Eurasian Skylarks in conservation agriculture

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(Med et dansk resumé: Sanglærker i 'conservation agriculture')

Abstract Tillage systems and crop management have been proven to drastically change the soil ecosystem and hence change the foraging potential of agricultural fields for bird species. The size of the effect was investigated through transect counts of Eurasian Skylarks *Alauda arvensis* and collection of arthropods by ground search in conservation agriculture (CA) and conventional tilled (CT) spring barley fields located in Central Jutland, Denmark, in four fields of each type between 30 June and 24 July 2019. A mean of five times the number of birds and slightly less than two and a half times the weight of arthropods was found in CA fields compared to CT fields. The species diversity of arthropods tended to be higher in CA fields, with arachnids and Lepidoptera/Tenthredinidae larvae significantly more abundant. Using the daily energy requirements of a pair of Skylarks and their brood, the average daily foraging area that a breeding pair must search to satisfy the daily energy demand for themselves and their brood was estimated to be 587 m² in CA fields compared to 1337 m² in CT fields. Besides the five times higher density of Skylarks, the results suggest that spring barley fields grown according to CA rules provide enough food for a second brood, which does not seem to be the case in CT fields.

Introduction

Over the last century, farming in the rich part of the world has experienced a vast technological development which has significantly changed agricultural practice and introduced the use of agrochemicals and powerful machinery. Over the same time period we have seen a decline both in farmland birds and arthropods in these areas (Benton *et al.* 2002, Baudron & Giller 2014), signifying a loss of biodiversity and ecosystem services provided by wild animals living within the farmland. Reversing this trend of decline would be favourable both for agriculture, if beneficial species can be attracted to fields, and for conservation of biodiversity.

To achieve this revitalization of arthropod and bird communities in modern agriculture, it is important to know the availability of useful food sources in the food web. The basic element of a decomposer food web at the surface of agricultural fields is dead organic matter on the soil. In natural systems such as forests, a layer of leaf litter exists which provides cover against predators and provides a constant nutrient source for fungi and bacteria so that a basis for a stable food web is established (Neher 1999).

In fields, the stubble, crop residues and live or dead mulch may provide a layer of organic material similar to the litter layer in forests. Such a litter layer constitutes the foundation for growth of bacteria and fungi. The hyphae of fungi decompose dead organic matter and serve as the main food for many springtail species. Many surface living generalist predators such as carabid beetles and spiders feed on springtails inhabiting the soil surface (Bilde *et al.* 2000). At this point in the food chain, arthropods have reached a body mass that is worth eating for many birds along with earthworms (Neher 1999). These bigger organisms are also important for decomposition because they manipulate both the soil and the dead organic matter to facilitate the presence of fungi (Brussard *et al.* 2007).

Farmland birds feed on both plant seeds and arthropods. Bird survival and density is highly dependent on food availability, and the use of pesticides has lowered the abundance of insects (Attwood *et al.* 2008) and seeds from weeds (Vats 2014). In addition to the use of agrochemicals, tillage also has devastating effects on the soil food web by reducing the density of many springtail species (Holland 2004). Their absence is likely to give a bottom-up effect in the ecosystem, reducing the density of carnivorous arthropods such as the carabid beetles *Bembidion* and *Trechus* (Mitchell 2019) and arachnids while tillage also reduces soil manipulators such as earthworms and ants (Brévault *et al.* 2007), all of which are also beneficial for farming.

It is known that intensification of agriculture results in lowered biodiversity (Baudron & Giller 2014). Since the demand for food production is growing as the human population increases, going back to former agricultural practices from before 1960 is not an option. An alternative could be switching to conservation agriculture (CA) which is considered the preferred sustainable agricultural practice all over the world by the UN (FAO 2013). This practice utilises agrochemicals to control pests and is especially dependent on herbicides (Koepke 2003, Chauhan *et al.* 2012) but has other benefits for the environment, biodiversity, and for soil erosion.

CA originated as a practice of either no or reduced tillage to alleviate soil erosion in the Americas and Australia (Ribeiro *et al.* 2007) and no tillage can be regarded as the first principle of CA. Two other principles were later added to constitute the three core principles of CA:

1. Less soil disturbance through reduced or no-tillage and direct seeding to avoid soil compaction, erosion, and water loss.
2. Constant soil cover, such as crop residues or cover crops, to avoid soil erosion, improve soil nutrition and function as litter, thereby creating a sink for carbon.
3. Crop rotation to mitigate problems with diseases, weeds, and other pests.

