Agroforest Syst (2023) 97:1601–1612
https://doi.org/10.1007/s10457-023-00881-9

Development of the breeding bird community of a silvoarable agroforestry system with short rotation coppice strips over a 16-year period

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Received: 4 November 2022 / Accepted: 7 August 2023 / Published online: 27 August 2023

Abstract Modern silvoarable agroforestry systems (AFS) with short rotation coppice strips (CS) are considered as a potential measure to increase structural diversity in agricultural landscapes and to promote biodiversity while simultaneously producing arable crops and woody biomass. However, studies investigating the actual potential of these novel land use systems to promote biodiversity are scarce. We therefore investigated the importance of a silvoarable AFS with different CS variants as habitat for breeding birds on an experimental site in northern Germany, which was studied several times over a 16-year period since its establishment. In addition, the habitat function and quality of CS was compared with hedgerows. The results show that establishing CS on arable land creates additional habitats for shrub and tree breeding species and thus increases species numbers and territory densities. Tree harvest resulted in a decrease in species numbers and densities. However, since Aspen rows (for timber production) or native woody species were retained during harvesting in some CS, suitable nesting opportunities for some species remained. A sharp decline in Skylark territories was observed within the open land of the AFS, from nine breeding pairs in the year after establishment (2009) to only two breeding pairs each in 2022 and 2023. Compared to CS, hedgerows were more species-rich and had much higher territory densities. We conclude that the integration of CS into croplands can promote some species of woody habitats, especially if measures such as the integration of trees of different heights or native woody species and sectional harvesting are implemented. However, CS still clearly lag behind hedgerows in terms of their habitat quality. Furthermore, the establishment of CS may have negative effects on threatened open land species like the Skylark. The requirements of these species should therefore be considered when planning AFS. Establishing AFS with CS could especially be an option in cleared, intensively used agricultural landscapes, where CS could represent a trade-off between the promotion of birds and agricultural production.

Keywords Biodiversity · Species richness · Alley cropping · Perennial biomass crop · Bioenergy · Hedgerow

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Introduction

Biodiversity in Europe has declined dramatically in recent decades, with farmland species being particularly affected (Donald et al. 2001; Kamp et al. 2021;

Richner et al. 2015; Warren et al. 2021). A major reason for this decline is the intensification of agriculture and the associated loss of important habitats and structural elements such as hedgerows, field margins, fallows or extensively managed arable land and grassland (Burns et al. 2016; Busch et al. 2020; Donald et al. 2002; Hertzog et al. 2023; Newton 2004; Stoate et al. 2001). Restoring high levels of habitat heterogeneity and structural diversity within habitats is therefore considered as an important measure to maintain and restore biodiversity in temperate agricultural landscapes (Benton et al. 2003; Wilson et al. 2005).

With this in mind, modern silvoarable agroforestry systems (AFS) with short rotation coppice strips (CS) are considered as a possible measure to increase habitat and structural diversity in cleared agricultural landscapes and to promote biodiversity (Glemnitz et al. 2013; Nerlich et al. 2013; Porter et al. 2009; Quinkenstein et al. 2009; Tsonkova et al. 2012). In this land use systems, strips of fast-growing trees for energy use such as Poplars (*Populus* spp.) or Willows (*Salix* spp.) are established on arable land and harvested every two to six years. Thus, on the same site, a simultaneous production of woody biomass and the cultivation of arable crops takes place (Böhm et al. 2014).

Currently, this new type of AFS is not very common in Central Europe and especially in Germany (Beer and Theuvsen 2019; Tsonkova et al. 2018). In Germany, cultivation is almost exclusively limited to experimental sites (Otter and Beer 2021). Therefore, there is still a lack of knowledge on the actual potential of these novel land use systems to promote biodiversity in agricultural landscapes (Boinot et al. 2022; Mupepele et al. 2021; Tsonkova et al. 2012). With this work, we would like to contribute to closing this knowledge gap and expand the data base on the potential of modern AFS with CS as a measure to increase biodiversity in agricultural landscapes. For this purpose, surveys are carried out on the habitat potential for breeding birds on an AFS experimental site in northern Germany, which has been studied several times over a period of 16 years since its establishment. These surveys include the following key age and management phases: 2009, the year after establishment of the AFS; 2013, before harvesting of trees within the CS; 2014, after a majority of the trees within the CS were harvested; and 2023, the third year after the last harvest of the CS, and the 16th growing season after establishment of the AFS overall. The aim of this study is to determine how species numbers and breeding bird assemblages of the AFS changed since its establishment and what impact harvesting of trees within the CS had on the breeding bird community. Furthermore, hedgerows were surveyed in 2023 to evaluate the habitat function and quality of CS in comparison to hedgerows, which are the counterpart of CS in traditional AFS (cf. Nerlich et al. 2013) and are considered as important habitats for birds in agricultural landscapes (Hinsley and Bellamy 2000).

