tillage operations or by cultivating competitive crops which efficiently suppress arable plants (BOND & GRUNDY 2001, WEIBULL et al. 2003, ALBRECHT 2005).

Most publications focusing effects of organic farming on arable plant diversity are based on short (≤ two years) or mid-term (3–8 years) investigations. The most prominent effect during this initial phase after conversion is usually achieved through the prohibition of herbicide treatments which benefits successful establishment of seedlings from the soil seed bank (BECKER & HURLE 1998). According to JONASON et al. (2011), this may even be the major factor determining farmland plant species richness between organic and conventional farming practices. Little is known, however, on the impact of management during the subsequent longer-term time periods. Then, e.g. multi-species rotations with their high share of legumes and spring sown crops may increasingly affect the species composition. In addition, also long-term nutrient decline could impact vegetation development. Thus, particularly stockless farms reveal a widespread decrease of soil fertility with increasing duration of organic farming because farmers do not cultivate sufficient proportions of forage crops which cannot be sold on the market (KOLBE 2016). Such factors may benefit the development of the arable flora at later stages after conversion and hence be a reason why various studies reported considerable increases of arable plant populations when fields had been managed organically for a longer time period (BECKER & HURLE 1998, RYAN et al. 2010, ROTCHÉS-RIBALTA et al. 2014).

Recent meta-analyses turned out that the positive effects of organic farming on plant species diversity mainly work at a small scale while benefits on the farm or landscape level are less pronounced (BENGTSSON et al. 2005, GIBSON et al. 2007, GABRIEL et al. 2010). In our study we intended to check if benefits are really restricted to the plot scale or if we can detect such biodiversity effects also at the farm level. Furthermore, studies found that organic farming mainly favors species which were already common in the study area (BENGTSSON et al. 2005, GIBSON et al. 2007, GABRIEL et al. 2010, SCHNEIDER et al. 2014). Therefore, we also asked if the increase of common 'weeds' is really a recurring principle in long-term organic farming. In this context we particularly emphasized problematic weeds which may seriously impact crop yields. Due to their potential impact on the growing conditions of the crop plants, the development of crop cover and yield were also included in our study.

In terms of rare arable plants, most studies that compared conventional to organic found a wider range of rare arable species, as well as larger populations of such species in the fields under organic management (ALBRECHT et al. 2016). As rare arable plants also occurred in our study area, their development was another important objective of our investigation. Finally, we also focused the change of arable pollinator plants which can fulfill important ecosystem function by providing food supply for pollinators (BATÁRY et al. 2013).

Favorable conditions to evaluate the effects of organic farming on arable plant communities by tracking their development on a whole farm scale from the start of transition over a 23 year time span were provided on the Scheyern Research Station in southern Bavaria, Germany. There, ten arable fields arranged in two blocks were converted from conventional to organic in autumn 1992 and an area-covering survey of the arable flora had already started two years earlier. In contrast to our one-farm study, some of the few other long-term investigations focusing the duration of organic farming on arable plant diversity were based on chronosequencies (BECKER & HURLE 1998, JONASON et al. 2011). There, space-for-time substitutions attempt to infer a temporal trend by studying different-age sites (STOHLGREN 2007). Although our one-farm study lacks such replications, it provides continuous observations on permanent plots and thus avoids possible error of chronosequencies by comparing locations with different site conditions or management histories. As initial results of our seed bank (ALBRECHT 2005) and field studies (ALBRECHT et al. 2008) had already been reported, the objective of this re-investigation was to emphasize the long-term effects of organic management.

The following questions were analysed: (1) How does the conversion to organic farming modify species diversity and population densities of the arable plants? (2) Are effects of long-term organic management more pronounced at the plot than at the farm scale? (3) Is there a clear temporal succession of changes in species richness soon after conversion and effects on population densities acting more on the long term? (4) Do frequent plant species profit more from organic farming than rare and endangered ones? (5) Does increasing plant species diversity go along with an increased number and cover of pollinator plant species?

2. Materials and Methods

2.1 Study site and management system

The analyses were performed on the Scheyern Research Station which is situated in the Tertiärhügelland (Tertiary Upland), southern Bavaria, Germany. Moderately acidic Cambisols with varying admixtures of loess provide good soil fertility in main parts of this area. Climate is humid with an average annual temperature of 8.1 °C and precipitation of 818 mm/year (Climate-Data.org, https://en.climate-data.org/continent/europe). Our study farm included 10 fields arranged in two blocks covering a total area of 27.0 ha. Before the study, all fields were cultivated equally with winter wheat in 1991 and spring barley in 1992 to level out different starting conditions caused by different crops. During this period, mineral fertilisation and chemical weed control of the preceding conventional farming were continued. After harvest in autumn 1992, management was changed to organic farming with a 7-yr rotation comprising grass-clover, potatoes, winter wheat, sunflowers, white lupine (replaced by a seed mixture for rotational fallow from the 4^{th} year), winter wheat and winter rye. During the first years of the project, legume-rich under-crops were frequently sown, however, due to negative impacts on the yield of the main crop (see Fig. 1), this practice was subsequently phased out. With the start of organic farming the percentage of autumn sown crops in the rotation declined from 80% to 42%. Mechanical weed control was performed in all crops except grass-clover, cereals were treated with a tined weeder two to three times during early crop development. Organic fertilisers (cattle slurry and stable manure) were applied at 130–200 kg N/ha to winter wheat and potatoes. To increase productivity by incorporating organic crop residues to greater soil depths, the plough layer was expanded from 22 cm in 1991 to 28 cm in 2001 (Median values; significant difference with Wilcoxon signed-rank test at $p < 0.05$).

The dominant plant community of winter cereal fields in the study region is the *Aphano-Matricarietum chamomillae* R. Tx. 1937 where the character species *Aphanes arvensis* and *Matricaria chamomilla* indicate fertile (± sandy) loam or clay with a good water holding capacity. According to HOFMEISTER & GARVE (1998) this is the most common arable plant association in Germany. Due to its high productivity, low competitive and rare arable plants are usually seldom at these sites.