In addition to the effects mentioned above, other side effects of the different agricultural practices have come to light. Earthworms and springtail abundance rises in a no-tillage system (Holland 2004, Lahmar 2010) as do insect abundance and diversity (Jones *et al.* 2006) even though chemical pesticides are allowed in CA. Such increased abundance of insects and other invertebrates can be expected to result in higher availability of food sources for predators at higher trophic levels.

The effects of CA on vertebrates have been studied internationally, mainly in the Americas where CA is widespread, and a greater abundance and diversity of birds, mammals, and reptiles has been shown (Holland 2004, Jones *et al.* 2006, Field *et al.* 2007, Ribeiro *et al.* 2007, Barré *et al.* 2018). There are, however, not many studies of CA from Europe. This study investigates the abundance of Eurasian Skylark *Alauda arvensis* (Skylark from here on) in mid-summer in conventional tillage (CT) and conservation agriculture (CA) systems. Besides bird counts, arthropods were also sampled, with a direct focus on species suitable as food for Skylark (Elmegaard *et al.* 1994), to assess the possible food resources within the habitats. On the basis of the abundance of arthropod food items found in the two tillage systems, an attempt was made to estimate the area needed for a pair of Skylarks to satisfy the daily energy demands of themselves and their brood.

Methods

The investigation was undertaken in eight fields, four CA and four CT fields, within an approximately 10 km radius of each other in Central Jutland, Denmark (centre approximately 56.003 N, 9.743 E) between 30 June and 24 July 2019. The crop was spring barley in all fields. Only CA field number 2 and 4 had tall trees on more than two sides, and where trees were absent, the areas adjacent to the fields were covered with low vegetation, such as

Tab. 1. Mean density of Skylarks/ha in relation to field and tillage system (CA = conservation agriculture, CT = conventional tillage).
Gennemsnitlig tæthed af Sanglærker/ha mellem marker og pløjesystemer (CA = conservation agriculture, CT = pløjede marker).

Field *Mark*	Area *Areal*	Skylarks *Lærker*	Skylarks/ha *Lærker/ha*
CA1	12.4	8	0.64
CA1	12.4	11	0.88
CA2	12.1	23	1.90
CA2	12.1	17	1.40
CA3	12.26	20	1.63
CA3	12.26	13	1.06
CA4	15.02	10	0.66
CA4	15.02	4	0.26
CT1	9.93	1	0.10
CT1	9.93	2	0.20
CT2	6.58	2	0.30
CT2	6.58	1	0.15
CT3	11.24	3	0.26
CT3	11.24	1	0.09
CT4	8.31	4	0.48
CT4	8.31	1	0.12
P-value			0.003

a 0.5 ha overgrown garden, a field of approximately 1 m tall spruce trees, an area of wetland around a pond, or wheat fields. The total area of CA fields combined was 51.8 ha, while that of CT fields was 36.1 ha, such that a total area of 87.8 ha was investigated. The area of the individual fields can be seen in Tab. 1.

The same number of CA and CT fields was investigated per observation day to limit differences due for example to weather conditions. All observations were performed pre-harvest.

Bird counts

A total of 16 bird counts were made, with two counts conducted in each field. Counting was done as transect counts by walking the tramlines at a speed of approximately 3 km/h. While walking a tramline, an area of twice the distance between two tramlines was observed on each side of the walked tramline. The distance between tramlines was 24 m in all fields, and thus during each counting occasion, a 96 m wide transect or band of each sample field was assessed and all relevant skylarks were counted.

Birds considered relevant were those that either flew up from the sample field transect upon disturbance, landed within the crop transect, or marked the field as territory through song. Passing Skylarks or Skylarks present in vegetation outside the sample fields or further away than two tramline widths from the observer were ignored.

Transects were made to the extent needed to cover the whole of each sample field, and no area within the field was counted twice during a survey to avoid recounts. When parts of transects overlapped, such as the edges of fields, areas which had previously been counted were also ignored to avoid repeats.

Since the bird counts were made between 30 June and 24 July, the counts reflect birds raising their second brood while some birds counted were probably fledglings from the first brood.

Arthropod sampling

Arthropods were collected once in each field through a ground search. Eight replicates were made within each field and the site for each replicate was chosen randomly. A circular metal barrier of diameter 0.25 m² and height 5 cm was used to limit the sampling area in the plots to 2 m² per field.