Materials and methods

Study site

Surveys were carried out on an AFS experimental site (coordinates: 52°19’54.7"N 10°37’52.8"E) in the municipality of Lehre (district of Helmstedt, Lower Saxony, Germany). The site was established at the beginning of May 2008 and consists of nine short rotation coppice strips (CS) and cropland of annual summer or winter crops between them (Fig. 1). The silvoarable AFS has a total area of 17.7 ha, of which 14.5 ha is cropland, 2 ha is CS, 0.6 ha is headland (grassland with short sward) in the center of the AFS (Fig. 1) and another 0.6 ha is margins between the CS and the cropland (1.5 m of margins on each side of the CS).

The CS each have a length of 225 m (total length 2,025 m) and a width of 10 m. Cropland width is 48 m in the northern part and 96 m in the southern part (Fig. 1). Each of the nine CS consists of three 75 m long sections representing different CS variants: “Conventional” (CS-C), “Aspen” (CS-A) and “Ecological” (CS-E):

- *CS-C* consists of six Poplar rows (planting scheme 2×0.5 m, i.e. planting density of 10,000 trees/ha) with three different fast-growing Poplar clones (“Koreana” (*P. koreana* x *P. trichocarpa*), “Max 1” (*P. nigra* L. x *P. maximowiczii*) and “Hybride 275” (P. *maximowiczii* x *P. trichocarpa*)) in equal proportions. This variant is intended for

