Wpływ pojedynczych elementów krajobrazu i informacji socjalnej na występowanie i liczebność ptaków polnych

---

The effect of singular landscape elements and social information
on the distribution and abundance of farmland birds

Sylwia Pustkowiak

INSTYTUT OCHRONY PRZYRODY
PAN

Kraków, 2022

AUTOR: **mgr inż. Sylwia Pustkowiak**
Instytut Ochrony Przyrody Polskiej Akademii Nauk
Al. A. Mickiewicza 33, 31-120 Kraków

PROMOTOR: **dr hab. Piotr Skórka, prof. IOP PAN**
Instytut Ochrony Przyrody Polskiej Akademii Nauk
Al. A. Mickiewicza 33, 31-120 Kraków

PROMOTOR
POMOCNICZY: **dr Zbigniew Kwieciński**
Instytut Biologii, Uniwersytet Szczeciński
Ul. Wąska 13, 71-415 Szczecin
Instytut Biologii Środowiska,
Wydział Biologii, Uniwersytet im. Adama Mickiewicza
Ul. Uniwersytetu Poznańskiego 6, 61-614 Poznań

Spis treści

SPIS PUBLIKACJI 4

PODZIĘKOWANIA 5

FINANSOWANIE 6

STRESZCZENIE 7

SUMMARY 10

WSTĘP 12

HIPOTEZY I CEL BADAŃ 17

MATERIAŁY I METODY 19

WYNIKI 28

WNIOSKI 32

PODSUMOWANIE 37

LITERATURA 39

SPIS PUBLIKACJI

1. Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z.M., Tryjanowski, P., Skórka, P. 2021. Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews* 96: 1386-1403. DOI: 10.1111/brv.12707
2. Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Skórka, P. The scale-dependent association between bird diversity and singular point elements in agricultural landscapes (SPEL) differing in management intensity [w trakcie procesu redakcyjnego w czasopiśmie *Agriculture, Ecosystems and Environment*].
3. Pustkowiak, S., Kwieciński, Z., Bełcik, M., Skórka, P. Does social information change the number, distribution and size of animal territories when habitat heterogeneity varies? [maszynopis]

PODZIĘKOWANIA

Serdecznie dziękuję promotorowi dr hab. Piotrowi Skórce – za zaufanie, którym mnie obdarzył siedem lat temu, za możliwość poznania profesjonalnego warsztatu pracy badacza, wsparcie merytoryczne, inspiracje i dyskusje oraz zaangażowanie w mój rozwój. Dziękuję dr Zbigniewowi Kwiecińskiemu – za pomoc merytoryczną, zaangażowanie w terenie i sympatyczną atmosferę. Prof. Piotrowi Tryjanowskiemu dziękuję za włączenie mnie do swojego zespołu badawczego i możliwość czerpania wiedzy z inspirującego środowiska naukowego Katedry Zoologii Uniwersytetu Przyrodniczego w Poznaniu.

Dziękuję koleżankom i kolegom: Dorocie Kotowskiej, Aleksandrze Splitt, Magdalenie Lendzie, Joannie Kajzer-Bonk, Annie Misiewicz, Michałowi Bełcikowi, Michałowi Żmihorskiemu – za wspólnie spędzony czas, ten naukowy i pozanaukowy. Cieszę się, że dzięki doktoratowi mogłam poznać tak wartościowych ludzi.

Szczególne podziękowania należą się mojej Rodzinie. Rodzicom dziękuję za wsparcie w całym procesie edukacji. Dzieciom – Zosi i Mikołajowi – za ogrom cierpliwości w czekaniu na moje powroty i wyrozumiałość w trudnych chwilach. W końcu szczególnie gorąco dziękuję Mężowi Piotrowi - za nieustanne wspieranie mnie w moich dążeniach i czuwanie nad Naszą codziennością w kluczowych dla mnie momentach. Najbliżsi najlepiej znają cenę całego przedsięwzięcia. Mam nadzieję, że uda mi się zrekompensować Wam czas, którego zawsze mi brakowało.

FINANSOWANIE

Moja rozprawa doktorska została sfinansowana z projektu badawczego Sonata Bis 4 (2014/14/E/NZ8/00165) Narodowego Centrum Nauki oraz z dotacji dla doktorantów Studium Doktoranckiego Nauk Przyrodniczych PAN przy Instytucie Botaniki im. W. Szafera Polskiej Akademii Nauk w Krakowie

Rozprawa doktorska została przygotowana w trakcie trwania studiów doktoranckich w Studium Doktoranckim Nauk Przyrodniczych PAN w Krakowie.

STRESZCZENIE

Ptaki są ważnym składnikiem bioróżnorodności krajobrazu rolniczego i jednocześnie jedną z najbardziej zagrożonych grup kręgowców w Europie. Ich ochrona obejmuje kilka strategii opartych na zmianach użytkowania gruntów i mniej intensywnym gospodarowaniu. Wszystkie te działania mają na celu zwiększenie heterogeniczności siedlisk – jednej z najważniejszych cech środowiska wpływających na rozmieszczenie zwierząt i zwiększającą bogactwo gatunkowe. Jednak koncepcje teoretyczne opisujące wzorce bioróżnorodności obszarów rolnych zwykle pomijają rolę pojedynczych, często bardzo małych, naturalnych lub wytworzonych przez człowieka elementów punktowych w krajobrazie rolniczym. Pojedyncze elementy punktowe w krajobrazie rolniczym (SPEL; np. pojedyncze drzewa, krzewy, kapliczki, słupy) mogą stanowić ważne zasoby siedliskowe dla różnych gatunków, a tym samym zwiększać różnorodność ptaków, ale ich znaczenie nigdy nie zostało kompleksowo przeanalizowane ani empirycznie przetestowane. Jednak nie tylko właściwości fizyczne siedliska opisują jego jakość, zwłaszcza że heterogeniczność siedlisk może również zwiększać nieprzewidywalność jego przydatności lub jakości. Dlatego, wiele zwierząt wybiera siedlisko na podstawie informacji socjalnej, którą może być obecność osobników tego samego gatunku, znana jako przyciąganie wewnątrzgatunkowe. Informacja socjalna uważana jest za wiarygodną wskazówkę jakości siedliska i dlatego może mieć duże znaczenie dla gatunków podczas wyboru miejsc lęgowych w bardziej heterogenicznych, a zatem mniej przewidywalnych krajobrazach.

W mojej rozprawie doktorskiej definiuję i identyfikuję pojedyncze elementy punktowe w krajobrazie rolniczym (SPEL) powszechnie występujące na obszarach rolniczych. Przedstawiam również przegląd dostępnej literatury opisującej każdy SPEL i oceniam jego znaczenie dla ptaków krajobrazu rolniczego. Wykorzystując technikę skanowania horyzontu, przepytałam ornitologów na temat ich osobistych obserwacji i wniosków dotyczących potencjalnej roli takich struktur dla ptaków. Podczas badań terenowych po raz pierwszy oceniałam związek między liczebnością

i typami SPEL, a bogactwem gatunkowym i liczebnością ptaków w dwóch skalach przestrzennych w krajobrazach rolniczych różniących się intensywnością użytkowania gruntów rolnych. Kolejne badania terenowe miały na celu zweryfikowanie czy informacja socjalna może modyfikować wpływ heterogeniczności siedlisk na liczbę, skupiskowość i wielkość terytoriów pospolitego ptaka krajobrazu rolniczego – pliszki żółtej Motacilla flava L.

Zidentyfikowałam 17 SPEL różniących się stopniem naturalności i czasem trwania. Analiza literatury ujawniła luki w wiedzy, ponieważ niektóre SPEL są często wymieniane w badaniach ekologicznych (np. drzewa, krzewy, słupy), podczas gdy inne, takie jak np. kapliczki, ambony myśliwskie, znaki drogowe, czy sterty wapna są pomijane. Ornitolodzy często obserwują ptaki na różnych SPEL i kojarzą je z wieloma funkcjami ważnymi dla populacji ptaków. W badaniach empirycznych w skali krajobrazu bogactwo gatunkowe ptaków było pozytywnie skorelowane z liczbą SPEL w krajobrazie mało intensywnie użytkowanym, ale nie było takiej korelacji, wbrew oczekiwaniom, w bardziej intensywnie użytkowanym. W skali punktowej więcej gatunków i o większej liczebności występowało przy drzewach, słupach, krzewach i kapliczkach w porównaniu do punktów referencyjnych zlokalizowanych w polach i przy drogach. Analizy ordynacyjne w obu skalach przestrzennych wykazały istotny udział SPEL w różnicowaniu składu gatunkowego ptaków polnych. Eksperyment z emisją śpiewu pliszki żółtej wykazał, że informacja socjalna nie wpływała na liczbę i grupowanie terytoriów pliszki. Wielkość terytorium jednak zmniejszyła się w wyniku odtwarzania informacji socjalnej w krajobrazie o mniejszej heterogeniczności siedlisk, ale wzrosła w krajobrazie o większej heterogeniczności siedlisk. Kontrola proceduralna wykazała jednak podobny efekt jak informacja socjalna wskazując, że procedura przyjęta podczas eksperymentu również mogła mieć wpływ na wyniki.

Moje prace stworzyły podstawy teoretyczne do rozważań o SPEL oraz dostarczyły pierwszych empirycznych dowodów na związek między liczebnością i typami SPEL, a populacjami ptaków żyjących na terenach rolniczych. Ponadto udało się uzyskać pierwsze eksperymentalne wyniki, że informacja socjalna może modyfikować wpływ heterogeniczności siedlisk na wielkość terytorium ptaków żyjących na terenach rolniczych.

SUMMARY

Birds are an important component of farmland biodiversity and, at the same time, one of the most endangered group of vertebrates in Europe. Their conservation includes several strategies based on land-use alterations and less intensive management. All these actions are aimed at increasing the heterogeneity of habitats - one of the most important characteristics of the environment affecting the distribution of animals and increasing species richness. However, concepts describing farmland biodiversity usually ignore the role of singular, often very small, natural or man-made point elements present in agricultural landscapes. Singular point elements in a landscape (SPEL; e.g., singular trees, shrubs, chapels, pylons) may provide basic resources for different species, thus may increase bird diversity but their importance has never been comprehensively reviewed nor empirically tested. Moreover, physical characteristics of the habitat are not the only one describing its suitability, especially since habitat heterogeneity may also indicate unpredictability of habitat suitability in space. Many animals select habitat based on social information, e.g. conspecific presence, known as conspecific attraction. Social information is regarded as a reliable cue and may be more important for species in more heterogeneous landscapes lowering uncertainty in habitat selection process.

In my doctoral dissertation, I define and identify singular point elements in the agricultural landscape (SPEL) commonly occurring in the agricultural space. I also provide a review of the available literature describing each SPEL and evaluate their importance for farmland birds. Using a horizon-scanning technique and internet I asked field ornithologists about their personal observations and impressions about potential roles of such structures for birds. Then, in first comprehensive field study I assessed the associations between the number and types of SPEL and bird diversity and species composition at two spatial scales in agricultural landscapes differing in management intensity. Finally, in a large field experiment I tested whether the social information may modify effects of habitat heterogeneity on the number, clustering pattern and size of territories of a common farmland bird - yellow wagtail Motacilla flava L.

I identified 17 SPEL varying in naturalness and age. Analysis of the literature revealed knowledge gaps, because some SPEL are frequently mentioned in ecological studies (e.g. trees, shrubs, pylons), while others such as for example spiritual sites, hunting platforms, road signs, or piles of lime are ignored. Ornithologists often observe birds on various SPEL and link them with many functions important for bird populations. In field study at the landscape scale, species richness was positively associated with the number of SPEL in less intensively managed landscape, but not in more intensively managed one. At the point scale, I found more species with higher abundance next to the trees, pylons, shrubs, and chapels than at the reference points (open fields) in both regions. Ordination analysis at both scales showed significant contribution of SPEL to the species composition. The experiment with the broadcast of yellow wagtails' songs showed that social information had no effect on number and clustering of wagtail territories. However, territory size decreased due to broadcast in less heterogeneous landscapes but increased in more heterogenous ones. Unexpectedly, the procedural control had similar effect as the social information indicating that experimental manipulation also impacted the results.