Collection was performed using a pooter (a vial with a tube through the lid to suck up insects) for five minutes to collect the potential food items for each replicate. The vegetation within the metal barrier was removed first, but with shaking before removal so any invertebrates on vegetation within the sampling barrier would fall back inside it. Dead individuals were ignored, and flying insects were caught if possible.

In the laboratory, individuals of high abundance were identified to species, while those of low abundance were identified to genus, family, or order. Only individuals of arthropod orders known to be relevant food items for Skylarks (Elmegaard *et al.* 1994) were identified to species or genus level. This meant that the groups Myriapoda and Acarina were excluded from the dataset.

After identification, the arthropods were dried for 24 hours at 60 °C and weighed to assess the biomass of arthropods available as food for Skylarks in each field type.

These estimates of available biomass of arthropods were used to assess the area that must be searched by a breeding pair of Skylarks to satisfy their daily energy demand, including that of their brood, using equation 1.

$$A_{fam} = \frac{E_{fam}}{M_f \times E_A \times CE} \quad (1)$$

where Afam is the area that must be searched to satisfy the daily demand of a Skylark pair with brood, Mf is the average mass of arthropods per area unit in field type f (CT or CA), EA is the average energy content of arthropods, Efam is the average daily energy demand of two adult Skylarks with brood, and CE is the average conversion efficiency of birds eating arthropods. For EA, the value 527.5 kcal per 100 g dry matter insects, which is the mean nutritional value found by Ramos-Elorduy *et al.* (1997), was used, and for Efam, the value 92.7 kcal/day (Tieleman *et al.* 2004) was used. The value of CE was 0.76, which is assumed to be the average CE value for passerines that consume arthropods (Bairlein 1997).

Statistical analyses

The data was analysed using R (R Core Team 2015) and the packages lme4 (Bates *et al.* 2015) and lmerTest (Kuznetsova *et al.* 2017). Bird density was first found by dividing the number of birds per area of each field observation, and the data was then log transformed to achieve a normal distribution determined by creating histograms, while heterogeneity of variances was determined by a Bartlett's test. An ANOVA was then performed to investigate the influence of tillage systems on bird density while using field ID as a random factor.

The densities of ten categories of arthropods – the genera *Trechus* and *Bembidion*, the families Carabidae, Staphylinidae, Lepidoptera and Tenthredinidae, Linyphiidae, bigger arachnids, all arthropods, species diversity, and total dry weight of arthropods per field were checked for homogeneity of variance with a Bartlett's test and for normality by creating histograms to determine whether the data fulfilled the requirements of a t-test. A P-value was then calculated with a t-test when possible, or a Man-Whitney U-test if t-test requirements were not met.

Results

Birds

A total of 121 Skylarks were counted: 15 individuals in CT fields and 106 in CA fields. Due to differences in the area covered by each field type, the numbers were converted into Skylarks per ha to allow comparison between fields (Fig. 1, Tab. 1). There were significantly more individuals in CA fields, with on average about five times more Skylarks per ha in CA fields compared to CT fields (ANOVA, $P < 0.01$).

Arthropods

A total of 344 relevant arthropods were collected: 144 were found in the CT fields and 200 in CA fields.

There was no significance difference (t-test, $P > 0.05$) between the two tillage systems for the arthropod categories Trechus, Bembidion, Carabidae, Staphylinidae,

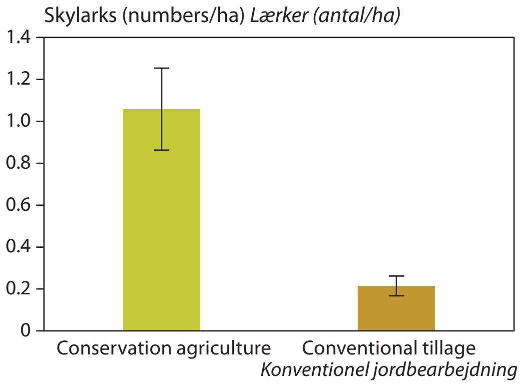

Fig. 1. Mean density (+/- SE) of Skylarks/ha in conservation agriculture (CA) and conventional tillage (CT) fields. The difference between tillage systems was significant (see Tab. 1).
Gennemsnitligt tæthed (+/- SE) af Sanglærker/ha på marker med conservation agriculture hhv. med konventionel jordbearbejdning. Forskellen var signifikant (se Tab. 1).