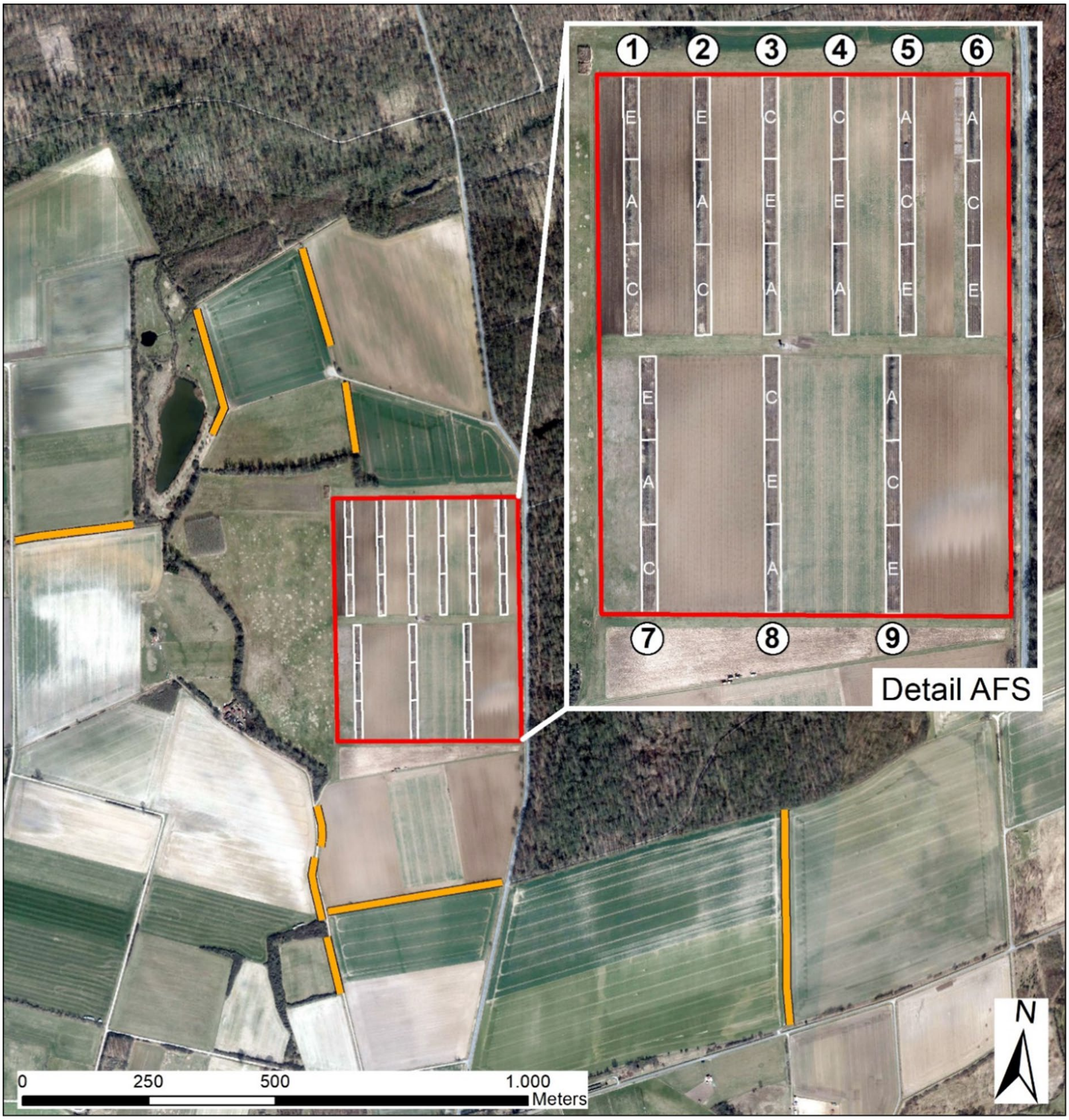

Fig. 1 View on the investigated AFS experimental site (bordered in red) and the hedgerows (orange lines, surveyed only in 2023). In the detail map of the AFS the different CS variants are shown (bordered in white; C = Conventional, A = Aspen and E = Ecological). Each CS is 225 m long and consists of three 75 m long sections of the different variants. Poplar clones of all variants in CS no. 2, 4, 6, 7 and 9 were harvested in 3-year rotation, Poplar clones of all variants in CS no. 1, 3, 5 and 8 were harvested in 6-year rotation. Distances between the CS are 48 m in the northern part of the AFS and 96 m in the southern part. Background: Orthophoto taken by the State Office for Geoinformation and Land Surveying of Lower Saxony on 21 March 2022

full use in short rotation and represents the conventional use option.

- *CS-A* consists of four rows of Poplars analogous to CS-C. In contrast to CS-C, the two middle Poplar rows were replaced by a row of Aspen (*Populus* *tremula*). They were planted at a spacing of 1.5 m and are used for timber production.

- *CS-E* also consists of four rows of Poplars analogous to CS-C. In addition, two rows of native tree and shrub species (a.o. *Prunus spinosa*, *Malus sylvestris, Rosa canina, Viburnum opulus, Sambucus nigra, Cornus sanguinea, Crataegus monogyna, Sorbus aucuparia* and *Ligustrum vulgare*) were planted on the windward side. The aim of this measure was to enhance the habitat function by providing diverse woody structures that offer additional habitats and by providing an additional supply of fruits and flowers for wildlife (e.g. for birds or flower-visiting insects).

The Poplar clones in all three CS variants were harvested in 3- or 6-year rotation, whereby strips to be harvested every 3 or 6 years alternate (Fig. 1) in order to maintain the windbreak function. The Poplar clones in all nine CS were harvested in January 2014 and February 2021, and the Poplar clones in five CS were additionally harvested in February 2011 and February 2017 in 3-year rotation (Fig. 1). The native woody species in CS-E were not harvested until 2014. Afterwards, they were harvested along with the Poplar clones during the regular harvests (2017, 2021). Trees in all CS variants were < 1.5 m high at the beginning of the surveys in 2009. In 2013, mean height of Poplar clones was about 8 m (6-year cultivation) and 5 m (3-year cultivation), respectively, and the native woody species reached heights of 3–4 m. In 2014, Poplar clones in all CS were re-sprouting after harvesting, while the native woody species had the same heights as in the previous year. In 2023, Poplar clones reached heights of 4–6 m and native woody species were 2–3 m high. Aspen within the CS-A variant have not been harvested since their establishment in 2008 and were about 8 m high in 2013/2014 and up to 16 m high in 2023.

The hedgerows surveyed for comparison in 2023 were located in the immediate vicinity of the AFS (between 100 and 500 m apart, Fig. 1). In total, the seven surveyed hedgerow sections had a length of 1,940 m. This roughly corresponds to the length of the investigated CS (2,025 m). The individual hedgerow sections were between 140 and 430 m long and on average 5 m wide. However, the width varied considerably both between the different sections and partly also within the individual sections (minimum width 2 m, maximum width 15 m). The total area of the hedgerows was 1.12 ha, i.e. much smaller than the area of the CS (2 ha). The hedgerows were characterized by shrubs and trees, typical species were *Acer campestre, A. platanoides, Alnus glutinosa, Cornus mas, C. sanguinea, Corylus avellana, Crataegus* spec., *Fraxinus excelsior, Ligustrum vulgare, Malus sylvestris, Populus tremula, Prunus avium, P. spinosa, P. padus, Quercus robur*, *Rosa* spec., *Salix* spec., *Sambucus nigra, Sorbus aucuparia, Ulmus minor* and *Viburnum opulus* with different proportions within the individual sections. The height of the hedgerows varied considerably, both within and between the sections (approximately between 4 and 15 m and thus in a similar range as the trees within the different CS variants in 2023).