2.2 Data collection

Sampling was performed at 103 plots which were 10 m × 10 m in size and which were ordered in a 50 m × 50 m grid. The plots were distributed over 10 fields which were arranged in two blocks. To avoid losses of the standard sampling area nine plots with grid points situated close to field edges were relocated to the interior field margin. Vegetation sampling started two years before and ended 23 years after conversion to organic farming. Field records were performed twice a year in early spring before weed control and shortly before harvest. They included the estimation of the percentage cover of each individual arable plant species and the total cover of crops and arable plants. The higher of the two estimations was used to calculate changes of individual species, values recorded before harvest were utilized to assess modifications of the total cover. To achieve standardized conditions for the analysis of vegetation changes, we exclusively used the data collected in winter cereals which were cultivated only every 2nd or 3rd year. Therefore, for comparing dependent variables, we defined four time periods: two years before the conversion with conventional winter wheat on all fields in 1991 (period 1), the initial phase up to three years after conversion from 1993 to 1995 (period 2), the consolidation period from the 4th (1996) to 6th year (1998) (period 3), and the long-term organic phase 22 and 23 years after conversion from 2014 to 2015 (period 4). As only seven fields were cultivated with cereal crops in 2014 and 2015, only 74 grid points representing a total area of 18.8 ha could be included in the field analyses. Cereals yields were calculated at 14% moisture using the data of the usual combine harvesting operations at field scale. As sampling exclusively in winter cereals may bias the evaluation of the overall species diversity of complete rotations, we additionally analysed the soil seed bank which reflects the total arable vegetation irrespective of actual management or climate conditions. For this purpose, we collected 20 to 30 soil cores from the whole plough layer of each of the 103 grid points by using soil borers with core diameters of 17 mm. These cores were mixed to attain one sample of 1 kg fresh weight per grid point. The samples were spread into seed trays where seedlings had 18 months to germinate (detailed description of this method is given by ALBRECHT & FORSTER 1996). Seed bank samples were collected during vegetation rest immediately before and in each of the first seven years after the change to organic farming, final sampling was performed 22 years after the conversion. To calculate the density of viable seeds per square meter we used data on bulk density and depth of the plough layer measured by the TUM Institute of Soil Ecology in 1991 and 2001 at the 50 m x 50 m grid point scale. Therefore, we first determined the (i) dry mass of the plough layer [kg/m²] = depth of plough layer [m] * bulk density [kg/m³] * 1000. Then, the soil dry mass was integrated in the calculation of the (ii) density of viable seeds (n/m²) = number of seedlings emerging per soil sample [n] * (dry mass of plough layer [kg/m²] / dry mass of soil sample [kg]).

Information on life forms and pollination systems of individual species were taken from the Flora Indicativa (LANDOLT et al. 2010) and BIOLFLOR database (KLOTZ et al. 2002). Arable plant species were divided into ubiquitous generalists (like *Cirsium arvense* or *Elymus repens*) and characteristic arable plants affiliated to the subclass *Violenea arvensis* Hüppe et Hofmeister 1990 after HOFMEISTER & GARVE (1998) and exclusively occurring on arable land. To evaluate the effect of organic farming on the regulating ecosystem function provided by the arable flora, the cumulative cover of pollinator plants was calculated. For species with different pollination systems (entomophily, autophily, anemophily), cover values were divided by the number of pollination strategies. Ephemerally occurring seedlings of woody plants were excluded from this analysis. Nomenclature of species follows THE PLANT LIST (2013). Crops and volunteer crops were excluded from all calculations of species richness.

2.3 Statistical analysis

The statistical significance of change of the percentage cover of each individual species between 1991 and 2014/15 was calculated by using the non-parametric Wilcoxon signed rank test (TER BRAAK & WIERTZ 1994, SOKAL & ROHLF 1998). To assess the changes of the community traits over the four time periods generalized linear models (GLMM) were calculated, with time since conversion to organic farming as fixed factor and the allocation to one of the ten study fields as nested random factor. In case of significance, pairwise post hoc Tukey-HSD tests were performed to find out significant differences between the individual time periods. To achieve normal distribution, values for the total arable plant cover were square root-transformed and numbers of seeds in soil were log-transformed before analyses. Calculations were performed using IBM SPSS Statistics for Windows, Version 25.0.

3. Results

Directly after conversion to organic farming, yields of winter cereals significantly declined from 6.7 to 3.2 t/ha and crop cover dropped from 70 to 35% (Fig. 1). With increasing duration of organic management, these values re-increased to 5.2 t/ha and 60%, respectively. Despite this re-increase in the final years of the study, cereal yields were still significantly below the initial values. The model revealed that the allocation to different fields had no significant influence.

Both the arable plant cover (Fig. 2) and the numbers of seeds in soil (Fig. 3) showed that the arable plant populations profited from the declining crop competition in the course of conversion to organic farming. While the median arable plant cover continuously increased from 2% under conventional to a final value of 40% after 23 years, the seed bank did not show such a consistent development. It initially increased from 4200 to 18,600 seeds m^{-2}, from the 4^{th} to the 6^{th} year, however, it re-declined to 9000 seeds m^{-2} (Fig. 3). From then on, seed numbers increased again until they achieved a final level of 33,300 seeds m^{-2}. Both the increase of the arable plant cover and of the number of seeds in soil were significant. The position in different fields had no significant impact on both the arable plant cover and the soil seed bank.

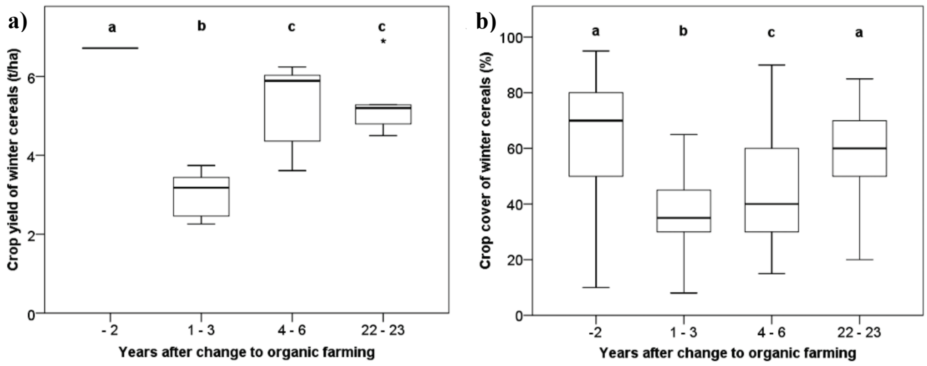

Fig. 1. Boxplots showing **a)** the development of crop yield and **b)** crop cover in winter cereals over the four time periods: 2 years before, and 1–3, 4–6, and 22–23 years after the conversion to organic farming. Significant differences in pairwise Tukey tests at $p < 0.05$ are indicated by different letters.

Abb. 1. a) Veränderung des Getreideertrags und **b)** der Getreidedeckung über die vier Untersuchungsphasen 2 Jahre vor und 1–3, 4–6 und 22–23 Jahre nach Umstellung auf Ökologischen Landbau. Unterschiedliche Buchstaben über den Box Plots bedeuten signifikante Unterschiede bei $p < 0,05$ nach paarweisem Tukey-Test.