Linyphiidae, all arthropods and species diversity. However, there were significantly more Lepidoptera/Tenthredinidae larvae and bigger Arachnids in CA fields than in CT fields (Man-Whitney U-test, $P < 0.05$; Fig. 2, Tab. 2).

Similarly, there was a significant effect of tillage sys-

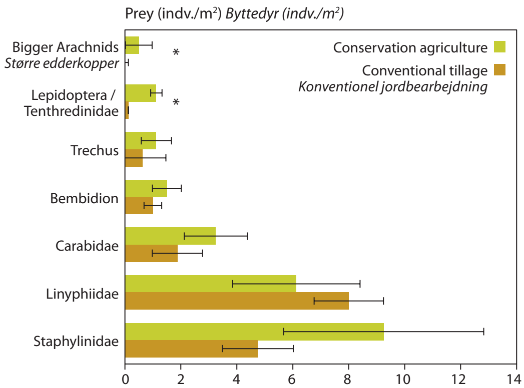

Fig. 2. Mean density (+/- SE) of arthropods of the selected groups Staphylinidae, Lyniphiidae, Carabidae, Bembidion, Trechus, Lepidoptera and bigger arachnids in conservation agriculture (CA) and conventional tillage (CT) fields. The asterisks indicate significant difference ($p < 0.05$) between tillage systems.
Gennemsnitligt tæthed af artropoder (+/- SE) tilhørende grupperne Staphylinidae, Lyniphiidae, Carabidae, Bembidion, Trechus, Lepidoptera og større edderkopper på marker med conservation agriculture (CA) hhv. konventionel jordbehandling. Stjerner markerer signifikante forskelle (p < 0.05).

Tab. 2. Density of arthropods per m² for selected groups of arthropods in conservation agriculture (CA) and conventional tillage (CT) fields. Significant p-values in bold.
Tæthed af leddyr per m² for udvalgte grupper i marker med conservation agriculture (CA) hhv. konventionel jordbearbejdning (CT). Signifikante p-værdier står med fed.

Tillage Type	Field No	Species diversity	Trechus	Bem-bidion	Carabi-dae	Stapyli-nidae	Lepidoptera larvae	Lyni-phiidae	Bigger Arachnids	All	Dry Weight (g)
CA	1	14	2	2	5	4.5	0.5	6.5	0.5	19.5	0.0336
CA	2	15	2	1.5	3.5	17	1	7	0.5	38.5	0.0342
CA	3	15	0.5	2.5	4.5	13.5	0.5	11	0	25.5	0.0487
CA	4	6	0	0	0	2	2.5	0	1	6.5	0.0410
Mean	-	12.5	1.125	1.5	3.25	9.25	1.125	6.125	0.5	22.5	0.03938
Variance	-	3.775	0.893	0.935	1.953	6.190	0.820	3.943	0.354	12.894	0.00552
CT	1	10	0.5	0.5	1	7	0	6.5	0	19.5	0.0107
CT	2	6	1.5	0	1.5	6.5	0	6	0	15.5	0.0110
CT	3	8	0	0	0.5	4	0	8	0	15.5	0.0152
CT	4	10	0.5	3.5	4.5	1.5	0.5	11.5	0	21.5	0.0324
Mean	-	8.5	0.625	1	1.875	4.75	0.03125	8	0	18	0.0173
Variance	-	1.656	1	1.458	1.556	2.194	0.217	2.151	0	2.598	0.0888
P-value	-	0.144	0.439	0.635	0.41	0.28	**0.0336**	0.497	**0.0455**	0.465	**0.0209**

tem on biomass of arthropods (Man-Whitney U-test, P = 0.02) and biomass of arthropods was 2.27 times larger in CA fields than in CT fields (Fig. 3, Tab. 2).

The average energy content of arthropods was 0.208 kcal/m² for CA fields and 0.091 kcal/m² for CT fields. Maximum energy content was 0.257 kcal/m² for CA fields and 0.171 kcal/m² for CT fields, and minimum energy content was 0.177 kcal/m² for CA fields and 0.056 kcal/m² for CT fields. In CA fields, Skylark pairs had to forage on an average of 587 m² to meet the daily energy requirements of adults and brood, while in CT fields the average area the birds needed to cover was 1337 m². These figures are, however, minimum estimates because the arthropod density only constitutes the general foundation for fulfilling the energy demand. These figures would be modified by the availability of the food items, which may depend on the crop structure and density, and by the capacity of the arthropods to escape. Furthermore, the different species may constitute very variable food quality for Skylarks (Bairlein 1997). Although these factors are largely unknown, the figures do suggest that the area that must be searched in CT fields is 2.3 times larger than in CA fields, or that the foundation for sustaining a breeding Skylark population in July is 2.3 times better in CA than in CT fields.