Survey methods, data preparation and data analysis

The study site for the breeding bird surveys in 2009, 2013, 2014 und 2023 covered the entire area of the AFS consisting of the nine CS and the adjacent cropland (Fig. 1). Breeding birds were surveyed by territory mapping technique according to the German methodological standards of Südbeck et al. (2005). Surveys were carried out in the early morning hours (from sunrise to 10 am) during suitable weather conditions (no strong wind, no rain) between the end of March/beginning of April and mid-June on five dates per year. All visual and acoustical bird observations were denoted on maps using standardised species codes and behavioural symbols. After the end of the breeding season, breeding territories were defined on the basis of the observations made during fieldwork. The number of registrations required to delineate a territory and the specification of the behaviours and recording periods to be observed were carried out in accordance with the species-specific instructions of Andretzke et al. (2005). According to these methodological guidelines, usually at least two detections are required within the species-specific breeding season to delineate a territory. These detections must include the observation of territory-indicating behavior (especially singing males, but also warning adult birds, observation of pairs etc.). In certain cases, however, individual observations can also be considered as territories. This includes observations that indicate breeding with a high degree of certainty, for example food or nesting material carrying adult birds within the typical breeding season of the respective species or the observation of juvenile birds. The exact criteria and temporal specifications used to determine breeding bird territories according to these german methodological standards are species-specific and described in detail for each species in Andretzke et al. (2005).

In 2023, an additional survey of different hedgerows within the immediate vicinity of the studied AFS (Fig. 1) was conducted to compare the habitat function and quality of CS and hedgerows. Thereby, the same method was used as described above. Furthermore, in 2022 a survey of the open land (cropland, headland, margins) within the AFS was carried out to examine the occurrence and abundance of open land species, in particular the Skylark. Again, the same method was used as in the other study years.

Based on the determined territories, species numbers and abundances were calculated for the respective years. As it was not possible to clearly assign the territories of the breeding birds to the respective CS variants within the AFS, no comparison of the three CS variants was made, but the CS were considered as a unit. Within the AFS, territories were thus allocated to the open land (cropland, headland, margins) between the CS or to the CS. In addition, the Bray-Curtis Similarity Index was calculated to determine how breeding bird communities within the AFS differed between study years and how species composition differed between CS and hedgerows. For the temporal comparison within the AFS, the absolute number of breeding pairs was used as abundance value, since the area size of the AFS was exactly the same in each year. For the comparison between CS and hedgerows, territory densities per hectare were used as abundance values, since the area of these habitat types differed considerably. The Bray-Curtis Similarity Index can assume values between 0% (no common species) and 100% (identical species inventory with equal species-specific abundances). For calculating the index, the software BioDiversity Pro (McAleece et al. 1997) was used.

Results

Development of the breeding bird community within the investigated silvoarable agroforestry system over a period of 16 years

A total of 17 species were found within the AFS in all four study years (Table 1). In 2009, the year after establishment of the AFS, only the Skylark was recorded. In 2013 (before the harvest of the Poplar clones), nine, in 2014 (after the harvest of the Poplar clones in all CS) six and in 2023 12 species were found. The total breeding bird density within the whole AFS (17.7 ha) was 5.1 BP (breeding pairs)/10 ha in 2009, 16.4 BP/10 ha in 2013 and 11.9 BP/10 ha both in 2014 and in 2023.

The Skylark was detected in all years and was the only species that used the cropland and the other open areas (headland, margins) within the AFS for breeding. The number of breeding pairs, however, declined markedly since the establishment of the AFS, from nine breeding pairs in 2009 to seven breeding pairs in 2013 and 2014 to only two breeding pairs in both 2022[1] and 2023.

In 2009, the second growing season after the AFS was established, no breeding birds were found within the CS. In 2013, the sixth growing season after planting, eight species were found within the CS. Yellowhammer (7), Chaffinch (6) and Blackcap (4) accounted for several territories, while the five remaining species were recorded with one territory each. In 2014, after harvesting in winter, only the Aspen rows in CS-A and the native woody species in CS-E remained, while the Poplar clones in all CS variants were completely harvested and started to regrow during spring. In the breeding season following the harvest, five species were found within the CS: Chaffinch (6) and Yellowhammer (4) had the most territories, while the other species had just one or two territories. In 2023, the third growing season after the last harvest and the 16th growing season since the establishment of the AFS, a total of 11 species were found within the CS. Yellowhammer (5) was again particularly abundant, and Whitethroat (3) as well as

[1] In 2022, breeding birds were only surveyed within the open land habitats (cropland, headland, margins) of the AFS, but the CS were not surveyed (see survey methods).