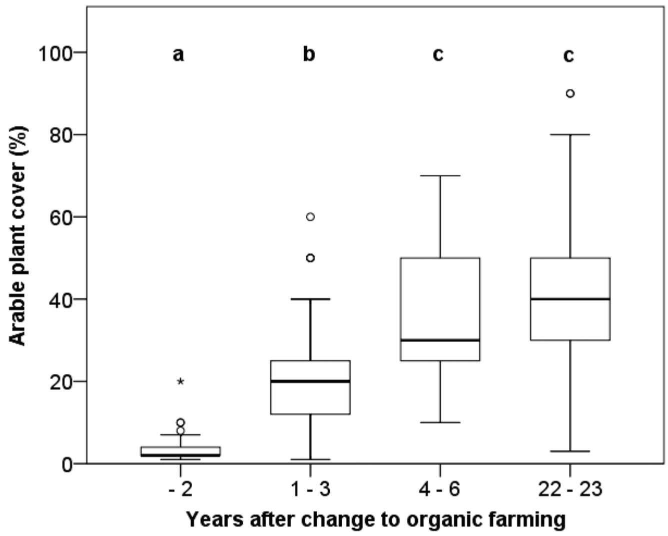

Fig. 2. Development of the arable plant cover before and after the change to organic farming. Significant differences are indicated by different letters.

Abb. 2. Veränderung der Gesamtdeckung der Ackerwildpflanzen nach der Umstellung auf ökologischen Landbau. Unterschiedliche Buchstaben über den Box Plots bedeuten signifikante Unterschiede zwischen den Phasen.

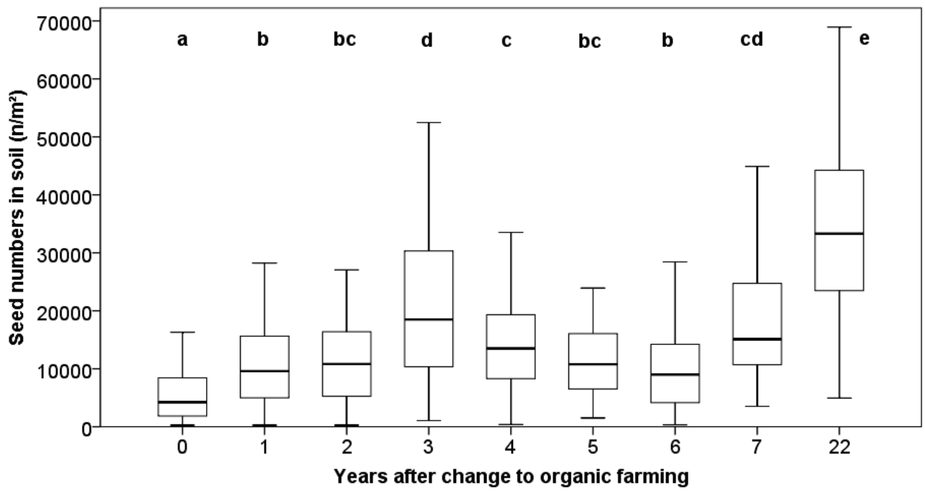

Fig. 3. Development of the seed numbers in soil before and after the change to organic farming. Significant differences are indicated by different letters.

Abb. 3. Veränderung der Samenbanken im Boden vor nach der Umstellung auf ökologischen Landbau. Unterschiedliche Buchstaben über den Box Plots bedeuten signifikante Unterschiede zwischen den Phasen.

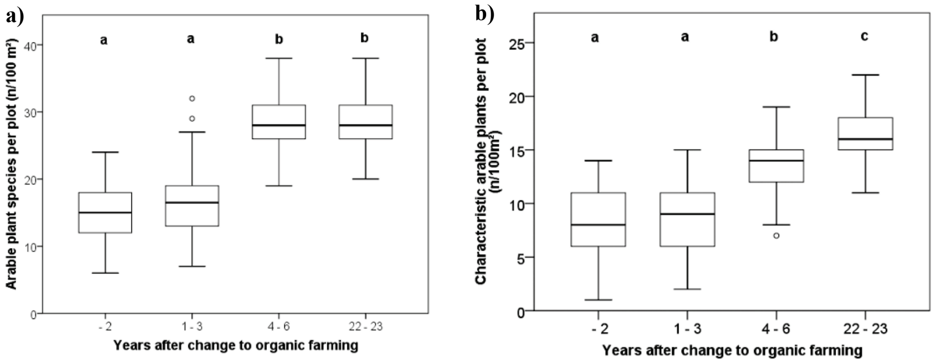

Fig. 4. Boxplots showing the development of total number of **a)** arable plant species per plot and **b)** number of characteristic arable plant species per plot in winter cereals over the four time periods: 2 years before, 1–3, 4–6, and 22–23 years after the conversion to organic farming, respectively. Significant differences are indicated by different letters.

Abb. 4. a) Veränderung der Gesamtzahl und **b)** Anzahl der charakteristischen Ackerwildpflanzen pro Aufnahmefläche während die vier Untersuchungsphasen: 2 Jahre vor und 1–3, 4–6 und 22–23 Jahre nach Umstellung auf Ökologischen Landbau. Unterschiedliche Buchstaben über den Box Plots bedeuten signifikante Unterschiede zwischen den Phasen.

During the first three years of organic farming the total number of plant species per sampling plot showed little response to the new growing conditions (insignificant increase from 15 to 16.5 species per plot; Fig. 4a). From the 4^{th} to the 6^{th} year, however, species numbers sharply increased to 29 species and maintained this level until the end of the study. Similarly, also the numbers of characteristic arable plants showed scarcely any initial reaction (from 8 to 9 species per grid point; Fig. 4b), but significantly increased to 14 species from the 4^{th} to the 6^{th} year and to the final level of 16 after 23 years. The position in different fields showed no significant impact on the species richness.

On the scale of the whole farm, the total number of plant species consistently increased from 67 to 87 and 106 over the first six years after the introduction of organic farming (Fig. 5a). After 23 years, their number had re-decreased to 79 species. The total number of characteristic arable plant species increased from an initial value of 25 to between 30 and 33 after the conversion. Total numbers of species in the soil seed bank were 50 and 48 before and immediately after the conversion (Fig. 5b), then the values showed an undirected fluctuation between 61 and 68 species. The number of characteristic arable plant species found in the seed bank was 21 before the introduction of organic farming and achieved its maximum of 28 species 22 years after conversion.

The total number of plant species found in this study was 168, including 23 crop and volunteer crop species. Among the 67 species occurring frequently enough to test their change in the established vegetation statistically, 36 increased, 27 stayed unchanged and only 4 decreased (Table 1).