In this thesis, I created a theoretical background to study SPEL and provided the first empirical evidence of an association between SPEL numbers and farmland bird populations. I also found experimental evidence that social information may modify the effect of habitat heterogeneity on the territory area of a farmland bird.

.

WSTĘP

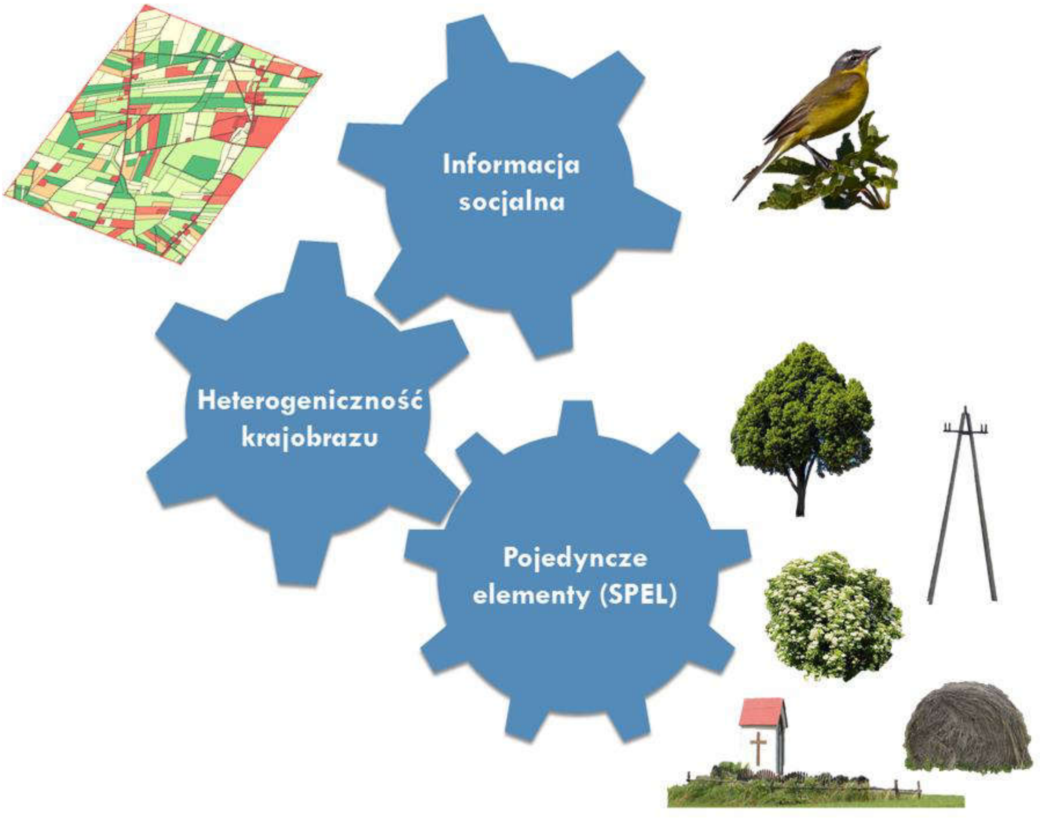
Homogenizacja krajobrazu i utrata siedlisk są zjawiskami dotkliwie uderzającymi w bioróżnorodność ekosystemów rolniczych, powodując tym samym zanik wielu usług ekosystemowych (Tscharntke i in., 2005, 2012a; Emmerson i in., 2016). Łagodzenie tych negatywnych zmian to trudne zadanie, ponieważ transformacja krajobrazu jest napędzana czynnikami społeczno-gospodarczymi i jest bezpośrednio związana z produkcją rolną (Renwick i in., 2014), a przebudowa krajobrazu na dużą skalę jest bardzo kosztowna (Ansell i in., 2016). Działania podejmowane w celu ochrony i zrównoważonego rozwoju terenów rolniczych obejmują szereg programów, takich jak programy rolnośrodowiskowe, dyrektywa azotanowa czy promocja rolnictwa organicznego. Skuteczność tych podejść w przywracaniu bioróżnorodności obszarów jest obecnie przedmiotem wielu analiz i dyskusji (Wretenberg i in., 2007; Kleijn i in., 2011; Lindenmayer i in., 2012; Pe'er i in., 2014; Zmihorski i in., 2016), często zależy bowiem od badanej skali przestrzennej (Batáry i in., 2011; Gonthier i in., 2014) lub typu krajobrazu (Wretenberg i in., 2007; Tryjanowski i in., 2011).

Ptaki polne to grupa zwierząt pełniąca liczne funkcje w ekosystemach rolniczych (Kirk i in., 1996; Gregory i in., 2005); wpływają one między innymi na obieg pierwiastków, rozsiewanie i dyspersje roślin, kontrolę tak zwanych szkodników (Boesing i in., 2017). Populacja ptaków polnych uległa znacznemu zmniejszeniu w Europie (Krebs i in., 1999; Donald i in., 2001, 2006), a efekt ten był znacznie większy w zachodniej części kontynentu (Tryjanowski i in., 2011). Zidentyfikowano szereg czynników odpowiadający za spadek populacji ptaków na terenach rolniczych, takich jak intensyfikacja produkcji rolniczej związana z mechanizacją i chemizacją (Krebs i in., 1999), wprowadzenie nowych metod uprawy (Skórka i in., 2013), zmiana struktury zasiewów na danym obszarze (Wilson i in., 2017) czy szeroko rozumiane przekształcenia krajobrazu, w tym jego homogenizacja, czyli zubożenie różnorodności upraw i udziału siedlisk marginalnych przy jednoczesnym scalaniu gruntów (Santana i in., 2017; Redlich i in., 2018).

Opracowanie skutecznych praktyk mających na celu ochronę ptaków na terenach rolniczych wymaga zrozumienia czynników kształtujących dynamikę lokalnych populacji oraz kierujących złożonym procesem wyboru siedliska, które przekładają się na bogactwo gatunkowe. Za jedną z miar krajobrazowych pozytywnie wpływających na bogactwo gatunkowe ptaków uznawana jest jego heterogeniczność krajobrazu, czyli przestrzenna i czasowa zmienność struktury i kompozycji siedlisk (Tews i in., 2004; Fahrig i in., 2011). Większa różnorodność siedliskowa krajobrazu zapewnia większą liczbę nisz i zasobów, wspierając w ten sposób większą liczbę gatunków pełniących różne funkcje w ekosystemie (Benton i in., 2003). Wpływ heterogeniczności na bogactwo gatunkowe może się różnić w zależności od rozpatrywanej skali przestrzennej (Pickett i Siriwardena, 2011; Tscharntke i in., 2012b; Morelli i in., 2013).

Poza wielkoskalową strukturą i kompozycją krajobrazu, duże znaczenie dla ptaków mogą mieć różnego rodzaj u wyspy siedliskowe na terenach uprawnych, będące lokalnymi płatami półnaturalnych siedlisk lub mikrosiedlisk np. remizy śródpolne, wychodnie skalne, obrzeża pól, rowy (Šálek i in., 2018). Tews i in., (2004) zaznaczyli, że występowanie danego gatunku może być warunkowane istnieniem specyficznych struktur przestrzennych w środowisku („keystone structures"). Najnowsze koncepcje dotyczące jakości siedlisk podkreślają znaczenie tzw. „Small Natural Features" czyli „obszarów o znaczeniu ekologicznym nieproporcjonalnym do ich wielkości" (Hunter Jr., 2016), które zostały szerzej opisane w specjalnym zeszycie Biological Conservation (tom 211, rocznik 2016). Tego typu niewielkie składniki krajobrazu mogą stanowić gorące miejsca bioróżnorodności; jednak ze względu na niewielki rozmiar nie są uwzględniane w większości dostępnych statystyk użytkowania gruntów. Ideę tę można rozszerzyć zwracając uwagę na pojedyncze elementy punktowe występujące w krajobrazie, zarówno naturalne, jak i sztuczne (np. pojedyncze drzewa i krzewy, słupy energetyczne, kapliczki śródpolne, głazy, stosy obornika, stogi siana itp.) W prezentowanej dysertacji wprowadziłam pojęcie pojedynczych elementów punktowych w krajobrazie rolniczym - Singular Point Elements in Agricultural Landscape (SPEL). SPEL to różne pojedyncze, często bardzo niewielkie, naturalne lub sztuczne struktury powszechnie występujące w krajobrazie pól, o zróżnicowanej historii i dynamice czasowej, mogące stanowić także ważny element krajobrazu kulturowego (Ungaro i in., 2016). Mogą one także pełnić funkcję wysp śródpolnych i dostarczać ptakom niezbędnych zasobów w przestrzeni zdominowanej przez pola uprawne, wspierając w ten sposób funkcjonowanie całego ekosystemu. Według definicji jaką wprowadziłam w publikacji otwierającej rozprawę doktorską (**praca 1**), SPEL powinien spełniać następujące kryteria: (1) jego struktura jest wyraźnie odmienna (zazwyczaj pionowa) od otaczającego środowiska użytków rolnych, a na zdjęciu satelitarnym prezentuje się jako pojedynczy punkt odróżniający się od otaczającej macierzy krajobrazowej; (2) jego rozmiar jest niewielki, często poniżej rozdzielczości większości publicznie dostępnych warstw pokrycia terenu, więc jego powierzchnia nie jest mierzona ani uwzględniana w większości oficjalnych statystyk dotyczących użytkowania gruntów; (3) jego wielkość jest mniejsza od powierzchni terytoriów gatunków ptaków żyjących na terenach rolniczych, a zatem nie zapewnia wszystkich zasobów potrzebnych osobnikowi. Niektóre SPEL są dobrze rozpoznawane i mają długą historię, np. pojedyncze stare drzewa (Hartel i in., 2017), lecz większość jest słabiej opisana i nie była oceniana pod kątem wkładu dla utrzymania bioróżnorodności. Ogólnie rola pojedynczych elementów punktowych dla ptaków w krajobrazie rolniczym, poza pojedynczymi drzewami, jest raczej słabo rozpoznana i nigdy nie została poddana systematycznemu przeglądowi.

Ptaki wybierają odpowiednie tereny do zasiedlenia bazując na informacji o fizycznych cechach danego siedliska, takich jak np. różnorodność siedlisk i występowanie pojedynczych elementów punktowych (Ryc. 1). Pomimo, że heterogeniczność często jest pozytywne skorelowana z liczbą gatunków, to z punktu widzenia pojedynczego gatunku wysoka heterogeniczność może być jednak niekorzystna, gdyż wraz ze wzrostem tej cechy zmniejszeniu ulega autokorelacja przestrzenna, czyli przewidywalność jakości siedliska (Jager i in., 2005). Może to powodować, że decyzja o zasiedleniu takiego miejsca musi być podjęta na podstawie oceny większej liczby cech środowiska. Ponadto większa liczba innych gatunków w siedliskach heterogenicznych może powodować zwiększoną rywalizacją międzygatunkową i/lub drapieżnictwo. Ze względu na potencjalnie dużą nieprzewidywalność heterogenicznych siedlisk, osobniki mogą wspierać się wykorzystaniem informacji socjalnej podczas wyboru miejsca rozrodu (Doligez i in., 2003; Schmidt i in., 2010). Informacją socjalną może być obecność innych osobników, ich zachowanie, wydawane przez nie dźwięki lub inne ślady ich obecności lub aktywności (Hromada i in., 2008). Informacja socjalna może być czerpana od osobników należących do tego samego bądź różnych gatunków. Najważniejsze jednak, że informacja socjalna może zmniejszać niepewność w wyborze siedliska, a tym samym zwiększać dostosowanie osobnika (Ward i in., 2010). Uważa się, że wokalizacja osobników tego samego gatunku stanowi pozytywną informację socjalną, wskazującą na wysoką jakość siedliska i zwiększającą atrakcyjność powierzchni (Fletcher Jr., 2007). Związana z wysoką heterogenicznością siedlisk nieprzewidywalność może powodować, że osobniki, aby ocenić jakość siedliska, będą polegać na informacji socjalnej w siedliskach heterogenicznych bardziej, niż w homogenicznych. Hipoteza dotycząca modyfikacji wpływu informacji socjalnej na rozmieszczenie osobników w krajobrazach różniących się heterogenicznością siedlisk nie została jednak dotąd przetestowana.