Table 1 Detected breeding bird species and species-specific number of territories within the investigated agroforestry system in the four survey years

Species name	RL G	RL L	2009	2013	2014	2023
Skylark *Alauda arvensis*	!	!	9	7	7	2
Yellowhammer *Emberiza citrinella*	*	N		7	4	5
Whitethroat *Sylvia communis*	*	*		1	1	3
Garden Warbler *Sylvia borin*	*	!		1	2	1
Chaffinch *Fringilla coelebs*	*	*		6	6	
Blackcap *Sylvia atricapilla*	*	*		4		2
Red-backed Shrike *Lanius collurio*	*	N				2
Blackbird *Turdus merula*	*	*				1
Chiffchaff *Phylloscopus collybita*	*	*				1
Goldfinch *Carduelis carduelis*	*	N				1
Lesser Whitethroat *Sylvia curruca*	*	*				1
Marsh Warbler *Acrocephalus palustris*	*	*		1		
Robin *Erithacus rubecula*	*	*			1	
Song Thrush *Turdus philomelos*	*	*				1
Tree Sparrow *Passer montanus*	N	N		1		
White Wagtail *Motacilla alba*	*	*				1
Willow Warbler *Phylloscopus trochilus*	*	*		1		
Total no. of species			1	9	6	12
Total no. of territories			9	29	21	21
No. of species / territories in CS			–	8 / 22	5 / 14	11 / 19
Breeding bird density AFS in BP/10 ha			5.1	16.4	11.9	11.9
Breeding bird density CS in BP/km			–	10.9	6.9	9.4

RL = Red List Status for Breeding Birds in G = Germany (Ryslavy et al. 2020) and in L = Lower Saxony (Krüger and Sandkühler 2022). Red List Categories: * Least Concern, N Near Threatened, ! Vulnerable. BP = Breeding Pairs, AFS = Agroforestry system, CS = Short rotation coppice strips

Blackcap and Red-backed Shrike (2 each) also had several territories. All other species had only one territory. The total breeding bird density within the CS (2,025 m) was 10.9 BP/km (equivalent to 10.9 BP/ha) in 2013, 6.9 BP/km (6.9 BP/ha) in 2014 and 9.4 BP/km (9.4 BP/ha) in 2023.

Of the species detected within the CS, only Yellowhammer, Whitethroat, and Garden Warbler occurred in all three study years (2013, 2014, 2023) following the successful establishment of the woody strips. Among these, Yellowhammer was particularly abundant with 4–7 territories per year. All other species were absent in at least one of these three study years or only occurred in one year with 1–2 breeding pairs only.

The composition of the breeding bird community of the AFS changed significantly over time. Bray-Curtis Similarity Index between 2009 and 2023 reached only 13%. The highest similarity (76%) was reached between 2013 (before harvest) and 2014 (after harvest). Between these two years and the year 2023, however, Bray-Curtis Similarity only reached values of 38–44%; Between 2009 and 2013/2014, Bray-Curtis Similarity Index was also at a similar level of 37–47%.

All species found within the investigated AFS are common and widespread in Germany and in the federal state Lower Saxony. The Skylark is considered as vulnerable both in the Red List of Breeding Birds in Lower Saxony and Germany due to strong population declines in recent decades (Ryslavy et al. 2020; Krüger and Sandkühler 2022). The Garden Warbler is classified as vulnerable in Lower Saxony. However, the species is non-threatened throughout Germany.

Comparison of the habitat function and quality of short rotation coppice strips and hedgerows for breeding birds

A total of 19 species were detected during the comparative survey of CS and hedgerows in 2023, including 15 within the hedgerows and 11 within the CS (Table 2). The number of breeding pairs detected in the hedgerows (37) was about twice as

Table 2 Detected breeding bird species and their territory densities (in breeding pairs (BP) per ha) within the investigated short rotation coppice strips (CS) and hedgerows (HR) in 2023

Species name	RL		CS	HR
	G	L		
Yellowhammer *Emberiza citrinella*	*	N	2.5 (5)	8.9 (10)
Whitethroat *Sylvia communis*	*	*	1.5 (3)	6.3 (7)
Blackcap *Sylvia atricapilla*	*	*	1.0 (2)	0.9 (1)
Red-backed Shrike *Lanius collurio*	*	N	1.0 (2)	0.9 (1)
Blackbird *Turdus merula*	*	*	0.5 (1)	0.9 (1)
Chiffchaff *Phylloscopus collybita*	*	*	0.5 (1)	0.9 (1)
Garden Warbler *Sylvia borin*	*	!	0.5 (1)	0.9 (1)
Blue Tit *Cyanistes caeruleus*	*	*		4.5 (5)
Great Tit *Parus major*	*	*		2.7 (3)
Icterine Warbler *Hippolais icterina*	*	N		1.8 (2)
Chaffinch *Fringilla coelebs*	*	*		0.9 (1)
Stonechat *Saxicola rubicola*	*	*		0.9 (1)
Goldfinch *Carduelis carduelis*	*	N	0.5 (1)	
Hawfinch *Co. coccothraustes*	*	*		0.9 (1)
Lesser Whitethroat *Sylvia curruca*	*	*	0.5 (1)	
Long-tailed Tit *Aeg. caudatus*	*	*		0.9 (1)
Nightingale *Lus. megarhynchos*	*	N		0.9 (1)
Song Thrush *Turdus philomelos*	*	*	0.5 (1)	
White Wagtail *Motacilla alba*	*	*	0.5 (1)	
Total no. of species			11	15
Total no. of territories			19	37
Breeding bird density in BP/ha			9.4	33.0
Breeding bird density in BP/km			9.4	19.1