The list of species which significantly increased comprises a large number of highly competitive plants like *Anthemis arvensis*, *Apera spica-venti*, *Atriplex patula*, *Cyanus segetum*, *Chenopodium album*, *Cirsium arvense*, *Convolvulus arvensis*, *Elymus repens*, *Fallopia convolvulus*, *Galium aparine*, *Galinsoga ciliata*, *Matricaria chamomilla*, *Papaver rhoeas*, *Persicaria lapathifolia*, *P. maculosa*, *Rumex crispus*, *R. obtusifolius*, *Sonchus asper*,

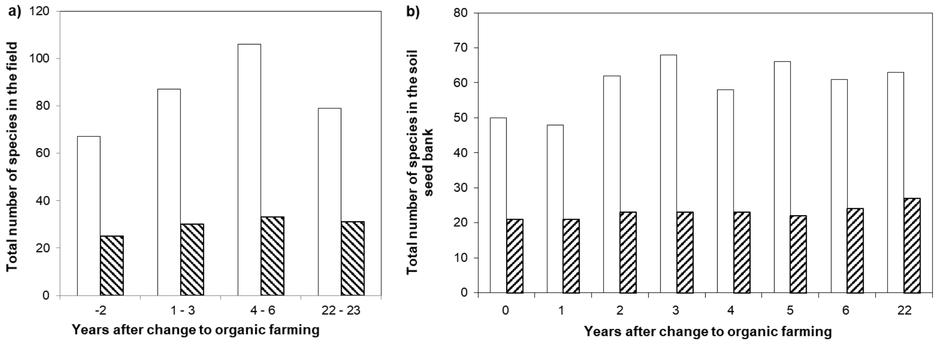

Fig. 5. Change of **a)** the total numbers of species in winter cereal fields and **b)** in the soil seed bank at the farm scale before and after the conversion to organic farming. White bars represent total number of species without crops, hatched bars indicate characteristic arable plants.

Abb. 5. Veränderung **a)** der Gesamtartenzahl auf Betriebsebene in Wintergetreidebeständen und **b)** im Bodensamenvorrat vor und nach der Umstellung auf Ökologischen Landbau. Weiße Balken repräsentieren die Gesamtartenzahl ohne Kulturarten, schraffierte Balken zeigen die Zahl charakteristischer Ackerwildpflanzen.

Stellaria media, and *Tripleurospermum inodorum*. They all can cause severe weed infestation problems in arable land (HOLZNER & GLAUNINGER 2005; Table 1). Other species showed an initial increase but re-declined with the duration of organic farming. This group mainly included omnipresent pioneer species with the capacity for long distance wind dispersal like *Conyza canadensis*, *Epilobium* spp., *Sonchus* spp., *Taraxacum officinale*. With 33 increases, 13 unchanged species and one decrease, the seed bank studies generally confirmed the tendencies already detected in the field data. Indicators for temporary moisture in soil like *Gnaphalium uliginosum*, *Juncus bufonius*, *Myosurus minimus*, *Plantago intermedia* or *Sagina procumbens* (HOFMEISTER & GARVE 1998) remained unchanged or even decreased. Only one characteristic arable plant species, *Papaver rhoeas*, newly occurred after the introduction of organic management. In the soil seed bank, species with highest constancies at the beginning and end of the study were *Matricaria chamomilla* and *Capsella bursa-pastoris*, the summer annuals *Galinsoga ciliata*, *Poa annua* and *Chenopodium album* showed the highest increases. The number of pollinator plants significantly increased from 12 to 20 species per plot and their cumulative cover stepped from 2.4% to 17.2% (Fig. 6). The position in different fields showed no significant influence on the development of the pollinator plants.

Nine arable plant species listed in the local Red Data Book of the study region (SCHEURER & AHLMER 2003) were found on the research station, however, all of them were already found before the conversion to organic farming. Among the five species occurring frequently enough to test for significant changes, *Cyanus segetum* and *Legousia speculum-veneris* had increased, *Odontites verna* and *Sherardia arvensis* remained unchanged, and *Myosurus minimus* declined. *Anagallis minima*, *Anchusa arvensis*, *Papaver argemone* and *Scleranthus annuus* were too rare for statistical testing.

Table 1. Changes of individual species in the established vegetation and in the soil seed bank from before (1991–1992) to the initial (1993–1998) and late (2014–2015) phase after conversion to organic farming. Symbols indicate significant increase (+), no significant change (±), and a significant decline (-) tested by Wilcoxon signed-rank tests. Competitive ability (from 1 = very low to 5 = highly competitive) after HOLZNER & GLAUNINGER (2005). Pollination systems are: au = self-pollination (autophily), an = wind-pollination (anemophily), en = insect-pollination (entomophily).

Tabelle 1. Entwicklung einzelner Arten im Feldbestand und im Bodensamenvorrat vor (1991–1992), zu Beginn (1993–1998) und am Ende (2014–2015) der Umstellung auf Ökolandbau. Die Symbole kennzeichnen Zunahmen (+), nicht signifikante Veränderungen (±) und signifikante Abnahmen (-) nach Wilcoxon Vorzeichentest. Die Konkurrenzkraft nach HOLZNER & GLAUNINGER (2005) reicht von 1 = sehr gering bis 5 = sehr stark. Die Bestäubungssysteme sind: au = Selbstbestäubung (Autophilie), an = Windbestäubung (Anemophilie) und en = Insektenbestäubung (Entomophilie).

Species	Changes in the established vegetation			Changes in soil seed banks			Species characteristics		
	1991/1996–98	1996–98/2014–15	1991/2014–15	1992/1998	1998/2014	1992/2014	Arable species	Competitive ability	Pollination system
Achillea millefolium	+	±	±						en
Agrostis stolonifera				±	±	+			an
Anagallis arvensis	±	±	±	±	±	±	×	1	au
Anthemis arvensis	+	+	+	+	+	+	×	3	au en
Apera spica-venti	+	+	+	+	-	+	×	3–4	an
Aphanes arvensis	+	±	+	±	+	+	×	1	au en
Arabidopsis thaliana	+	+	+	±	+	+		1	au en
Atriplex patula	+	-	+					3	an en
Capsella bursa-pastoris	±	±	+	±	+	+		1–2	au en
Cerastium glomeratum	±	±	+	±	+	+			au en
Cerastium holosteoides	±	±	+						au en
Chenopodium album	+	±	+	+	+	+		5	an
Chenopodium ficifolium				±	±	±		2–3	an
Chenopodium polyspermum	+	-	±	+	+	+	×	2–3	an
Cirsium arvense	+	±	+	±	±	+		5	au en
Cirsium vulgare	+	-	+						en
Concolvulus arvensis	±	±	±					3	au en
Conyza canadensis	+	±	+					3	en
Cyanus segetum	±	+	+				×	3	en
Elymus repens	+	±	-					4–5	an
Epilobium spp.	+	-	±	+	±	±			au
Equisetum arvense	±	±	±					1–2	
Erophila verna	±	±	±						au
Euphorbia helioscopia				±	±	+	×	2	en
Fallopia convolvulus	+	±	+	±	+	±	×	3–4	au
Galeopsis tetrahit	+	±	+					3–4	en
Galium aparine	+	-	+	+	-	±		4–5	au en
Galinsogs ciliata	+	±	+	+	+	+	×	3	au
Geranium dissectum	+	+	+				×		au en
Gnaphalium uliginosum	±	±	-	+	±	+		1–2	au en
Juncus bufonius	±	-	±	+	±	+		1	an