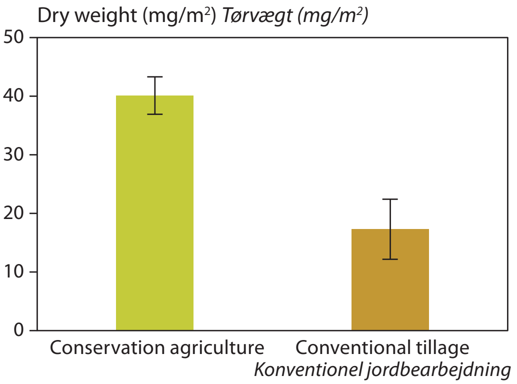

Fig. 3. Mean dry weight (+/- SE) of arthropods per m² in conservation agriculture (CA) and conventional tillage (CT). The difference between tillage systems was significant (p = 0.02, Tab. 2).
Gennemsnitlig tørvægt af artropoder (+/- SE) per m² på marker med conservation agriculture (CA) hhv. konventionel jordbearbejdning (CT) marker. Forskellen var signifikant (p = 0.02, Tab. 2).

Discussion

These results that show a higher abundance of Skylarks in CA fields compared to CT fields in July are in line with the results of Field *et al.* (2007), McLaughlin & Mineau (1995), Holland (2004) and Jones *et al.* (2006), who concluded that birds were more abundant in CA fields, and Field *et al.* (2007) and Jones *et al.* (2006), who investigated Skylarks specifically. It is known that crop species have a big influence on bird habitat preference (Kragten & de Snoo 2008), but this factor was not a variable in our studies because the crop in all fields was spring barley. Instead, there was a difference in row distance between

Five times as many Skylarks were found in July in conservation agriculture fields compared to conventional tilled fields.
Photo: Eva F. Henriksen.
Der var fem gange så mange Sanglærker i pløjefri kornmarker i juli som i konventionelt drevne kornmarker, ligesom der var næsten to en halv gange så mange invertebrater målt i vægt.

the two tillage systems, with CA fields having a row distance of 25 cm, while CT fields only had 15 cm between rows, which may play a role for the Skylarks. However, this factor was not found to be important by Morris *et al.* (2004) who found no difference in Skylark abundance between winter wheat fields with row distances of 12.5 cm and 25 cm.

The fact that there was an average of about five times more Skylarks in CA fields in July demonstrates that converting from CT to CA can be a possible way to improve biodiversity of both arthropods and birds in modern farmland in mid-summer. This conversion was obtained merely by excluding tilling from the normal farming procedure and hence exert minimal disturbance compared to the current mainstream agricultural (CT) routine; however, the inclusion of cover crops and retaining straw residues in the field may also play a role in the effects of CA.

The nonsignificant results for the arthropod groups, *Trechus*, *Bembidion*, Carabidae, Staphylinidae, Linyphiidae, and 'all arthropods' is not a surprising find when compared to international studies. No consensus exists on what difference CT and CA makes with regard to arthropod abundance, and the results from other studies are highly variable (Holland 2004). However, Palma *et al.* (2014) in an international review of the effects of CA compared to CT found significant increases in arthropod diversity (with greater increases for predators than for phytophagous arthropods), and Garbach *et al.* (2017) in an international review of ecosystem services in different agricultural systems found that biodiversity and habitat creation increased in four investigations, was neutral in one, while no investigations showed negative effects. Henneron *et al.* (2015) found significantly higher densities of most arthropod groups in CA compared to CT fields in a 14-year study in Northern France. It appears therefore that most investigations indicate a higher density and biodiversity of arthropods in CA than in CT fields. Despite the reviews and meta-analyses of the effects of CA on the arthropod fauna, it has not been possible to find other investigations of the impact of CA on arthropod biomass.