Ryc.1. Schemat obrazujący relacje między czynnikami potencjalnie wpływającymi na występowanie i liczebność ptaków polnych. Pojedyncze elementy krajobrazu mogą pozytywnie wpływać na występowanie i zróżnicowanie gatunkowe ptaków polnych, a ich efekt może być powiązany z heterogenicznością krajobrazu rolniczego. Informacja socjalna stanowi pozytywny sygnał dla osobników i sprzyja osiedlaniu się na danym terenie, ale jej wartość dla danego osobnika może być różna w zależności od heterogeniczności siedlisk.

HIPOTEZY I CEL BADAŃ

W ramach zaprezentowanej rozprawy doktorskiej postawiłam następujące hipotezy:

1) Występowanie pojedynczych elementów punktowych (SPEL) jest pozytywnie związane z występowaniem i bogactwem gatunkowym ptaków na terenach rolniczych zarówno w skali krajobrazowej, jak i lokalnej.

2) Różne typy pojedynczych elementów punktowych (SPEL) wspierają różne gatunki, zwiększając w ten sposób całkowite bogactwo gatunków i zmienność w składzie gatunkowym populacji ptaków.

3) Pozytywna relacja między pojedynczymi elementami punktowymi (SPEL) a ptakami krajobrazu rolniczego jest silniejsza (bardziej pozytywna) w krajobrazie intensywnie użytkowanym, niż w ekstensywnie użytkowanym.

4) Dodanie informacji socjalnej może zwiększyć liczebność i skupiskowość terytoriów oraz zmniejszyć ich wielkość u wybranego gatunku ptaka – pliszki żółtej Motacilla flava L.

5) Efekt informacji socjalnej na lokalne populacje pliszek będzie silniejszy w krajobrazach o większej heterogeniczności siedlisk niż w krajobrazach o mniejszej heterogeniczności siedlisk

W ramach przeglądu literatury dotyczącej pojedynczych elementów punktowych (**praca 1**) moim celem było zdefiniowanie oraz identyfikacja SPEL w krajobrazie rolniczym, a także opis znaczenia SPEL dla ptaków na podstawie zebranej literatury. Przeprowadzone w ramach tej pracy skanowanie horyzontu oraz badanie ankietowe miało na celu zestawienie opinii ekspertów z badaniami literaturowymi i wskazanie luk w wiedzy o związkach gatunków ptaków ze SPEL.

Empiryczne badanie związków między ptakami krajobrazu rolniczego a SPEL było przedmiotem **pracy 2.** W badaniach tych sprawdzano relatywne znaczenie

SPEL dla ptaków w odniesieniu do heterogeniczności upraw oraz innych czynników potencjalnie wpływających na ptaki. Badania zostały wykonane w dwóch regionach Polski różniących się intensywnością rolnictwa.

Do sprawdzenia efektów informacji socjalnej i heterogeniczności siedlisk na rozmieszczenie i liczebność terytoriów ptaków polnych (**praca 3)**, wybrano pliszkę żółtą - gatunek pospolitego ptaka wróblowego zasiedlający otwarte pola, występujący w krajobrazach o zróżnicowanej różnorodności siedlisk. Jest to gatunek, który notuje umiarkowany spadek populacji, jednak lokalnie może być bardzo liczny (Kuczyński i Chylarecki, 2012). Pierwotnie uznawany był za gatunek łąkowy (Tomiałojć i Stawarczyk, 2003), obecnie jednak chętniej gnieździ się na polach oprawnych, wybierając tereny bogate w uprawy okopowe i warzywne (Kuczyński i Chylarecki, 2012).

MATERIAŁY I METODY

Przegląd wiedzy – pojedyncze elementy punktowe w krajobrazie rolniczym (SPEL)

Badania pojedynczych elementów punktowych poprzedzone zostały szczegółową analizą literatury dotyczącej znaczenia omawianych struktur dla ptaków polnych (**praca 1**). W pierwszej części pracy wprowadziłam definicję pojedynczego elementu punktowego. Na podstawie doświadczeń terenowych zebranych wspólnie ze współautorami oraz wyszukiwania, w systematyczny sposób, słów kluczowych w bazie czasopism Web of Science stworzyłam listę 17 pojedynczych elementów punktowych występujących w przestrzeni pól uprawnych. Na liście tej znalazły się między innymi pojedyncze drzewa i krzewy, kapliczki śródpolne, słupy energetyczne, słupki ogrodzeniowe, sterty obornika i słomy. Następnie powtórzyłam wyszukiwanie literatury używając jako słów kluczowych zwrotów odnoszących się do każdego konkretnego elementu. Na podstawie zebranej literatury stworzyłam dla każdego elementu punktowego opis stanu wiedzy na temat jego znaczenia dla ptaków polnych wraz z zestawieniem tabelarycznym funkcji jakie poszczególne elementy mogą pełnić (np. miejsce gniazdowania, żerowania, polowania). Ostatnim elementem pracy była ankieta przeprowadzona wśród polskich ornitologów i obserwatorów ptaków na temat ich obserwacji i spostrzeżeń dotyczących znaczenia pojedynczych elementów dla ptaków polnych.

Procedura terenowa – pojedyncze elementy punktowe w krajobrazie rolniczym (SPEL)

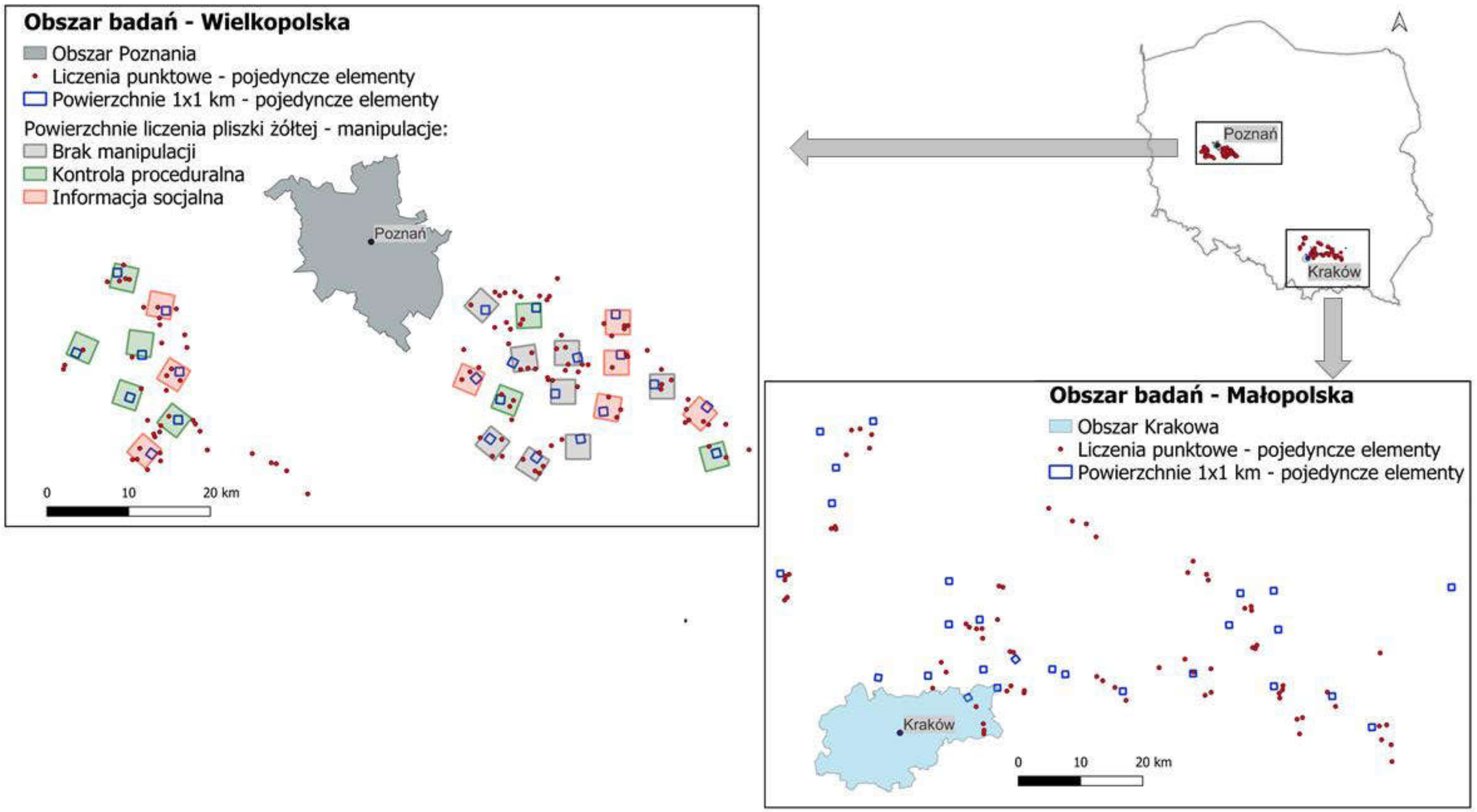
Wyniki uzyskane w pracy 1 były testowane empirycznie. Badania terenowe dotyczące roli pojedynczych elementów punktowych dla ptaków (**praca 2**) przeprowadzone były na obszarze dwóch regionów: w ekstensywnie zagospodarowanym krajobrazie południowej Polski (woj. małopolskie, Ryc. 2) oraz w intensywniej zagospodarowanym krajobrazie zachodniej Polski (województwo wielkopolskie, Ryc. 2). W ramach obu regionów przeprowadzone zostały dwa odrębne badania ptaków: w skali krajobrazowej w 2016 r. (50 powierzchni o rozmiarze 1 km^2 o zróżnicowanej liczbie elementów, 24 powierzchnie w Wielkopolsce, 26 w Małopolsce) oraz w skali punktowej w latach 2018 i 2020. Do podejścia w skali punktowej wybrane zostały punktowe elementy czterech typów: drzewa, krzewy, słupy energetyczne i kapliczki polne, łącznie 128 punktów. Jako miejsce kontrolne wyznaczone zostały punkty na polach bez żadnego elementu (32 punkty). Wiele elementów punktowych znajduje się wzdłuż dróg, co może mieć negatywny wpływ na ptaki (Benítez-López i in., 2010). Aby uwzględnić ewentualny wpływ drogi na ptaki wybrane zostały dodatkowe 33 punkty wzdłuż dróg bez żadnych elementów. Przy wyborze powierzchni do badań kierowano się następującymi kryteriami: w skali krajobrazu liczba elementów miała być możliwie słabo lub nieskorelowana z heterogenicznością siedliska (różnorodnością upraw i innych typów pokrycia terenu); przy badaniach w skali punktowej miejsca liczeń ptaków wybierano tak, aby nie było innych SPEL niż badany element w promieniu 100 m. W obu skalach wybierano powierzchnie z niskim udziałem powierzchni leśnej (nie większy niż 1%) i zabudowań (nie większy niż 5%).