Species	Changes in the established vegetation			Changes in soil seed banks			Species characteristics		
	1991/1996–98	1996–98/2014–15	1991/2014–15	1992/1998	1998/2014	1992/2014	Arable species	Competitive ability	Pollination system
Lactuca serriola	+	±	±						au en
Lamium amplexicaule	±	±	±	+	±	+	×	1-2	en au
Lamium purpureum	+	±	±	+	+	+	×	2	en au
Lapsana communis	+	+	+	±	+	+		2–3	au en
Legousia speculum-veneris	+	±	+	±	+	+	×	2	au en
Matricaria chamomilla	+	±	+	+	+	+	×	3	en
Matricaria discoidea	-	+	±					2	au en
Myosotis arvensis	+	±	+	±	+	+	×	1–2	au en
Myosurus minimus	±	-	-	±	±	±			au en
Odontites verna	±	±	±				×		au an en
Papaver rhoeas	±	+	+	±	+	+	×	3	en
Plantago intermedia	+	-	±	±	±	+			an au
Poa annua	+	±	+	±	+	+		1	au an
Poa trivialis	+	-	+	+	-	±		2–3	an
Persicaria hydropiper	+	+	+					2-3	au
Persicaria maculosa	±	±	±				×	3–4	au en
Polygonum aviculare	+	-	+	+	±	±		2–3	au
Polygonum lapathifolium	+	-	±	±	+	+		4	au en
Ranunculus repens	+	-	±					2	au en
Rumex crispus	±	+	+	±	+	+			an
Rumex obtusifolius	+	+	+	+	+	+			an
Sagina procumbens				±	±	±			au en
Sherardia arvensis	+	±	±				×	1	au en
Solanum nigrum	-	±	-	±	-	-		2-3	en
Sonchus arvensis	±	±	±					3–4	au en
Sonchus asper	+	-	+	±	±	+	×	3	en
Sonchus oleraceus	+	-	±	±	±	±		2–3	en
Stellaria media	+	±	+	+	+	+		3	au en
Taraxacum officinale	+	-	-	+	-	±		2–3	au en
Thlaspi arvense	+	+	+	±	+	+	×	2	au en
Trifolium campestre	±	±	±					1	en
Tripleurospermum inodorum	+	±	±	±	+	+		4	en
Veronica arvensis	+	+	±	±	+	+	×	1	au en
Veronica hederifolia	±	±	+	±	+	+	×	2	au en
Veronica persica	+	+	+	+	+	+	×	2–3	au en
Veronica polita	+	+	±	±	±	±	×		au en
Vicia angustifolia	±	±	±				×	2	au en
Vicia hirsuta	+	+	+				×		au
Vicia tetrasperma	+	±	+				×		au
Viola arvensis	±	±	±	-	+	±	×	1–2	au en
Sum of increased species	44	16	36	18	26	33			
Sum of constant species	21	35	27	28	16	13			
Sum of decreased species	2	16	4	1	5	1			

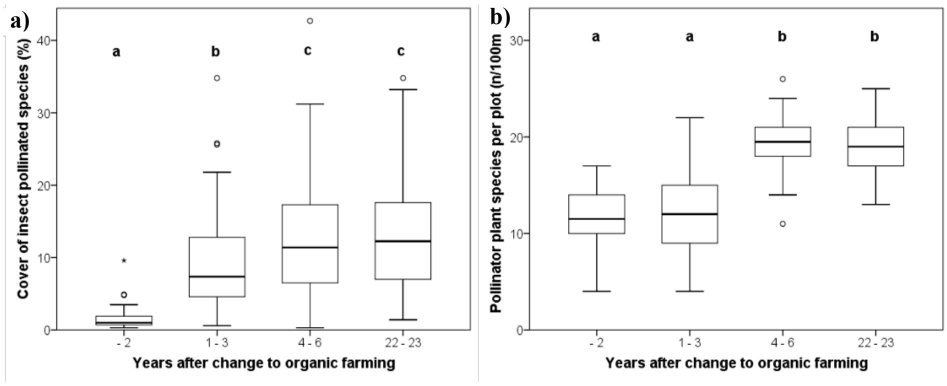

Fig. 6. Boxplots showing the development of **a)** the number and **b)** cumulative cover of insect-pollinated plant species in winter cereals 2 years before, and 1–3, 4–6, and 22–23 years after the conversion to organic farming. Significant differences are indicated by different letters.

Abb. 6. Veränderung **a)** der Anzahl und **b)** der kumulativen Deckung insektenbestäubter Arten pro Aufnahmefläche während der vier Untersuchungsphasen 2 Jahre vor und 1–3, 4–6 und 22–23 Jahre nach der Umstellung auf Ökologischen Landbau. Unterschiedliche Buchstaben über den Box Plots bedeuten signifikante Unterschiede zwischen den Phasen.

4. Discussion

4.1 Arable plant development and management

On the Scheyern Research Station cover of arable plants significantly increased from 2% before the conversion to organic farming to 30% four to six years later and 40% 22 to 23 years after this change. These results are in line with BECKER & HURLE (1998) who observed a mean cover of 29% after more than eight years of organic management on farms in Southwest Germany and FULLER et al. (2005) who found a median cover of 37% in organic cereal fields in England. This strong increase also became evident in the rise of the soil seed bank from 6400 to 33,300 seeds m^{-2}. These data are consistent with RYAN et al. (2010) who found an increase from 13,000 to 48,000 seeds m^{-2} over 25 years and WITTMANN et al. (2014) where values rose from 13,240 to 33,200 seeds m^{-2} in 18 years. Our results also confirm LUNDKVIST et al. (2008) who observed that the introduction of organic farming facilitates problematic arable plant species with high competitive ability.

This increase in the arable plant density with time since conversion to organic farming can be mainly explained by the exclusion of herbicides (JONASON et al. 2011). Another less considered factor working more in the long term is the declining crop competition due to decreasing nutrient concentrations (KOLBE 2016). Reasons were seen in the farmer's preference of production towards the maintenance of soil fertility (WATSON et al. 2002). Thus, interior parts of cereal crop fields in England held a cover of only 55% compared to 81% on non-organic fields (FULLER et al. (2005). In our study, cover of cereal crops declined from an initial value of 70% to 60% after 23 years of organic farming. Such crop cover can provide highly favorable conditions for arable plants (ALBRECHT 2005).