The dry weight of arthropods, representing the biomass present as a food source for Skylarks within the fields in July, was 2.3 times higher in CA fields compared to CT fields. This shows that even with the use of pesticides, if tillage (ploughing, harrowing, and trembling) is not performed and there are more cover crops and residue retention than in current Danish farming regimes, a greater abundance of arthropod food items can be available for insect feeding birds to exploit. A higher density of food items provides the foundation for higher foraging efficiency, though in the present work the reliance of Skylarks also on seeds from weeds is not taken into account (Eraud *et al*. 2014). On average, our results suggest that in CA fields Skylarks have to search less than half the area they must search in CT fields to fulfil their daily energy demand during chick rearing.

The five times larger density of Skylarks in CA compared to CT fields suggests that there is a threshold in density of available arthropods required to sustain a breeding pair of Skylarks; this threshold is close to the obtained density in CT fields but clearly lower than the obtained density in CA fields. Our results also suggest that Skylarks are more likely to try to raise a second brood in CA than in CT fields.

Our investigation does not reveal anything about the density of Skylarks in the fields when raising their first brood in May and June and should therefore be interpreted with some caution concerning the quality of the two cropping systems for Skylarks over a complete breeding season. Furthermore, our study deals only with one crop, spring barley. Nevertheless, our results are very clear concerning the situation in spring barley in July and call for a more thorough investigation of the importance of CA in relation to CT farming throughout the year, and especially during the full breeding season from May to July. If the conditions in CT farming are too harsh and arthropod densities are below a threshold for breeding attempts in July, this may explain the observed decline in Skylark breeding pairs in Denmark (Vikstrøm *et al.* 2020).

Acknowledgements

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Resumé

Sanglærker i 'conservation agriculture'

Dyrkningssystemer og afgrødevalg har stor betydning for økosystemet i landbrugsmarker og for fødegrundlaget for fuglene. Betydningen af dyrkningssystem blev her undersøgt for Sanglærker *Alauda arvensis* via transekt-tællinger, og deres fødegrundlag blev undersøgt ved indsamling af leddyr v.h.a. 'ground search' (grundig afsøgning af jordoverfladen) i conservation agriculture (CA) og i konventionelle dyrkede (CT) vårbygmarker i Midtjylland (56.003451 N, 9.743161E). Der blev lavet undersøgelser i fire marker af hver type mellem 30. juni og 24. juli 2019. I conservation agriculture pløjes og harves jorden ikke, jorden holdes altid dækket af afgrøder eller halmrester, og der benyttes et alsidigt sædskifte. Kemiske pesticider er tilladte og bruges hovedsageligt til ukrudtsfjernelse før såning, men der ses generelt alligevel positive effekter på biodiversitet, næringsindhold i jorden, samt begrænsning af nedsivning.

Resultaterne viste, at der var omkring fem gange så mange Sanglærker i CA som i CT (Tab. 1, Fig. 1), og der var 2,3 gange større biomasse af leddyr i CA (Fig. 3). Artsdiversiteten af leddyr havde en ikke-signifikant tendens til at være højere i CA-felter, og edderkopper og sommerfugle-/bladhvepselarver fandtes i signifikant højere tætheder i CA (Tab. 2, Fig. 2). Ved hjælp af estimater af de daglige energibehov for et par Sanglærker med unger i reden blev det gennemsnitlige daglige areal, som et ynglepar skal gennemsøge for at tilfredsstille det daglige energibehov for sig selv og deres unger anslået til 587 m² i CA-marker sammenlignet med 1337 m² i CT-felter. Dette resultat kombineret med fem gange højere tæthed af Sanglærker tyder på, at vårbygmarker dyrket i henhold til CA-reglerne giver nok mad til et andet kuld, hvilket ikke ser ud til at være tilfældet i CT-marker.

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EBBA2 nu frit tilgængeligt på nettet

For mere end et år siden blev European Breeding Bird Atlas 2 (EBBA2) offentliggjort (se DOFT 115: 187-189, 2021). Bogen har været en så stor succes, at den er genoptryk flere gange, og British Birds/BTO har udnævnt den til årets bedste fuglebog i 2021. For at gøre resultaterne af EBBA2 mere tilgængelige, er der nu oprettet et nyt EBBA2-websted, hvor alle har fri adgang på www.ebba2.info til at se interaktive udbredelseskort over alle europæiske ynglefugle, finde ud af mere om projektet og dets output og fremsætte dataanmodninger. Webversionen af EBBA2 supplerer bogen, hvor detaljerede artsbeskrivelser og sammenfattende kapitler kan findes. Mange tak til alle, der bidrog til atlasset (i Danmark via Atlas III) og nyd den nye hjemmeside!