W ramach badań SPEL w skali krajobrazu na każdej powierzchni w sezonie lęgowym w 2016 roku przeprowadzone zostały dwa liczenia ptaków: pierwsze od 15 kwietnia do 15 maja oraz drugie od 16 maja do 15 czerwca. Badania terenowe prowadzono przy dobrej pogodzie od świtu do godz. 11 rano, a każda powierzchnia kontrolowana była przez godzinę. Liczone były wszystkie ptaki z wyjątkiem tych lecących kierunkowo na dużej wysokości (prawdopodobnie migrujących i niezwiązanych z powierzchnią).

W skali punktowej przeprowadzone zostały dwa 10-minutowe liczenia ptaków w każdym punkcie badawczym wiosną 2018 roku (Wielkopolska) i 2020 roku (Małopolska), pierwsze między 15 kwietnia a 15 maja, a drugie między 16 maja a 15 czerwca. Ptaki liczono w promieniu 100 m od punktu obserwacyjnego wyznaczonego w odległości 50 m od elementu (obserwator nie podchodził do samego elementu, żeby nie odstraszyć siedzących na nim ptaków). Pozostałe wytyczne były podobne do tych z części krajobrazowej (pogoda, godziny badań i wykluczenie migrantów latających na dużych wysokościach). Na niektórych obszarach czasem trudno było wyznaczyć elementy punktowe (zwłaszcza kapliczki), które nie są otoczone innymi elementami; dlatego policzone zostały wszystkie SPEL w promieniu 200 m od punktu obserwacyjnego (z wyłączeniem badanego elementu), aby uwzględnić ich liczbę jako współzmienną. Odnotowane zostało również procentowe pokrycie typów użytkowania gruntów w promieniu 100 m od punktu obserwacyjnego.

Procedura terenowa – eksperyment z informacją socjalną

Badania dotyczące wpływu informacji socjalnej na rozmieszczenie pliszki żółtej (**publikacja 3**) przeprowadzono w zachodniej Polsce (woj. wielkopolskie, Ryc. 2) gdzie wybrane zostały 24 powierzchnie o powierzchni 9 km^2 każda. Przy wyborze obszaru badań posłużono się danymi z Powszechnego Spisu Rolnego 2010 (Główny Urząd Statystyczny, 2013), wybierając gminy o wysokim udziale roślin okopowych, warzyw i rzepaku, preferowanych przez pliszkę żółtą (Kuczyński i Chylarecki, 2012). Przy wyznaczaniu terenu badań brane były pod uwagę następujące kryteria: niski udział lasów (nie wyższy niż 1%) oraz pokrycie osiedli mieszkaniowych nie większe niż 5%.

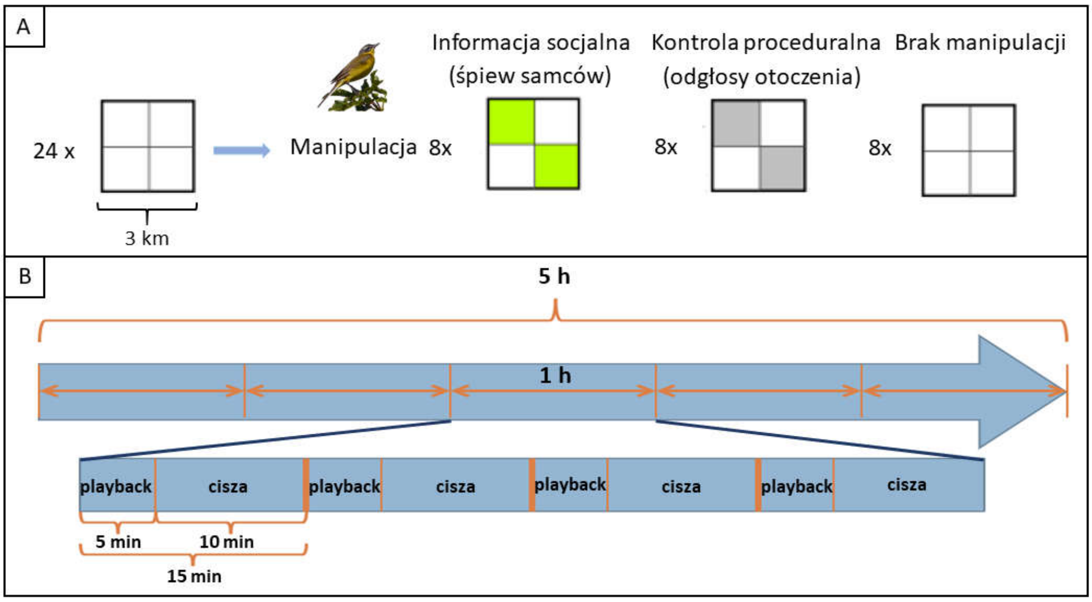


Ryc. 2. Rycina obrazująca rozmieszczenie terenu badań pojedynczych elementów punktowych (SPEL) w Wielkopolsce i Małopolsce (punkty i powierzchnie 1 km^2) oraz badania rozmieszczenia pliszki żółtej w Wielkopolsce wraz z przydzielonymi manipulacjami eksperymentalnymi.

Każda powierzchnia badawcza skontrolowana została sześć razy w każdym sezonie lęgowym od 15 kwietnia do 15 lipca w latach 2016-2017. Podczas kontroli na mapach kartograficznych notowano występowanie pliszki żółtej. W 2017 roku mapowanie pliszek żółtych rozpoczęło się po zakończeniu eksperymentu z emisją informacji socjalnej. Zebrane zostały także dane o strukturze użytkowania terenu jako stopień pokrycia poszczególnych upraw i innych typów użytkowania gruntów. Wszystkie dane zostały zdigitalizowane w QGIS v. 3.22.7 (QGIS Association, 2022).

W 2017 roku losowo przydzielono 24 powierzchnie do 3 grup eksperymentalnych (po 8 w każdej grupie): informacja socjalna, kontrola proceduralna i brak manipulacji. Informacja socjalna obejmowała śpiew terytorialny samców pliszki żółtej. Kontrola proceduralna obejmowała odtwarzanie dźwięków otoczenia (tj. dźwięku poruszającej się roślinności, wiatru i innych dźwięków dochodzących z otaczającego krajobrazu) i została uwzględniona w celu oceny potencjalnego wpływu procedury terenowej (tj. regularnych wizyt pracowników terenowych, obecności sprzętu terenowego) na zachowanie ptaków. Powierzchnie zostały podzielone na cztery ćwiartki o powierzchni 2,25 km^2. Do manipulacji eksperymentalnych wybrano dwie ćwiartki sąsiadujące po przekątnej (ryc. 3A), w których odtwarzany był albo śpiew samców pliszki żółtej, albo kontrola proceduralna w pięciu losowo wybranych miejscach w każdej ćwiartce (10 punktów odtwarzania na każdą powierzchnię).

Playback śpiewu pliszki żółtej składał się z 5-minutowych fragmentów wokalizacji, pomiędzy którymi znajdowały się 10-minutowe fragmenty ciszy (Ryc. 3B). Piosenki i głosy samców pobrano ze strony internetowej XenoCanto – platformy do udostępniania nagrań ptaków (www.xeno-canto.org). Wykorzystaliśmy wyłącznie nagrania o najwyższej jakości dostępnej dla tego portalu, pochodzące z podobnego krajobrazu rolniczego w Polsce i wschodnich Niemczech. Playback kontroli proceduralnej zaaranżowano w taki sam sposób jak informacji socjalnej, a odgłosy zostały nagrane na pobliskim terenie rolniczym na początku sezonu (przed przybyciem większości ptaków śpiewających).



Ryc. 3. Układ eksperymentalny wykorzystany w badaniu informacji socjalnej. A - podział powierzchni na poszczególne typy manipulacji i rozmieszczenie obszarów objętych playbackiem wewnątrz powierzchni. B - Układ ścieżki odtwarzania z informacją socjalną i kontrolą proceduralną.

Playback odtwarzany był z głośników (JAM HX-P710) połączonych przez bluetooth z odtwarzaczem Mp3 (Philips GoGear Azure SA5AZU08KF). Oba urządzenia zawieszono na drzewie, krzewie lub słupie na wysokości 0,5-1 m. Eksperyment odbył się w 2017 roku w okresie przylotu pliszek i zasiedlania terytoriów i trwał dwa tygodnie (17-30 kwietnia). Głośniki rozstawiano codziennie od godz. 7 rano. Odtwarzanie trwało 5 godzin, głośniki były zbierane od godziny 12:00.

Dla każdej powierzchni krajobrazowej i powierzchni kołowej o promieniu 100 m (skala punktowa) obliczono: (1) średnią wielkość pola za pomocą warstwy z podziałem katastralnym z serwisu www.geoportal.gov.pl (Główny Urząd Geodezji i Kartografii, 2017), (2) całkowitą długość dróg oraz (3) heterogeniczność krajobrazu wyrażoną jako wskaźnik różnorodności Simpsona oparty na udziale różnych typów użytkowania gruntów przy użyciu pakietu „vegan" (Oksanen i in., 2020) w R (R Core Team, 2021).

Do zbadania wpływu SPEL na bogactwo gatunkowe i liczebność ptaków polnych wykorzystano uogólnione modele addytywne (GAM) przy użyciu pakietu „mgcv" (Wood, 2017) z ujemnym rozkładem dwumianowym i dopasowaniem krzywej z użyciem metody ograniczonego maksymalnego prawdopodobieństwa („REML"). Zmiennymi zależnymi w obu podejściach było bogactwo gatunków ptaków (łączna liczba z dwóch kontroli) i liczebność (maksymalne liczebności każdego gatunku z dwóch wizyt). Dla obu regionów wykonano odrębne modele GAM. W modelach w skali krajobrazowej główną zmienną objaśniającą była nieliniowa funkcja całkowitej liczby SPEL na powierzchni. W modelach dla skali punktowej głównymi zmiennymi objaśniającymi był typ punktu (kategoryczna zmienna o sześciu poziomach: cztery typy elementów i dwa punkty kontrolne: punkt przy drodze i w polu). Wykorzystano również następujące zmienne objaśniające w obu skalach przestrzennych: heterogeniczność siedlisk, średnia wielkość pola i całkowita długość dróg. W modelach dla skali krajobrazowej uwzględniono również liczbę typów SPEL w obrębie powierzchni jako zmienną liniową. W skali punktowej wprowadzono dodatkową funkcję nieliniową – liczbę wszystkich pozostałych elementów (z wyłączeniem badanego elementu) w promieniu 200 m od punktu obserwacyjnego. W każdym modelu kontrolowany był efekt możliwej autokorelacji przestrzennej.

Ponadto, aby zrozumieć, w jaki sposób SPEL wpływają na zmienność składu gatunkowego, przeprowadzona została kanoniczna analiza korespondencji (CCA) w Canoco 5 (Šmilauer i Lepš, 2014). Wykonano oddzielne modele CCA dla dwóch regionów i dwóch skali przestrzennych. W pierwszym CCA w skali krajobrazowej badany był związek frekwencji poszczególnych typów elementów w obrębie powierzchni ze składem gatunkowym ptaków, kontrolując efekt innych zmiennych objaśniających (heterogeniczność siedlisk, długość dróg i średnią wielkość pola). Drugi model CCA analizował względny wkład całkowitej liczby SPEL, heterogeniczności siedlisk, średniej wielkości pola i długości drogi w kształtowanie składu gatunkowego ptaków na powierzchni krajobrazowej. W skali punktowej pierwszy model CCA wyjaśniał skład gatunkowy rodzajem badanego punktu (sześć poziomów: cztery typy SPEL, kontrola pola i kontrola drogi), przy usunięciu wpływu innych zmiennych objaśniających (heterogeniczność siedliska, wielkość pola, długość drogi, współrzędne punktu, liczba pozostałych elementów w promieniu 200 m). Drugi model CCA analizował względny wkład poszczególnych typów punktów, liczby pozostałych elementów w promieniu 200 m, heterogeniczności siedlisk, wielkości pola i długości dróg, w kształtowanie składu gatunkowego ptaków.