Despite strong competition by arable plants, the yield of winter cereals in the growing seasons of 2014 and 2015 achieved 5.2 t/ha. Extremely favorable climate conditions during these years resulting in the highest cereal yields ever achieved in Germany (The World

Bank; https://data.worldbank.org/indicator/AG.YLD.CREL.KG, accessed 2020-02-22) may have contributed to this high value. However, if the preference of production towards the maintenance of soil fertility will continue, declining yields and further increasing 'weed infestation' may be the consequence. Higher percentages of forage crops and underseeds being particularly efficient in reducing weed infestation problems in organic fields (ALBRECHT 2005) could help to counteract this challenge.

4.2 Biodiversity effects of long-term organic farming

Our study confirms FULLER et al. (2005), BENGTSSON et al. (2005), and TUCK et al. (2014) who found increased floral species richness in organic fields. The observation that this increase of species richness mainly occurred during the initial phase after the introduction of organic farming and then remained at a constantly high level also agrees with JONASON et al. (2011). The trigger which presumably induced this trend is the successful recovery of arable plant populations from the soil seed bank after ceasing herbicide applications. But also long-term management practices had a significant influence on the development. In our seed bank studies, several summer annual species showed the highest increases in constancy and seed numbers. Obviously, the increase of summer annual crops from 20 to 58% of the rotation facilitated these species which were relatively seldom before the conversion. In addition, also species from outside the arable fields significantly contributed to the increase of species richness. During the initial phase after the conversion to organic farming, wind dispersed generalists and seedlings of woody plants with wind and animal dispersed seeds substantially contributed to the species pool. Establishment of such plants was facilitated by the low crop cover initially after the conversion (ALBRECHT 2005) and by setting aside some fields adjacent to the study area (ALBRECHT et al. 2008). With the duration of organic farming, however, such ephemeral plants were successively replaced by species of arable habitats. Mainly two types of species profited on the long term: Characteristic arable plants which are closely confined to arable management and generalists tolerating arable farming practices but also occurring in other disturbed habitats. As most of the characteristic species almost exclusively occur in arable land, their increase can be considered much more important for nature conservation than the overall increase of species richness. However, also common generalists like *Elymus repens*, *Cirsium arvense* or *Galium aparine* significantly increased. As they can cause significant crop losses due to their high competitive ability (Table 1), this is certainly an unintended effect of organic farming.

In our study, the majority of threatened arable plants remained constant or increased. Thus, our results agree with the literature review by HOLE et al. (2005) and support their conclusion that organic farming can substantially contribute to the conservation of rare arable plants. Such beneficial effects, however, can only work if the rare species are still present. The longer fields had been under conventional exploitation, the higher the rare species risk of extinction. Therefore, fields with a long history of organic farming provide the best chances to conserve rare arable plants. If their populations are already extinct, actively transferring seeds to extensively used sites could be a more promising way to re-establish them than to rely on their spontaneous colonization (ALBRECHT et al. 2016).

In our study we deliberately selected winter cereal crops because they best represent the total species richness and the presence of rare arable plants under Central European growing conditions (ALBRECHT et al. 2016). The positive effects we observed in our study contradict SCHNEIDER et al. (2014), who performed random vegetation sampling in organic fields in different regions across Europe and North Africa. They found that organic farming scarcely had significant benefits on species diversity when sampling plots had no selection bias by preferring certain crops. This comparison shows that the results of a biodiversity assessment in organic farming may depend with the objective and the method of the study: While our study design aimed at providing as precise a picture as possible of the changes in the total plant assemblage, the method of SCHNEIDER et al. (2014) reflects the species diversity at a certain point in time regardless of the cultivated crop. The latter approach may be more useful to assess e.g. ecosystem functions simultaneously provided by all fields of a farm.

4.3 Pollinator function

The increase of plant species richness was accompanied by a strong increase of the cover and the diversity of forage plants for pollinating insects. These results show that the spontaneous plants of organic fields can provide an important source of food for pollinators in the agricultural landscape. Our values of the cover and species numbers of pollinator plants are even higher than the results obtained by GABRIEL & TSCHARNTKE (2007) and BATÁRY et al. (2013) who also found significantly greater food supply for pollinators in organic fields. This distinction may be due to differences between the respective plant assemblages. Most soils of our study sites are loamy and moderately acidic. When cultivated with winter cereals, such sites particularly favor Asteraceae species like *Matricaria chamomilla*, *Anthemis arvensis*, *Cyanus segetum* and some smaller insect-pollinated species like *Viola arvensis* and *Myosotis arvensis* (HOFMEISTER & GARVE 1998). If spring crops are sown within the rotation, plant communities usually harbor a higher share of wind-pollinated species from the *Chenopodiaceae* or *Polygonaceae* families. There, however, most of the organic crops themselves are insect-pollinated. On the Scheyern Research Station sun flowers, potatoes, leguminous crops, and grass clover amounted for almost 50% of the whole rotation. Therefore, crop species and insect-pollinated arable plants together can provide an important food source for pollinators over the entire crop rotation. This stands in clear contrast to the crop spectrum of conventional farming with its preference for wind-pollinated cereal crops and the associated monocotyledonous weeds. These results demonstrate that organic management in arable land can seriously contribute to the regulating ecosystem services. In the discussion on the biodiversity effects of organic farming this aspect should gain greater importance in the future.

4.4 Effects of sampling scale

Various studies on the effect of organic farming on arable species diversity were performed on a small plot scale. Meta-analyses by BENGTSSON et al. (2005) and GABRIEL et al. (2010) criticized that this approach leads to a strong sampling bias as organic management increases diversity mainly at a small plot level while effects at the farm or landscape scale remain small. Our results confirm that the benefits for biodiversity were more expressed at the small scale, however, effects were also visible over the whole arable land of the farm (Fig. 5). Therefore, our results prove that benefits of organic farming can exceed the microscale of sampling points. The high crop yields harvested on the Research Station also confirm the observation of these authors that the impact of organic farming on biodiversity is more expressed in highly productive landscapes than in regions with less fertile soils and a high structural diversity.