Values in brackets: Absolute number of detected territories per species. RL = Red List Status for BreedingBirds in G = Germany (Ryslavy et al. 2020) and in L = Lower Saxony (Krüger and Sandkühler 2022). Red List Categories: * Least Concern, N Near Threatened, ! Vulnerable

high as in the CS (19), as was the number of breeding pairs per kilometer (Hedgerows: 19.1 BP/km; CS: 9.4 BP/km). Relative to plot size, hedgerows had 3.5 times the density of breeding pairs per hectare (33 BP/ha) than CS (9.4 BP/ha).

Seven of the 19 species recorded occurred in both habitat types. These species either had similar territory densities in both habitat types or their densities were higher in the hedgerows. In addition, eight species were found only in the hedgerows and four species were found only in the CS.

The most common species in both habitat types were Yellowhammer and Whitethroat. However, both had much higher densities in the hedgerows than in the CS. In addition, two cavity-nesting species (Blue tit and Great tit) were found in the hedgerows with several breeding pairs. These two species were absent in the CS. All other species were detected with 1–2 breeding pairs in hedgerows and/or CS, including one species classified as vulnerable in Lower Saxony (Garden Warbler, both habitat types). In addition, several species classified as near threatened in Lower Saxony were detected: Yellowhammer and Red-backed Shrike (both habitat types), Nightingale and Icterine Warbler (hedgerows) as well as Goldfinch (CS).

The Bray-Curtis Similarity (using breeding pairs per ha for species specific abundance) between hedgerows and CS was 34%. Species composition differed considerably as species numbers were higher in the hedgerows, some species occurred in only one of the two habitat types, and because territory densities of the most common shared species (Yellowhammer, Whitethroat) differed considerably.

Discussion

A major result of our study is that the establishment of CS on cropland increases species numbers and breeding bird densities. In contrast to 2009 (the year after establishment), where only the Skylark occurred within the AFS, in 2013, 2014 and 2023 several species of woody habitats used the CS for breeding. As a result, species numbers and territory densities within the AFS increased and the species composition changed significantly compared to the establishment phase. In addition, species numbers (but not territory densities) of tree and shrub breeding birds within the CS increased over time: the highest species numbers were found in 2023, when 11 species used the CS for breeding. This increase is probably explained by the further ageing of the woody crops and the associated improvement in vegetation structure. For example, the tall Aspen rows in CS-A were regularly used as song posts by various species (e.g. Yellowhammer, Whitethroat, Song Thrush or Whitethroat), and also in the CS-E variant, in which two rows of native woody species were established for further structural enhancement, many birds with territorial behavior were observed (in contrast to the CS-C variant). Although it is not possible (or only in very exceptional cases) to determine the exact nest locations of the species detected using the territory mapping technique, as no time-consuming search for nests is carried out (Bibby et al. 2000; Südbeck et al. 2005), a clear preference of tree and shrub breeding birds with territorial behavior for CS-E and CS-A was evident. Another argument for the enhancement potential of planting native woody species in CS-E is that hedgerows (with exclusively native woody species) had more species and breeding pairs than CS in our study. Furthermore, studies on short rotation coppice plantations (SRC) showed that hedgerows and groves are significantly more species-rich and densely colonised by birds than SRC with Poplars or Willows (Gruß and Schulz 2014; Zitzmann and Reich 2020). This indicates that the CS-E and CS-A variants can achieve a significant enhancement effect for tree or shrub breeding birds within modern silvoarable AFS with CS. However, further studies should be conducted to determine the exact enhancement potential of these measures in comparison to conventional cultivation practice (represented by the CS-C variant), for example by a complementary but very labor and time consuming search for the nests of the species breeding within the different CS variants.