Analiza danych – eksperyment z informacją socjalną

Heterogeniczność siedlisk w krajobrazie została wyrażona jako wskaźnik różnorodności Simpsona oparty na udziale różnych upraw i typów użytkowania gruntów, obliczony przy użyciu pakietu „vegan” w R. Obliczono także średnią wielkość pola przy użyciu warstwy z podziałem katastralnym ze strony geoportal.pl oraz całkowitą długość dróg na każdej powierzchni przy użyciu danych z projektu Open Street Map (OpenStreetMap Contributors, 2022). Przy obliczaniu heterogeniczności wykluczone zostały m.in. lasy, drogi, osiedla ludzkie, które nie są odpowiednim siedliskiem dla pliszki żółtej.

Na podstawie danych o występowaniu pliszki żółtej w każdym roku wyznaczono terytoria, stosując metodykę Kotowskiej i in. (2019). Terytoria były skupiskami stwierdzeń obliczonymi w oprogramowaniu CrimeStat (Levine, 2015) przy użyciu algorytmu hierarchicznego grupowania najbliższego sąsiedztwa (NNH) ze 100 symulacjami i co najmniej trzema punktami wymaganymi do wyznaczenia klastra (terytorium), jak zakłada kombinowana metoda kartograficzna (Tomiałojć, 1980a, b; Bibby i in., 2000). Liczba klastrów stanowiła oszacowanie liczby terytoriów (Kotowska i in., 2019) z dodatkową informacją o liczbie stwierdzeń pliszki w każdym klastrze. Elipsoidy klastrów zostały wyeksportowane do QGIS, gdzie wyznaczono ich centroidy i obliczono indeks najbliższego sąsiedztwa (NN index - miara skupienia terytoriów) dla każdej powierzchni.

Przeanalizowano odpowiedź trzech głównych zmiennych zależnych w każdym roku badań: liczby terytoriów na powierzchniach, wskaźnika skupiskowości terytoriów na powierzchniach (NN index) oraz powierzchnię każdego terytorium. Oczekiwaną liczbę terytoriów dopasowano za pomocą uogólnionego modelu liniowego (GLM) z ujemnym rozkładem dwumianowym za pomocą funkcji „glm.nb” z pakietu „MASS” (Venables i Ripley, 2002). Dla wskaźnika najbliższego sąsiedztwa dopasowaliśmy model liniowy (LM). Liniowy model mieszany (LMM) został natomiast wykorzystany do analiz powierzchni terytorium przy użyciu pakietu „lme4” (Bates i in., 2015), z identyfikatorem powierzchni uwzględnionym jako czynnik losowy. Osobne modele zostały przygotowane dla danych z 2016 i 2017 roku. Wykorzystano zmienne objaśniające: typ manipulacji eksperymentalnej, wskaźnik heterogeniczność siedliska w danym roku, średnia wielkość pola w obrębie powierzchni, długość dróg oraz interakcję między rodzajem manipulacji, a heterogenicznością siedliska w danym roku. Do modelowania powierzchni terytorium użyto dodatkowej zmiennej – liczby stwierdzeń pliszki na każdym terytorium – jako współzmiennej, aby uwzględnić fakt, że większe terytoria były nieznacznie skorelowane z liczbą stwierdzeń pliszki.

.

WYNIKI

Przegląd literatury (**praca 1**) obejmował ponad 300 prac naukowych, w których poszukiwałam odniesień do relacji ptaków polnych z pojedynczymi elementami punktowymi. Badania ujawniły zróżnicowanie terminologii stosowanej w odniesieniu do pojedynczych elementów punktowych. Większość cytowanych prac pochodziła z obszaru Europy (65%) i Ameryki Północnej (20%). W badanym materiale nie znalazłam prac, które analizowałyby wpływ szerszego spektrum pojedynczych elementów punktowych na ptaki. W badaniach populacyjnych ptaków nieliczne prace naukowe uwzględniały niektóre typy elementów punktowych (najczęściej pojedyncze drzewa i krzewy, słupy energetyczne). Rola pojedynczych drzew i krzewów dla ptaków była też stosunkowo dobrze opisana w literaturze.

W ankiecie, którą wypełniło 163 doświadczonych ornitologów, respondenci wskazywali częste i bardzo częste obserwacje ptaków na pojedynczych drzewach, krzewach, słupach energetycznych, w kałużach, na słupkach ogrodzeniowych i stogach siana. Elementami, na których ptaki obserwowano rzadko lub nigdy przez większość respondentów były turbiny wiatrowe, studnie i strachy na wróble. Większość specjalistów wskazywała na wyraźny pozytywny wpływ drzew (90%), krzewów (87%), kałuż (83%), stogów siana (64%), pryzm obornika (52%) i stosów kamieni (51%). W opiniach ekspertów najbardziej negatywny wpływ na ptaki miały turbiny wiatrowe (62% „negatywne", 18% „umiarkowanie negatywne"). Dwie trzecie badanych uważało, że SPEL są najważniejsze dla ptaków w okresie lęgowym (67,5%). Dużo niższy odsetek respondentów wskazał, że SPEL są ważne w pozostałych porach roku (sezon zimowy 17,8%, migracja jesienna 11%, migracja wiosenna 3,7%). Spośród wszystkich SPEL, drzewom i krzewom przypisano wszystkie proponowane funkcje (miejsce gniazdowania, żerowania, odpoczynku, miejsce śpiewu i polowania) w podobnych proporcjach według respondentów. Sterty obornika i kałuże zostały wskazane jako ważne źródło pożywienia. Turbiny wiatrowe uzyskały najniższe oceny we wszystkich proponowanych funkcjach. Każdy respondent został również poproszony o wymienienie pięciu gatunków ptaków, które, w jego opinii, najczęściej używają elementów punktowych. Dziesięć najczęściej wymienianych gatunków to: myszołów zwyczajny *Buteo buteo* L., gąsiorek *Lanius collurio* L., trznadel zwyczajny *Emberiza citrinella* L., pustułka zwyczajna *Falco tinnunculus* L., potrzeszcz *Emberiza calandra* L., srokosz *Lanius excubitor* L., pliszka żółta *Motacilla flava* L., szpak zwyczajny *Sturnus vulgaris* L., skowronek zwyczajny *Alauda arvensis* L. i bocian biały *Ciconia ciconia* L.

Badania empiryczne zależności między występowaniem SPEL a populacją ptaków polnych **(praca 2**) wykazały w Małopolsce pozytywny związek między liczbą SPEL a bogactwem gatunkowym ptaków, podczas gdy liczba typów SPEL była ujemnie związana z bogactwem gatunkowym. Analogiczna analiza dla liczebności ptaków nie wykazała istotnego związku między zmiennymi. Analizy dla Wielkopolski nie wykazały żadnego istotnego związku między zmiennymi objaśniającymi, w tym SPEL, a bogactwem gatunkowym i liczebnością gatunków ptaków. Testy osi ordynacyjnych kanonicznej analizy korespondencji (CCA), wykazały, że istnieje istotny związek między występowaniem różnych typów SPEL i składem gatunkowym ptaków w obu regionach. Elementami, które znacząco przyczyniły się do zróżnicowania składu gatunkowego w Małopolsce były słupy energetyczne (8% wyjaśnionej zmienności; pseudo-F = 2,1; p = 0,002), drzewa (7,6% wyjaśnionej zmienności; pseudo-F = 2,0, p = 0,002) i inne (rzadkie) SPEL (7,6% wyjaśnionej zmienności; pseudo-F = 2,0; p = 0,004). W Wielkopolsce istotny wkład w kształtowanie składu gatunkowego wykazały krzewy (6,4% wyjaśnionej zmienności; pseudo-F = 1,5; p = 0,02), słupy energetyczne (6% wyjaśnionej zmienności; pseudo-F = 1,4; p = 0,05) oraz sterty obornika (5,9% wyjaśnianej zmienności; pseudo-F = 1,4; p = 0,048). Po uwzględnieniu wszystkich zmiennych objaśniających w CCA, zmiennymi, które znacząco przyczyniły się do zróżnicowania składu gatunkowego w Małopolsce były całkowita liczba SPEL (9,6% wyjaśnionej zmienności; pseudo-F = 2,5; p = 0,002) oraz marginalnie długość dróg (5,9% wyjaśnionej zmienności; pseudo-F = 1,5; p = 0,05). Analogiczny model CCA w Wielkopolsce dał tylko marginalnie istotne wyniki w teście dla wszystkich osi ordynacyjnych, a zmiennymi, które znacząco przyczyniły się do zróżnicowania składu gatunkowego były wielkość pola (6,2% wyjaśnionej zmienności; pseudo-F = 1,4; p = 0,03) i heterogeniczność upraw (5,9% wyjaśnionej zmienności; pseudo-F = 1,4; p = 0,044).

W skali punktowej w obu regionach bogactwo gatunkowe i liczebność ptaków były istotnie większe w punktach z słupami energetycznymi w porównaniu z punktami kontrolnymi w polach. Punkty z drzewami wiązały się z większym bogactwem gatunkowym i liczebnością w Małopolsce, ale tylko z większym bogactwem gatunkowym w Wielkopolsce. Stanowiska z kapliczkami w Wielkopolsce zawierały więcej gatunków ptaków niż kontrolne stanowiska w polach. Wokół pojedynczych krzewów było znacznie więcej gatunków ptaków w Wielkopolsce i wyższa liczebność w Małopolsce w porównaniu do otwartych pól. Spośród pozostałych zmiennych zawartych w modelu pozytywny związek z bogactwem gatunkowym i liczebnością w Małopolsce wykazała zarówno całkowita liczba pozostałych SPEL w promieniu 200 m, jak i heterogeniczność siedlisk ($\beta_{\text{liczba gatunków}} = 1{,}512$; $p < 0{,}001$; $\beta_{\text{liczebność}} = 1{,}312$; $p < 0{,}001$). CCA wykazała istotny związek między typem badanego punktu a składem gatunkowym populacji ptaków w obu regionach. W Małopolsce istotny udział w różnicowaniu składu gatunkowego miały punkty w polach (3,2% wyjaśnionej zmienności; pseudo-F = 2,4; p = 0,002), drzewa (3,1% wyjaśnionej zmienności; pseudo-F = 2,2; p = 0,002) oraz kapliczki (2,5% wyjaśnionej zmienności; pseudo-F = 1,8; p = 0,01). W Wielkopolsce punktami mającymi istotny wpływ na ordynację były kapliczki (1,7% wyjaśnionej zmienności; pseudo-F = 2,1; p = 0,004) i pola (1,6% wyjaśnionej zmienności; pseudo-F = 1,9; p = 0,006).

W badaniach wpływu informacji socjalnej i struktury krajobrazu na występowanie i rozmieszczenie pliszki żółtej (**praca 3**) heterogeniczność upraw i innych użytków nie różniła się istotnie między latami. Liczba terytoriów pliszek oraz indeks skupiskowości terytoriów również nie wykazały istotnych różnic w badanych latach. Nie stwierdzono istotnego wpływu żadnej zmiennej objaśniającej na liczbę terytoriów pliszki żółtej oraz na indeks skupiskowości terytoriów zarówno w 2016 roku (przed manipulacją), jak i 2017 roku (po manipulacji). Powierzchnia terytorium była ujemnie skorelowana z wielkością pól w 2016 roku ($\beta = -0{,}057$; $p < 0{,}05$). Dane zebrane po manipulacji eksperymentalnej w 2017 r. wykazały różnice w wielkości terytorium pomiędzy powierzchniami o różnych typach manipulacji a powierzchniami bez manipulacji. Powierzchnia terytorium była również negatywnie związana z heterogenicznością siedlisk (ß = -5,441; p < 0,05). Efekty te jednak były modyfikowane przez interakcję między rodzajem eksperymentalnej manipulacji, a heterogenicznością krajobrazu. W obrębie powierzchni o bardziej homogennych siedliskach, gdzie odtwarzana była informacja socjalna i kontrola proceduralna, pliszki żółte miały mniejsze terytoria w porównaniu z powierzchniami bez manipulacji. W krajobrazach o wyższej heterogeniczności siedlisk zarówno odtwarzanie informacji socjalnej, jak i kontrola proceduralna wiązały się ze zwiększeniem powierzchni terytoriów w porównaniu z powierzchniami bez manipulacji. Długość dróg była również pozytywnie powiązane z wielkością terytoriów w 2017 roku (ß = 0,014; p < 0,05).