Erweiterte deutsche Zusammenfassung

Einleitung – Der Ökologische Landbau bietet günstige Voraussetzungen, die pflanzliche Artenvielfalt der Ackerflächen zu erhalten (BENGTSSON et al. 2005, HOLE et al. 2005, GABRIEL et al. 2006). Vor allem die durch Wegfall der Herbizidbehandlungen verbesserten Etablierungsbedingungen für Keimlinge zeigen hier oft schon kurzfristig eine positive Wirkung (JONASON et al. 2011). Weniger bekannt ist dagegen über die Langzeiteffekte des Ökolandbaues. Vielfältigere Fruchtfolgen mit erhöhten Anteilen von Sommerungen und der Rückgang der Bodennährstoffe, der besonders die Kulturpflanzen schwächt, können die Ackerwildpflanzen hier begünstigen (BECKER & HURLE 1998, RYAN et al. 2010, ROTCHÉS-RIBALTA et al. 2014). Solche langfristigen Veränderungen der Ackerwildkrautvegetation von vor bis 23 Jahre nach der Umstellung auf Ökolandbau sind Gegenstand der vorliegenden Studie. Da aktuelle Meta-Analysen zeigen, dass der Ökolandbau die Artenvielfalt der Ackerwildpflanzen eher kleinflächig und weniger auf Betriebs- oder Landschaftsebene begünstigt (GIBSON et al. 2007, GABRIEL et al. 2010), wurde analysiert, ob sich solche positiven Effekte auch langfristig auf kleinen Maßstab beschränken oder ob sie dann auch großflächig, z. B. auf Betriebsebene, wirksam werden. Zudem sollte geprüft werden, ob die Umstellung eher die bereits häufigen Arten einschließlich unerwünschter Problemunkräuter fördert (BENGTSSON et al. 2005, GABRIEL et al. 2010, SCHNEIDER et al. 2014), oder ob auch seltene Ackerwildkräuter profitieren können. Schließlich sollte untersucht werden, ob der Ökolandbau auch das Nahrungsangebot für blütenbesuchende Insekten verbessern kann (vgl. BATÁRY et al. 2013).

Methoden – Die Untersuchungen wurden auf Flächen der FAM-Versuchsstation Scheyern im oberbayerischen Tertiärhügelland durchgeführt, deren Bewirtschaftung im Herbst 1992 von konventionell auf ökologisch umgestellt wurde (s. ALBRECHT 2005, ALBRECHT et al. 2008). Die dort in Wintergetreide dominante Pflanzengesellschaft ist das *Aphano-Matricarietum chamomillae* R. Tx. 1937. Die Gesamtfläche der 10 untersuchten Ackerparzellen umfasste 27 ha. Zur Standardisierung der Ausgangsbedingungen wurde vor Erhebungsbeginn auf allen Flächen einheitlich Winterweizen angebaut und konventionell bewirtschaftet. Nach der Ernte im Herbst 1992 begann die ökologische Bewirtschaftung mit einer siebengliedrigen Fruchtfolge aus Kleegras, Kartoffeln, Winterweizen, Sonnenblumen, Lupinen, Winterweizen und Winterroggen. Leguminosenreiche Untersaaten wurden wegen verringerter Hauptfruchterträge nach drei Jahren wieder eingestellt (Abb. 1). Der Fruchtfolgeanteil der Winterungen sank mit der Umstellung von 80% auf 42%. In allen Kulturen außer Kleegras erfolgte mechanische Unkrautregulierung.

Die 103 jeweils 10 × 10 m große Probeflächen waren in einem 50 × 50 m Raster angeordnet. Die Vegetationsaufnahmen wurden zwei Jahre vor der Umstellung begonnen und über 23 Jahre nach der Umstellung fortgeführt. Um die Vergleichbarkeit der Ergebnisse sicherzustellen, wurden hier nur Daten des alle zwei bis drei Jahre angebauten Wintergetreides analysiert. Folgende vier Versuchsphasen wurden definiert: Phase 1 – Ausgangsphase mit konventionellem Winterweizenanbau (1991), Phase 2 – frühe Umstellungsphase (1993–1995), Phase 3 – Konsolidierungsphase (1994–1996) und Phase 4 – Endphase vom 22. bis zum 23. Jahr (2014–2015). Zur Analyse der Bodensamenvorräte wurden an jedem der 103 Messpunkte jeweils im Spätwinter 20–30 Bodenproben auf A_p-Tiefe entnommen und zu Mischproben von je 1 kg Frischgewicht vereinigt. Die Proben wurden in Styroporschalen ausgebreitet und auflaufende Keimlinge wurden 18 Monate lang notiert. Bestäubungssysteme der Arten wurden der Flora Indicativa (LANDOLT et al. 2010) und der BIOLFLOR Datenbank (KLOTZ et al. 2002) entnommen.

Die Veränderungen von Einzelarten wurden mit Wilcoxon-Tests analysiert (SOKAL & ROHLF 1998), am Gesamtbestand wurden die Veränderung der Deckung, der Gesamtartenzahl, der Zahl charakteristischer Ackerwildpflanzenarten sowie die Dichte lebensfähiger Samen im Boden ausgewertet. Als charakteristische Ackerwildpflanzenarten wurden solche betrachtet, die der Unterklasse *Violenea arvensis* Hüppe et Hofmeister 1990 angehören. Zur Abschätzung des Blütenangebotes wurde die kumulative Deckung insektenbestäubter Arten berechnet. Die Veränderungen dieser Merkmale wurden mit Hilfe verallgemeinerter linearer gemischter Modelle (GLMM) berechnet, mit *Zeit seit der Umstellung* als festem und der *Identität der zehn Ackerparzellen* als genestetem Zufallsfaktor. Anschließende paarweise Vergleiche einzelner Phasen erfolgten mit Tukey-Tests.

Ergebnisse – Die mittlere Deckung der Getreidepflanzen nahm nach der Umstellung zunächst von 70 auf 35 % ab (Abb. 1), stieg bis zum Untersuchungsende aber wieder auf 60 % an. Die Wildpflanzendeckung stieg im Gesamtzeitraum von 2 auf 40 % an (Abb. 2) und die Samenvorräte zeigten einen Anstieg von 4200 auf 33.300 Samen pro m^{-2} (Abb. 3). Die Artenzahl pro Aufnahmefläche, die vor der Umstellung bei 15 lag, stieg bis zum 4. bis 6. Umstellungsjahr signifikant auf 29 an und hielt dieses Niveau bis zum Versuchsende (Abb. 4a). Die Anzahl der charakteristischen Ackerwildpflanzen stieg in der Konsolidierungsphase signifikant von 8 auf 14 Arten an und erreichte nach 23 Jahren schließlich den Endwert von 16.

Auf Betriebsebene wuchs die Zahl jährlich gefundener Wildpflanzen in den ersten sechs Umstellungsjahren von 67 auf 106 an (Abb. 5a), nach 23 Jahren war sie aber wieder auf 79 gefallen. Die Zahl charakteristischer Ackerwildpflanzen stieg über den Gesamtzeitraum von 25 auf 33 Arten an. In der Samenbank wurden kurz vor und kurz nach der Umstellung 50 bzw. 48 Wildpflanzenarten gefunden (Abb. 5b), in den Folgejahren streuten die Zahlen zwischen 61 und 68. Die Zahl der charakteristischen Ackerwildpflanzen in der Samenbank erhöhte sich im Gesamtzeitraum von 21 auf 28 Arten.