Considering the effect of harvesting, it is striking that in 2014, the year after the harvest of the Poplar clones across all CS variants, fewer species in lower densities were breeding in the CS than in the year before the harvest (2013). Therefore, a negative effect of harvesting was clearly noticed. However, the retention of the Aspen rows in CS-A and the native woody species in CS-E meant that the CS were still used for breeding by species such as Chaffinch, Yellowhammer and Garden Warbler. Without these remaining trees and shrubs, there would have been no habitat structures for these species, similar to the situation in 2009, the year after the establishment of the AFS. Partially excluding trees and shrubs from harvesting is therefore an effective measure to mitigate the negative impact of harvesting on these species (cf. a. o. Göransson 1994 and Hanowski et al. 1997 for SRC). This measure would also have the advantage of always having woody structures to protect the cropland from wind erosion (cf. Böhm et al. 2014).

Another central finding of our study is the sharp decline in Skylark territories within the open land of the AFS over the years, so that in the 15th (2022) and 16th (2023) growing season after the establishment of the CS, only two of the former nine (2009) territories were still present. This result was expected, as Skylarks are known to avoid the proximity of vertical structures such as woodland or other woody habitats (cf. Bauer et al. 2005; Glesener et al. 2023; Oelke 1968; Wilson et al. 1997) and the growth of trees and shrubs within the CS thus resulted in the displacement of the species. From a species conservation point of view, this is particularly important because the Skylark is considered as threatened in Germany and in many other European countries and has suffered massive population declines in recent decades (Burns et al. 2021; Donald et al. 2006; Kamp et al. 2021). When establishing CS on arable land, this must be taken into account and, if possible, no sites should be used that represent important breeding habitats for the Skylark or other open land species. Otherwise, the increase in species numbers and territory densities due to the integration of CS would be dearly bought by the loss of territories of the Skylark or other threatened open land species. However, further research is needed on tree heights within CS and spacing between CS that are tolerated by the Skylark and other species. The Skylark would possibly benefit from short rotations as the trees would not reach great heights and the adjacent cropland might still be used for breeding. This is indicated by our results from 2013 to 2014: in both years, seven skylark territories were found within the AFS, which means only a slight decline in comparison to 2009. In those years, tree height within the CS was approximately 8 m (Aspen and Poplar Clones with 6-year rotation in 2013, Aspen in 2014). In 2022 and 2023, however, the Aspen already reached heights up to 16 m and significantly fewer Skylark territories were detected.

Our results clearly show that hedgerows provide habitat for more species than CS and that the species composition of both habitat types differs markedly. In addition, the surveyed hedgerows (19.1 BP/km, 33 BP/ha) were colonized in much higher densities than the CS (6.9–10.9 BP/km or ha, respectively). Thereby, the territory densities of the studied hedgerows were even rather low in comparison to other studies: Barkow (2001) found an average density of 53.3 BP/km in his study of several hedgerows throughout Germany, Flade (1994) reports mean densities of 28 BP/km for hedgerows in Northern and Central Germany, and in surveys of hedgerows in Northwest Germany 29.5 BP/km were found (Zitzmann and Reich

2020). Thus, the hedgerows considered in our study obviously do not even have a particularly high habitat potential for breeding birds and could be significantly improved in their habitat quality. Possible measures are the introduction of additional tree and shrub species to increase woody plant species and structural diversity, leaving old trees standing during regular hedge maintenance or by widening of the hedgerows (cf. Sybertz et al. 2020). In contrast, previous studies of CS found breeding bird densities close to ours: Löffler et al. (2016) found slightly higher densities for several CS in Saxony, averaging 15.8 BP/km, while Glemnitz et al. (2013) found slightly lower densities for CS in Bavaria, with an average of 5.2 BP/km (own calculations based on the data given). It must also be noted that the indication of breeding pairs per kilometer does not consider the width of the woody structures. Hedgerows in intensively used agricultural landscapes are usually quite narrow (see description of the investigated hedgerows), while the investigated CS were comparatively wide (i.e. 10 m). Therefore, taking width (and not just length) into account, territory densities (in BP/ha) in hedgerows are likely to be even higher in most cases and thus exceed densities in CS even more, just like in our study.