WNIOSKI

Przegląd literaturowy ujawnił luki w wiedzy dotyczącej znaczenia dla ptaków takich elementów jak kapliczki i krzyże śródpolne, sterty kamieni, wapna i gałęzi, głazy narzutowe, ambony myśliwskie, studzienki, znaki drogowe, stosy słomy czy strachy na wróble. Specjaliści natomiast są zgodni co do pozytywnego znaczenia większości omawianych przeze mnie elementów. Szeroki zasób literatury opisujący pozytywne znaczenie drzew i krzewów dla ptaków w krajobrazach rolniczych, w zestawieniu z wynikami ankiety przeprowadzonej wśród ornitologów, świadczą o wielofunkcyjności tych elementów.

Hipoteza dotycząca pozytywnego związku liczebności i różnorodności SPEL została przeze mnie potwierdzona w skali lokalnej, oraz częściowo w krajobrazowej. W skali krajobrazu liczba SPEL wpływała pozytywnie na bogactwo gatunkowe ptaków tylko w Małopolsce. W skali punktowej natomiast pojedyncze elementy pozytywnie wpływały zarówno na bogactwo gatunkowe jak i na liczebność ptaków w obu krajobrazach różniących się intensywnością produkcji rolniczej. Negatywny związek między liczbą typów SPEL a liczbą gatunków w Małopolsce stoi w sprzeczności z hipotezą nr 2, jednak kanoniczna analiza korespondencji wykazała, że w obu regionach i skalach przestrzennych różne typy elementów przyczyniały się istotnie do różnicowania składu gatunkowego. Modele CCA ujawniły zarówno gatunki silnie związane z danymi elementami (np. dudek *Upupa epops* L. ze stertami gałęzi, czajka *Vanellus vanellus* L. z oczkami wodnymi, czy świergotek łąkowy *Anthus pratensis* L. z słupkami ogrodzeniowymi), a także gatunki unikające SPEL (np. skowronek zwyczajny *Alauda arvensis* L., czy kuropatwa *Perdix perdix* L.). Unikanie pewnych typów elementów przez niektóre gatunki może częściowo wyjaśniać negatywny związek między zróżnicowaniem SPEL a bogactwem gatunkowym ptaków w Małopolsce, wynikający z modelu GAM dla skali krajobrazowej. Znaczący udział całkowitej liczby SPEL w kształtowaniu zgrupowań ptaków na powierzchniach w Małopolsce stanowi jednak wsparcie dla hipotezy nr 2. Ponadto, w pracy nie analizowano przestrzennego układu SPEL na powierzchniach, co potencjalnie mgło również wpływać na ptaki i modyfikację prostych efektów liczby SPEL na ptaki.

Ptaki inaczej reagowały na obecność SPEL w Wielkopolsce niż w Małopolsce. W Wielkopolsce pozytywny wpływ elementów na zróżnicowanie gatunkowe i liczebność ptaków polnych był istotny tylko w skali punktowej. W intensywnym krajobrazie rolniczym występujące elementy są często związane z przekształceniem terenu i rozwojem infrastruktury (np. słupy energetyczne, studzienki, sterty gruzu) co finalnie może mieć negatywny wpływ na ptaki (Donald i in., 2006). Za taką interpretacją przemawia także ilościowy rozkład typów elementów w obu regionach. W Wielkopolsce zróżnicowanie SPEL jest większe, a frekwencja występowania struktur antropogenicznych również jest wyższa przez co trudno wyodrębnić efekt elementu od innych efektów związanych z działalnością człowieka. Udział drzew, krzewów i słupów energetycznych, których pozytywny efekt został potwierdzony przez modele CCA oraz GAM w skali punktowej, w ogólnej liczbie SPEL w Małopolsce wynosi prawie 90%, podczas gdy w Wielkopolsce ta grupa stanowi około 60% wszystkich elementów. Wpływ pozostałych elementów o niższej frekwencji w Wielkopolsce prawdopodobnie nie jest tak znaczący, co może również wyjaśniać brak istotnej korelacji między liczbą elementów a zróżnicowaniem i liczebnością ptaków w tym regionie. Ponadto, w skali punktowej liczba pozostałych elementów poza badanym (ograniczonych do drzew, krzewów, słupów energetycznych i kapliczek) w promieniu 200 m od punktu obserwacyjnego była istotnym predyktorem bogactwa i liczebności gatunkowej w Małopolsce, ale analiza ordynacyjna wykazała, że tylko w Wielkopolsce ta zmienna miała istotny wpływ na skład gatunkowy. Wyniki te powodują, że weryfikacja hipotezy nr 3 jest niejednoznaczna, ale możemy wnioskować, że w intensywnym krajobrazie pozytywny wpływ SPEL ogranicza się do jego bliskiego sąsiedztwa, podczas gdy w mniej intensywnym krajobrazie efekty SPEL przenoszą się na większe obszary.

Informacja socjalna przekazywana przez ptaki tego samego gatunku zazwyczaj przyciąga osobniki, co skutkuje wzrostem liczebności, ale zdarzają się również przypadki braku tego efektu (Ahlering i in., 2010). Prezentowane przeze mnie badania nie wykazały istotnego związku między liczbą terytoriów pliszki żółtej a typem manipulacji oraz interakcją między typem manipulacji a heterogenicznością siedlisk. Druga analizowana zmienna - agregacja terytoriów pliszki w odpowiedzi na informację socjalną również nie wykazała istotnego efektu. Średnia wartość wskaźnika najbliższego sąsiedztwa w obu latach była natomiast powyżej jedności, zatem odległości między dwoma najbliższymi terytoriami były mniejsze niż oczekiwane przy losowym rozkładzie. Fakt, że terytoria pliszek w naturalny sposób wykazywały skupiskowe rozmieszczenie, może wyjaśniać brak wpływu informacji socjalnej na odległości między terytoriami. Wyniki te nie potwierdzają jednak założeń hipotezy 4.

Związek heterogeniczności siedlisk z bioróżnorodnością nie zawsze jest jednoznacznie pozytywny, u niektórych gatunków opisany został model kompromisu między zróżnicowaniem a obszarem ("area - heterogeneity tradeoff", Allouche i in., 2012). Gatunki o wąskiej niszy ekologicznej mogą negatywnie reagować na zwiększenie zróżnicowania siedlisk, którego skutkiem ubocznym jest zmniejszenie powierzchni siedliska preferowanego. Niejednoznaczne wyniki dotyczące relacji między heterogenicznością krajobrazu, a populacją ptaków polnych otrzymałam również w badaniach SPEL, gdzie istotnie pozytywny związek między tą zmienną a bogactwem gatunkowym i liczebnością ptaków został zanotowany jedynie w skali punktowej w Małopolsce. Negatywna korelacja między heterogenicznością krajobrazu została opisana u ptaków gniazdujących na ziemi, m.in. pliszki żółtej (Pickett i Siriwardena, 2011). Badania w ramach prezentowanej pracy doktorskiej wykazały, że heterogeniczność siedlisk nie wpływa na liczebność (liczbę terytoriów) ani na rozmieszczenie (skupiskowość), ale negatywnie wpływa na wielkość terytorium pliszki. Zwiększone bogactwo gatunkowe ptaków w odpowiedzi na rosnącą heterogeniczność może również powodować zwiększoną rywalizację o zasoby, a tym samym hamować wzrost populacji pliszki żółtej (Kadmon i Allouche, 2007). Potwierdzenie tej hipotezy wymagałoby jednak policzenia wszystkich gatunków na badanym obszarze.

Istotna interakcja między eksperymentalną manipulacją, a heterogenicznością siedliska ujawniła, że informacja socjalna może modyfikować negatywny wpływ heterogeniczności siedliska na wielkość terytorium pliszki żółtej. Na terenach o mniejszej heterogeniczności pliszki otrzymujące informację socjalną miały mniejsze terytoria w porównaniu do tych z powierzchni bez manipulacji. Może to sugerować, że pliszki zestawiają informacje o konkurencji wewnątrzgatunkowej z przypuszczalną jakością siedliska i pozostają na mniejszych terytoriach. Gdy heterogeniczność siedliska jest wysoka, ich terytoria pozostają podobnej wielkości (w porównaniu z powierzchniami o mniejszej heterogeniczności), podczas gdy wielkość terytorium na powierzchniach bez manipulacji zmniejsza się. Wynik ten zdaje się potwierdzać hipotezę nr 5, że sygnały socjalne odgrywają ważniejszą rolę w siedliskach heterogenicznych niż homogenicznych, natomiast, ze względu na wykrytą interakcję zmiennych, trudno jednoznacznie potwierdzić część hipotezy nr 4 dotyczącą prostego wpływu informacji socjalnej na wielkość terytoriów pliszki żółtej.

Kontrola proceduralna miała na celu oszacowanie ewentualnych skutków procedury manipulacyjnej (tj. regularnych wizyt personelu terenowego, obecności nowego nieznanego obiektu, np. głośnika). Niestety wielkość terytorium pliszki żółtej wzrastała wraz ze wzrostem heterogeniczności, również w warunkach kontroli proceduralnej, w porównaniu do powierzchni bez manipulacji. Wskazuje to na konieczność stosowania kontroli proceduralnej w badaniach nad informacją socjalną, ponieważ nieoczekiwany efekt obserwatora może wpływać na wyniki, a tym samym na interpretację roli informacji socjalnej w kształtowaniu rozmieszczenia ptaków. Wpływ kontroli proceduralnej można wytłumaczyć efektem strachu spowodowanego obecnością nowego obiektu w środowisku. W innych badania wykryto bowiem różnice między wiejskimi i miejskimi populacjami ptaków w reakcji na nowy przedmiot umieszczony w siedlisku, przy czym ptaki wiejskie rzadziej eksploatowały nieznane zasoby niż ptaki miejskie (Tryjanowski i in., 2016; Goławski i Sytykiewicz, 2021).

Obecna literatura prezentuje niewiele dowodów na interakcję między czynnikami środowiskowymi i informacją socjalną. Badania nad rozmieszczeniem lasówki granatowej Dendroica caerulescens J. F. Gmelin nie wykazały wpływu informacji socjalnej ani interakcji między cechami siedliska i sygnałami społecznymi (Cornell i Donovan, 2010). Należy zauważyć, że w moich badaniach emisja informacji socjalnej miała miejsce w czasie przylotu pliszki, natomiast mapowanie ptaków miało miejsce po zakończeniu emisji. Jest prawdopodobne, że pliszki na bardziej heterogenicznych powierzchniach były zainteresowane monitorowaniem terytorium symulowanego sąsiada, gdy wydawało się, że opuścił teren. Jednocześnie, na powierzchniach homogennych, po zakończeniu emisji osobniki pozostawały w obrębie mniejszych terytoriów niż samce z powierzchni bez manipulacji. Sugeruje to, że sygnały socjalne i cechy siedliska są dla ptaków komplementarne.

PODSUMOWANIE

Moje badania wskazują, że ważnym komponentem krajobrazu rolniczego są różnorodne pojedyncze elementy punktowe o zróżnicowanym tle historycznym i dynamice czasowej, które wspierają ptaki pełniąc dla nich wiele funkcji.