Insgesamt wurden 168 Pflanzenarten nachgewiesen, darunter 23 Kulturarten. Von den 67 Arten, die in der Vegetation häufig genug vorkamen, um Veränderungen statistisch zu prüfen, hatten 36 zugenommen, 27 blieben unverändert und 4 nahmen ab (Tab. 1). Unter den häufiger gefundenen Arten waren viele die mit mittlerer bis sehr hoher Konkurrenzkraft, die erhebliche Verunkrautungsprobleme verursachen können (Tab. 1). Andere Arten nahmen anfänglich zu und dann dauerhaft wieder ab, darunter Pionierarten mit effizienter Fernausbreitung wie *Conyza canadensis*, *Epilobium* spp., *Sonchus* spp. oder *Taraxacum officinale*. Mit 33 Gewinnern, 13 Konstanten und einem Verlierer bestätigen die Artenveränderungen in der Samenbank die Entwicklungstendenzen im Feldbestand. Die Arten mit den über den Untersuchungszeitraum konstant höchsten Samenzahlen und Stetigkeiten waren *Matricaria chamomilla* und *Capsella bursa-pastoris*, die sommer-annuellen Sippen *Galinsoga ciliata*, *Poa annua* und *Chenopodium album* zeigten die höchsten Zuwachsraten. Lediglich eine charakteristische Ackerwildpflanzenart, *Papaver rhoeas*, wurde nach der Umstellung neu nachgewiesen. Von den fünf Rote Liste-Arten, die häufig genug für eine statistische Auswertung vorkamen, nahmen zwei zu (*Cyanus segetum*, *Legousia speculum-veneris*), zwei blieben unverändert (*Odontites verna*, *Sherardia arvensis*) und eine (*Myosurus minimus*) ging zurück. Die Zahl der insektenbestäubten Arten stieg von 12 auf 20 pro Aufnahmefläche und ihre kumulative Deckung erhöhte sich von 2,4 auf 17,2 % (Abb. 5).

Diskussion – Die im Feldbestand und Samenvorrat der Wildpflanzen nach Umstellung auf ökologischen Landbau festgestellten Zunahmen stimmen mit Ergebnissen von BECKER & HURLE (1998), FULLER et al. (2005) und RYAN et al. (2010) überein und bestätigen auch LUNDKVIST et al. (2008), die eine besonders starke Zunahme konkurrenzkräftiger Ackerwildpflanzen fanden. Wahrscheinliche Ursachen für diese Entwicklung sind die Einstellung der Herbizidbehandlungen (JONASON et al. 2011) sowie eine reduzierte Kulturpflanzendeckung, mutmaßlich infolge eines verringerten Nährstoffangebots (FULLER et al. 2005). Trotz dieses relativ starken Unkrautaufkommens wurden 2014 und 2015 mit durchschnittlich 52 dt/ha ungewöhnlich hohe Getreideerträge erwirtschaftet, allerdings wurden in den beiden Jahren aufgrund günstiger Witterungsbedingungen auch deutschlandweit die höchsten jemals gemessenen Getreideerträge erzielt (THE WORLD BANK; https://data.worldbank.org/indicator/AG.YLD.CREL.KG, accessed 2020-02-22).

Auch die von FULLER et al. (2005), BENGTSSON et al. (2005) und TUCK et al. (2014) in ökologisch bewirtschafteten Äckern beobachtete erhöhte Artenvielfalt konnte bestätigt werden. Dieser Effekt tritt rasch nach der Umstellung auf, weil sich schon durch Unterlassung der ersten Herbizidapplikation deutlich günstigere Entwicklungsbedingungen für die Wildpflanzen einstellen (JONASON et al. 2011). Aber auch langfristige Bewirtschaftungsmaßnahmen zeigten deutliche Effekte. So steht der starke Zuwachs sommerannueller Sippen im Samenvorrat in Zusammenhang mit dem Anstieg des Sommerfruchtanteils von 20 auf 58 %. Auch störungsintolerante, ubiquitäte Arten mit effizienten Fernausbreitungsstrategien trugen nach der Umstellung maßgeblich zum Anstieg der Diversität bei, gingen mit zunehmender Dauer aber wieder deutlich zurück. Damit bleiben zwei Artengruppen, die vom Ökolandbau langfristig besonders profitierten: Charakteristische Ackerwildpflanzen und störungstolerante Generalisten. Da die meisten charakteristischen Ackerwildpflanzen eher geringe Konkurrenzkraft und eine enge Bindung an Ackerbewirtschaftung aufweisen (s. Tab. 1), ist ihre Zunahme naturschutzfachlich höher einzustufen als der Anstieg der Gesamtartenzahl. Auch vier der fünf gefundenen Rote Liste-Arten blieben unverändert oder nahmen zu. Dies bestätigt, dass Ökolandbau substantiell zur Erhaltung gefährdeter Ackerwildpflanzen beitragen kann (HOLE et al. 2005). Dazu müssen die Arten allerdings noch im Bodensamenvorrat vorhanden sein, was mit zunehmender Dauer einer intensiven konventionellen Bewirtschaftung immer unwahrscheinlicher wird.

Die Zunahme insektenbestäubter Pflanzen lag in dieser Studie sogar noch über den von GABRIEL & TSCHARNTKE (2007) und BATÁRY et al. (2013) beobachteten Werten. Die Asteraceen *Matricaria chamomilla*, *Anthemis arvensis* und *Cyanus segetum*, die hauptsächlich in Wintergetreideäckern vorkommen, hatten daran einen wesentlichen Anteil. In den Sommerungen sind die hier häufigen Chenopodiaceen- und Polygonaceen-Wildkräuter zwar zumeist windbestäubt, dort boten aber insektenbestäubte Kulturpflanzen wie Sonnenblumen, Kartoffeln, Leguminosen und Kleegras mit fast 50 % Fruchtfolgeanteil ein reichliches Blütenangebot. Im Ökolandbau können also Kulturpflanzen gemeinsam mit insektenbestäubten Ackerwildpflanzen über die gesamte Fruchtfolge ein attraktives Blütenspektrum bilden. Dies steht im klaren Gegensatz zu konventionell bewirtschafteten Äckern, wo windbestäubte Getreidearten und Ungräser dominieren.

Das Ergebnis der Meta-Analysen von BENGTSSON et al. (2005) und GABRIEL et al. (2010), nach denen der Ökolandbau die Artenvielfalt vor allem auf der Maßstabsebene einzelner Aufnahmeflächen begünstigt, kann durch unsere Studie so nicht bestätigt werden. Zwar waren auch hier positive Biodiversitätseffekte auf kleiner Maßstabsebene deutlicher ausgeprägt, es wurden aber auch auf Ebene des Gesamtbetriebes positive Effekte beobachtet. Die guten Erträge am Ende der Studie zeigen, dass sich Artenschutz und produktive Bewirtschaftung nicht gegenseitig ausschließen.

Author contributions

All authors performed field work and analyzed the data, HA supervised the research work and wrote the manuscript.

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