It was also striking that the common species of hedgerows and CS occurred either at equal or at higher densities in the hedgerows, thus favoring them over CS (especially Yellowhammer and Whitethroat). Our results thus show, similar to previous studies on breeding birds in CS, that these woody strips mainly provide habitat for widespread, common, mostly non-threatened and rather undemanding species in comparatively low densities (see also Glemnitz et al. 2013; Löffler et al. 2016). Similar results have already been found during studies on SRC. Here, the reasons for lower species richness and territory densities compared to forests, hedgerows or groves were attributed to the lower age of the woody plants and the reduced structural diversity within SRC; therefore, for example, species associated with habitat elements of mature woody habitats such as dead wood or tree cavities do not occur in SRC or only colonize them in very low densities (Archaux and Martin 2009; Berg 2002; Gruß and Schulz 2011, 2014; Hanowski et al. 1997; Martín-García et al. 2013; Porro et al. 2021; Riffell et al. 2011; Zitzmann and Reich 2020). This was also observed within the CS: There were not only fewer species, but certain species such as cavity breeders (Blue Tit, Great Tit) were completely absent, while they occurred with several breeding pairs within the investigated hedgerows. CS and SRC thus share the same problem: due to the short rotation periods, habitat elements of mature woody habitats cannot arise. Compared to hedgerows, the "counterpart" of CS in traditional AFS, CS are more monotonous in several respects: They only have a low diversity of woody species (in the case of CS-C and CS-A just species/varieties of the genus *Populus*) and usually consist of trees/shrubs of the same age, grown in strictly geometric planting schemes in each tree strip. Even in the CS-E variant, where the additional planting of native tree and shrub species resulted in a much greater woody species diversity than in CS-C and CS-A, the same woody species were established with the same proportions in standardised planting schemes. Each section of CS-E is thus identical in terms of woody species composition, age and vegetation structure. Hedgerows, on the other hand, are always unique: each hedgerow differs from others to a greater or lesser extent in terms of one or more factors such as composition of woody species, use history, recent use, age, width, length, alignment or adjacent land use (cf. Hinsley and Bellamy 2000, Sybertz et al. 2020). However, AFS with CS are modern agricultural production systems, which limits the possibilities to increase the complexity and diversity of their vegetation structure. Requirements on the quality of the wood and on the management of the crops, in particular the technical possibilities for harvesting as well as the harvesting costs, limit the scope (cf. Lamerre et al. 2015) and therefore do not allow a complex vegetation structure and intermixing of trees and shrubs, as is the case with hedgerows. Nevertheless, our results indicate that measures such as the integration of tree rows for timber production in CS-A or the additional planting of native woody species in CS-E can at least achieve some improvement for breeding birds. These measures thus represent a trade-off between enhancement for breeding birds and the land use requirements.

Conclusions

The establishment of CS on cleared arable land creates new habitats that enable additional species to colonise and ensure that bird species numbers and densities increase. However, CS clearly lag behind hedgerows in terms of their habitat quality for breeding birds. Thus, when species conservation is the primary concern, hedgerows are definitely the more important habitats for breeding birds and are strongly preferable over CS. However, in intensively used and cleared agricultural landscapes with a low proportion of woody habitats, where the implementation of "non-productive measures" such as hedgerows is often difficult due to high rental prices and the great competition for arable land (cf. Druckenbrod and Beckmann 2018), CS can also be an option to promote breeding birds. This is especially true when additional enhancement measures are implemented such as sectional harvesting, the integration of trees with longer rotation cycles for timber production, or the partial planting of native woody species within CS. When establishing modern AFS with CS, it is particularly important to consider the concerns of threatened open land species like the Skylark to ensure that the establishment of these novel production systems does not occur at their expense. To better estimate and consider the impacts on open land species, further research is needed.

Acknowledgements We thank J. Hoffmann (2009) and K. Sevke-Masur (2013, 2014) for the field work done. T. Echterling kindly provided us his Skylark data for the year 2022. We also thank the German Federal Ministry of Food and Agriculture and the Fachagentur Nachwachsende Rohstoffe e.V. for funding.

Author contributions Conceptualization, F.Z. and M.L.; methodology, F.Z.; formal analysis, F.Z.; writing—original draft preparation, F.Z.; writing—review and editing, F.Z. and M.L.; figures and tables, F.Z.; All authors have read and agreed to the published version of the manuscript.

Funding Open Access funding enabled and organized by Projekt DEAL. Field work in 2009 was carried out within the research project "Ökonomische und ökologische Bewertung von Agroforstsystemen in der landwirtschaftlichen Praxis; Teilvorhaben 3: Grünland- und Ackerflächen in Niedersachsen" (Grant No. 22009807), funded by the Bundesministerium für Ernährung und Landwirtschaft (BMEL) and the Fachagentur Nachwachsende Rohstoffe e. V. (FNR). Field work in 2013 and 2014 was carried out within the research project "Nachhaltige Erzeugung von Energieholz in Agroforstsystemen, Teilvorhaben 3: Strukturvielfalt und Biodiversität (AgroForst-Energie II)" (Grant No. 22000412), also funded by BMEL and FNR. No funding was received for conducting field work in 2022 and 2023 and no funding was received to assist with the preparation of this manuscript.

Data Availability All data generated or analysed during this study are included in this published article.

Declarations

Competing interests The authors declare no competing interests.

Conflict of interest The authors have no competing interests to declare.

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