Wpływ SPEL na liczebność i różnorodność ptaków polnych różni się w regionach różniących się intensywnością uprawy. Występowanie SPEL pozytywnie koreluje z bogactwem gatunkowym ptaków na mniej intensywnie uprawianych terenach. Na intensywniej zagospodarowanych terenach efekt SPEL jest widoczny w skali punktowej. Bogactwo gatunkowe i liczebność ptaków są punktowo wyższe w okolicy niektórych SPEL niż na polach. SPEL przyczynia się również do różnicowania składu gatunkowego ptaków w skali krajobrazowej i punktowej.

Ponieważ SPEL mogą kształtować rozmieszczenie ptaków na terenach rolniczych, należy uwzględniać ich efekt w modelach wybiórczości siedlisk, a biorąc pod uwagę niewielki obszar jaki zajmują, mają one potencjał, aby być skutecznym i mało konfliktowym narzędziem zwiększania lokalnej bioróżnorodności ptaków.

Heterogeniczność krajobrazu mierzona udziałem typów zagospodarowania powierzchni nie zawsze pozytywnie koreluje z bogactwem gatunkowym i liczebnością ptaków. W prezentowanych badaniach SPEL wpływ heterogeniczności na zróżnicowanie gatunkowe i liczebność ptaków był pozytywny tylko w skali punktowej w mniej intensywnie uprawianym krajobrazie, natomiast w intensywniej uprawianym efekt był nieistotny. Ponadto, heterogeniczność siedlisk negatywnie wpływała na wielkość terytoriów pliszki żółtej.

Pliszki żółte nie zwiększają liczby terytoriów ani nie grupują terytoriów w odpowiedzi zarówno na informację socjalną, jak i heterogeniczność siedlisk. Jednak informacja socjalna zmniejsza negatywny związek między heterogenicznością siedlisk a wielkością terytoriów pliszki żółtej. Jest to pierwsza eksperymentalna wskazówka na to, że informacja socjalna może modyfikować wpływ heterogeniczności siedlisk na wielkość terytorium ptaków polnych. Istotny efekt kontroli proceduralnej ukazuje jednak problemy interpretacyjne uzyskanych wyników.

LITERATURA

Ahlering MA, Arlt D, Betts MG, i in. (2010) Research Needs and Recommendations for the use of Conspecific-Attraction Methods in the Conservation of Migratory Songbirds. Condor 112:252–264. https://doi.org/10.1525/cond.2010.090239

Allouche O, Kalyuzhny M, Moreno-Rueda G, i in. (2012) Area-heterogeneity tradeoff and the diversity of ecological communities. Proc Natl Acad Sci U S A 109:17495–17500. https://doi.org/10.1073/pnas.1208652109

Ansell D, Gibson F, Salt D (2016) Learning from agri-environment schemes in Australia. Investing in biodiversity and other ecosystem services on farms. ANU Press, Canberra

Batáry P, Báldi A, Kleijn D, Tscharntke T (2011) Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proc R Soc B Biol Sci 278:1894–1902. https://doi.org/10.1098/rspb.2010.1923

Bates D, Maechler M, Bolker B, Walker S (2015) Fitting Linear Mixed-Effects Models Using lme4. J Stat Softw 67:1–48. https://doi.org/10.18637/jss.v067.i01

Benítez-López A, Alkemade R, Verweij PA (2010) The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biol Conserv 143:1307–1316. https://doi.org/10.1016/j.biocon.2010.02.009

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol Evol 18:182–188. https://doi.org/10.1016/S0169-5347(03)00011-9

Bibby CJ, Burgess ND, Hill DA, Mustoe S (2000) Bird census techniques. Academic Press, London, United Kingdom

Boesing AL, Nichols E, Metzger JP (2017) Effects of landscape structure on avian-mediated insect pest control services: a review. Landsc Ecol 32:931–944. https://doi.org/10.1007/s10980-017-0503-1

Cornell KL, Donovan TM (2010) Scale-Dependent Mechanisms of Habitat Selection for a Migratory Passerine: An Experimental Approach. Auk 127:899–908. https://doi.org/10.1525/auk.2010.09171

Doligez B, Cadet C, Danchin E, Boulinier T (2003) When to use public information for breeding habitat selection? The role of environmental predictability and density dependence. Anim Behav 66:973–988. https://doi.org/10.1006/anbe.2002.2270

Donald PF, Green RE, Heath MF (2001) Agricultural intensification and the collapse of Europe’s farmland bird populations. Proc R Soc London Ser B Biol Sci 268:25–29. https://doi.org/10.1098/rspb.2000.1325

Donald PF, Sanderson FJ, Burfield IJ, van Bommel FPJ (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. Agric Ecosyst Environ 116:189–196. https://doi.org/10.1016/j.agee.2006.02.007

Emmerson M, Morales MB, Oñate JJ, i in. (2016) How agricultural intensification affects biodiversity and ecosystem services. W: Advances in ecological research. Academic

Press, pp 43–97

Fahrig L, Baudry J, Brotons L, i in. (2011) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101–112. https://doi.org/10.1111/j.1461-0248.2010.01559.x

Fletcher, Jr. RJ (2007) Species interactions and population density mediate the use of social cues for habitat selection. J Anim Ecol 76:598–606. https://doi.org/10.1111/j.1365-2656.2007.01230.x

Golawski A, Sytykiewicz H (2021) How urban and rural birds respond to the colour of bird feeders? J Ornithol 162:1193–1198. https://doi.org/10.1007/s10336-021-01907-8

Gonthier DJ, Ennis KK, Farinas S, i in. (2014) Biodiversity conservation in agriculture requires a multi-scale approach. Proc R Soc B Biol Sci 281:20141358. https://doi.org/10.1098/rspb.2014.1358

Gregory RD, Van Strien A, Vorisek P, i in. (2005) Developing indicators for European birds. Philos Trans R Soc B Biol Sci 360:269–288. https://doi.org/10.1098/rstb.2004.1602

Główny Urząd Statystyczny (2013) Narodowy Spis Rolny 2010

Hartel T, Réti K-O, Craioveanu C (2017) Valuing scattered trees from wood-pastures by farmers in a traditional rural region of Eastern Europe. Agric Ecosyst Environ 236:304–311. https://doi.org/10.1016/j.agee.2016.11.019

Hromada M, Antczak M, Valone TJ, Tryjanowski P (2008) Settling Decisions and Heterospecific Social Information Use in Shrikes. PLoS One 3:26–30. https://doi.org/10.1371/journal.pone.0003930

Hunter Jr. ML (2016) Conserving small natural features with large ecological roles: An introduction and definition. Biol Conserv 211:1–2. https://doi.org/10.1016/j.biocon.2016.12.019

Jager HI, King AW, Schumaker NH, i in. (2005) Spatial uncertainty analysis of population models. Ecol Modell 185:13–27. https://doi.org/10.1016/j.ecolmodel.2004.10.016

Kadmon R, Allouche O (2007) Integrating the effects of area, isolation, and habitat heterogeneity on species diversity: A unification of island biogeography and niche theory. Am Nat 170:443–454. https://doi.org/10.1086/519853

Kirk DA, Evenden MD, Mineau P (1996) Past and Current Attempts to Evaluate the Role of Birds as Predators of Insect Pests in Temperate Agriculture. W: Nolan V, Ketterson ED (red) Current Ornithology. Springer, Boston, MA

Kleijn D, Rundlöf M, Scheper J, i in. (2011) Does conservation on farmland contribute to halting the biodiversity decline? Trends Ecol Evol 26:474–481. https://doi.org/10.1016/J.TREE.2011.05.009

Kotowska D, Skórka P, Walasz K (2019) Delineating the number of animal territories using digital mapping and spatial hierarchical clustering in GIS technology. Ecol Indic 107:105670. https://doi.org/10.1016/j.ecolind.2019.105670

Krebs JR, Wilson JD, Bradbury RB, Siriwardena GM (1999) The second silent spring? Nature 400:611–612. https://doi.org/10.1038/23127

Kuczyński L, Chylarecki P (2012) Atlas pospolitych ptaków lęgowych Polski. Rozmieszczenie, wybiórczość siedliskowa, trendy. GIOŚ, Warszawa

Levine N (2015) CrimeStat: A Spatial Statistics Program for the Analysis of Crime Incident Locations

Lindenmayer D, Wood J, Montague-drake R, i in. (2012) Is biodiversity management effective ? Cross-sectional relationships between management , bird response and vegetation attributes in an Australian agri-environment scheme. Biol Conserv 152:62–73. https://doi.org/10.1016/j.biocon.2012.02.026

Główny Urząd Geodezji I Kartografii (2017) Krajowa Integracja Ewidencji Gruntów. W: geoportal.gov.pl.

Morelli F, Pruscini F, Santolini R, i in. (2013) Landscape heterogeneity metrics as indicators of bird diversity: Determining the optimal spatial scales in different landscapes. Ecol Indic 34:372–379. https://doi.org/10.1016/j.ecolind.2013.05.021

Oksanen J, Blanchet, F. Guillaume Friendly M, Kindt R, i in. (2020) vegan: Community Ecology Package

OpenStreetMap Contributors (2022) Openstreetmap

Pe'er G, Dicks L V., Visconti P, i in. (2014) EU agricultural reform fails on biodiversity. Science 344:1090–1092. https://doi.org/10.1126/science.1253425

Pickett SRA, Siriwardena GM (2011) The relationship between multi-scale habitat heterogeneity and farmland bird abundance. Ecography 34:955–969. https://doi.org/10.1111/j.1600-0587.2011.06608.x

QGIS Association (2022) QGIS Geographic Information System

R Core Team (2021) R: A language and environment for statistical computing.

Redlich S, Martin EA, Wende B, Steffan-dewenter I (2018) Landscape heterogeneity rather than crop diversity mediates bird diversity in agricultural landscapes. PLoS One 13:e0200438. https://doi.org/10.1371/journal.pone.0200438

Renwick AR, Vickery JA, Potts SG, i in. (2014) Achieving production and conservation simultaneously in tropical agricultural landscapes. Agric Ecosyst Environ 192:130–134. https://doi.org/10.1016/j.agee.2014.04.011

Šálek M, Hula V, Kipson M, i in. (2018) Bringing diversity back to agriculture: Smaller fields and non-crop elements enhance biodiversity in intensively managed arable farmlands. Ecol Indic 90:65–73. https://doi.org/10.1016/j.ecolind.2018.03.001

Santana J, Reino L, Stoate C, i in. (2017) Combined effects of landscape composition and heterogeneity on farmland avian diversity. Ecol Evol 7:1212–1223. https://doi.org/10.1002/ece3.2693

Schmidt KA, Dall SRX, van Gils JA (2010) The ecology of information: an overview on the ecological significance of making informed decisions. Oikos 119:304–316. https://doi.org/10.1111/j.1600-0706.2009.17573.x

Skórka P, Lenda M, Moroń D, Tryjanowski P (2013) New methods of crop production and farmland birds: Effects of plastic mulches on species richness and abundance. J Appl Ecol 50:1387–1396. https://doi.org/10.1111/1365-2664.12148

Šmilauer P, Lepš J (2014) Multivariate Analysis of Ecological Data using CANOCO 5, druga ed. Cambridge university press, Cambridge

Tews J, Brose U, Grimm V, i in. (2004) Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. J Biogeogr 31:79–92. https://doi.org/10.5700/rege502

Tomiałojć L (1980a) The combined version of the mapping method. W: Oelke H (red) Bird Census Work and Nature Conservation. Proc.VI Intern. Conf. Bird Census and Atlas Work, Göttingen, pp 92–106

Tomiałojć L (1980b) Combined version of the mapping method. Notatki Ornitol 21:33–54

Tomiałojć L, Stawarczyk T (2003) Awifauna Polski: rozmieszczenie, liczebność i zmiany. Polskie Towarzystwo Przyjaciół Przyrody „Pro Natura", Wrocław

Tryjanowski P, Hartel T, Báldi A, i in. (2011) Conservation of farmland birds faces different challenges in Western and Central-Eastern Europe. Acta Ornithol 46:1–12. https://doi.org/10.3161/000164511x589857

Tryjanowski P, Møller AP, Morelli F, i in. (2016) Urbanization affects neophilia and risk-taking at bird-feeders. Sci Rep 6:1–7. https://doi.org/10.1038/srep28575

Tscharntke T, Clough Y, Wanger TC, i in. (2012a) Global food security, biodiversity conservation and the future of agricultural intensification. Biol Conserv 151:53–59. https://doi.org/10.1016/j.biocon.2012.01.068

Tscharntke T, Klein AM, Kruess A, i in. (2005) Landscape perspectives on agricultural intensification and biodiversity - Ecosystem service management. Ecol Lett 8:857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x

Tscharntke T, Tylianakis JM, Rand TA, i in. (2012b) Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biol Rev 87:661–685. https://doi.org/10.1111/j.1469-185X.2011.00216.x

Ungaro F, Häfner K, Zasada I, Piorr A (2016) Mapping cultural ecosystem services: Connecting visual landscape quality to cost estimations for enhanced services provision. Land use policy 54:399–412. https://doi.org/10.1016/j.landusepol.2016.02.007

Venables WN, Ripley BD (2002) Modern Applied Statistics with S, czwarta ed. Springer, New York

Ward MP, Benson TJ, Semel B, Herkert JR (2010) The use of social cues in habitat selection by Wetland birds. Condor 112:245–251. https://doi.org/10.1525/cond.2010.090238

Wilson S, Mitchell GW, Pasher J, i in. (2017) Influence of crop type, heterogeneity and woody structure on avian biodiversity in agricultural landscapes. Ecol Indic 83:218–226. https://doi.org/10.1016/j.ecolind.2017.07.059

Wood SN (2017) Generalized Additive Models: An Introduction with R, druga ed. Chapman and Hall/CRC, Boca Raton

Wretenberg J, Lindström Å, Svensson S, Pärt T (2007) Linking agricultural policies to population trends of Swedish farmland birds in different agricultural regions. J Appl Ecol 44:933–941. https://doi.org/10.1111/j.1365-2664.2007.01349.x

Zmihorski M, Kotowska D, Berg Å, Pärt T (2016) Evaluating conservation tools in Polish grasslands: The occurrence of birds in relation to agri-environment schemes and Natura 2000 areas. Biol Conserv 194:150–157. https://doi.org/10.1016/j.biocon.2015.12.007

BIOLOGICAL REVIEWS
Cambridge Philosophical Society

Biol. Rev. (2021), **96**, pp. 1386–1403.
doi: 10.1111/brv.12707

Small things are important: the value of singular point elements for birds in agricultural landscapes

Sylwia Pustkowiak[1]*, Zbigniew Kwieciński[2,3], Magdalena Lenda[1], Michał Żmihorski[4], Zuzanna M. Rosin[5,6], Piotr Tryjanowski[7,8] and Piotr Skórka[1]

[1]*Department of Biodiversity, Institute of Nature Conservation, Polish Academy of Sciences, Mickiewicza 33, 31-120, Kraków, Poland*
[2]*Institute of Biology, University of Szczecin, Wąska 13, 71-412, Szczecin, Poland*
[3]*Department of Avian Biology and Ecology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614, Poznań, Poland*
[4]*Mammal Research Institute, Polish Academy of Sciences, Stoczek 1, 17-230, Białowieża, Poland*
[5]*Department of Cell Biology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614, Poznań, Poland*
[6]*Department of Ecology, Swedish University of Agricultural Sciences, Box 7044, Se 750 07, Uppsala, Sweden*
[7]*Institute of Zoology, Poznań University of Life Sciences, Wojska Polskiego 71C, 60-625, Poznań, Poland*
[8]*Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 00, Prague 6, Czech Republic*

ABSTRACT

Farmland birds belong to the most endangered group of vertebrates in Europe. They are an important component of farmland biodiversity considering the numerous functions they perform (e.g. seed dispersal, improving germination, increasing gene flow, nutrient recycling, and pest control). Therefore, their decline imposes substantial risks on agricultural ecosystems. In general, farmland bird conservation includes land-use and management alterations leading to less-intensive farming and land-sparing for breeding habitats (e.g. agri-environment-climate schemes, and organic farming). However, theoretical concepts describing farmland biodiversity maintenance and applied conservation measures usually ignore the role of singular, often very small, natural or man-made elements in an agricultural landscape. These elements play a role in the populations of certain species, their biology and in the general species richness of farmland. Furthermore, the importance of these elements has never been empirically tested, which means that conservationists and practitioners are not aware of their measurable value for birds. Herein, we define and identify singular point elements in the agricultural landscape (SPELs) which are potentially important for breeding farmland birds. We also describe each SPEL and evaluate its importance for birds in farmland based on a systematic review of the available literature. Using a horizon-scanning technique, we then polled field ornithologists about their personal observations of birds in relation to SPELs and the evaluation of the potential roles of such structures for birds. We identified 17 SPELs that vary in naturalness and age: singular trees, singular shrubs, erratic boulders, puddles, electricity pylons, wind turbines, spiritual sites, hunting platforms, fence and border posts, wells, road signs, scarecrows, piles of manure, piles of brushwood/branches, piles of stones/debris, piles of lime, and haystacks. Analysis of the literature revealed knowledge gaps, because some SPELs are frequently mentioned in ecological studies (e.g. trees, shrubs, pylons), but others such as spiritual sites, stones, hunting platforms, wells, road signs, or piles of lime are ignored. Despite the fact that some authors incorporate the effects of some SPELs in their studies, little research to date has aimed to assess the impact of various SPELs on farmland bird species numbers and distribution. Horizon scanning revealed that ornithologists often observe birds on various SPELs and thus, attribute to SPELs many functions that are important for maintaining bird populations. Horizon scanning also highlighted the importance of SPELs for many declining bird species and suggested possible mitigation of negative changes in the agricultural landscape by retaining SPELs within fields. We suggest that a better understanding of the role of SPELs for farmland birds is required. We also recommend that SPELs are considered as a potential tool for the

---

* Address for correspondence (Tel: +48 663 272 661; E-mail: sylwia.pustkowiak@gmail.com)

conservation of birds, and existing conservation programs such as agri-environment-climate schemes and organic farming should be updated accordingly. Finally, we suggest that SPELs are included in predictive models that evaluate habitat suitability for farmland biodiversity.

Key words: agriculture, biodiversity, ecosystem services, farmland, landscape ecology, marginal habitat, novel habitat, point processes, singular elements, small landscape features

CONTENTS

I. Introduction 1387
II. Methods 1388
  (1) Definition of a singular point element in the agricultural landscape (SPEL) 1388
  (2) Identification of SPELs in the agricultural landscape 1389
  (3) Description of SPELs and their importance for birds 1390
  (4) Horizon scanning 1390
III. Results 1390
  (1) Identification of SPELs in the literature 1390
  (2) Description of SPELs and their roles for birds from the literature review 1390
    (*a*) Singular trees 1390
    (*b*) Singular shrubs 1391
    (*c*) Erratic boulders 1392
    (*d*) Puddles 1392
    (*e*) Electricity pylons 1392
    (*f*) Wind turbines 1393
    (*g*) Spiritual sites 1393
    (*h*) Hunting platforms 1393
    (*i*) Fence and border posts 1393
    (*j*) Wells 1393
    (*k*) Road signs 1394
    (*l*) Scarecrows 1394
    (*m*) Piles of manure 1394
    (*n*) Piles of brushwood/branches 1394
    (*o*) Piles of stones/debris 1394
    (*p*) Piles of lime 1395
    (*q*) Haystacks 1395
  (3) Horizon scanning: evaluation of SPELs 1395
IV. Discussion 1396
  (1) Further research and practical recommendations 1398
V. Conclusions 1399
VI. Acknowledgements 1399
VII. References 1399
VIII. Supporting information 1403

I. INTRODUCTION

In recent decades management intensity and landscape configuration in farmland ecosystems have changed substantially, leading to steep declines in farmland biodiversity (Donald, Green & Heath, 2001; Wretenberg *et al.*, 2007). Halting and reversing these declines is a challenging task since landscape transformation is driven by social and economic factors and is directly linked with agricultural production (Renwick *et al.*, 2014). Biodiversity conservation in farmland encompasses a range of different measures that take into account within-field processes and heterogeneity of habitat structure and functions at different spatial scales (Tscharntke *et al.*, 2005; Batáry *et al.*, 2011*a*,*b*; Kleijn *et al.*, 2011), but improving landscape features at large spatial scales is very costly. Total public expenditure on agri-environment-climate schemes aiming to increase biodiversity in the European Union was approximately 25 billion Euros for the 2014–2020 period (European Network for Rural Development, 2016) and over 7 billion USD in Australia over the last 25 years (Ansell, Gibson & Salt, 2016).

Many organisms inhabiting farmland are highly endangered species that are undergoing rapid population declines (Thomas *et al.*, 2004; Wretenberg *et al.*, 2007; Stanton, Morrissey & Clark, 2018), such as many common farmland bird species, which are often regarded as indicators of ecosystem health (Gregory *et al.*, 2005). There are many factors that affect farmland bird species richness varying from field management (Skórka *et al.*, 2013) and crop type (Wilson *et al.*, 2017) to landscape structure (Redlich *et al.*, 2018). However, besides large-scale landscape structure and composition, bird diversity in farmland may also benefit from in-field non-crop islands of local habitat patches or small habitat elements [e.g. forests, rocky outcrops, field margins, grasslands, ditches (Hiron *et al.*, 2013; Šálek *et al.*, 2018)], which provide birds with vital resources in otherwise impoverished and homogenised crop-dominated areas. Some of these elements were described as a 'small natural feature (SNF)', which is "a site with ecological importance that is disproportionate to its size; sometimes because it provides resources that limit key populations or processes that influence a much larger area; sometimes because it supports unusual diversity, abundance, or productivity" (Hunter, 2016, p. 2). To acknowledge their importance for biodiversity maintenance, some of these small features are protected and subsidised in agricultural policy (Hiron *et al.*, 2013) and some are protected as natural monuments comprising ecological value and cultural heritage (Dudley, Shadie & Stolton, 2013).

The definition of SNFs does not specify that such elements must be single, however, this concept may also apply to even smaller and singular point elements within an agricultural landscape (SPELs), both natural and man-made, e.g. individual trees, pylons, spiritual sites, boulders, piles of manure, etc. Their size is usually negligible and not considered in official land-use statistics nor in ecological research. Despite this, SPELs dispersed within an intensively managed landscape may interact with their surroundings, including with local biota, at different scales and in various ways. Some SPELs are well known and have a long history, such as single old trees (Hartel *et al.*, 2014; Le Roux *et al.*, 2014), but most are substantially less studied and/or have never been evaluated in terms of their contribution to biodiversity maintenance. New types of elements that are mainly associated with agricultural production and modern infrastructure have the potential to act as 'novel habitats' (Hobbs, Higgs & Harris, 2009). The impact of these objects is usually confined to a very small area, much lower than the habitat requirements, territory or home range of target species. Despite their small size they may constitute a key habitat element for certain species, determining whether these species occur or not. For example, electricity pylons have been found to increase bird species richness (Tryjanowski *et al.*, 2014) in intensive farmland but wind turbines generally have the opposite effect (Rosin *et al.*, 2016). Overall, the role of SPELs for birds in agricultural landscapes, except of single trees, is rather weakly understood, and to our knowledge has never been reviewed in a systematic manner. Because more and more agricultural land in Europe is being simplified and developed with modern infrastructure, the need to identify the importance of such elements for farmland birds is urgently required.

There are a large number of publications investigating the relationships between landscape composition and bird diversity (review in Tryjanowski *et al.*, 2011), but few incorporate SPELs in their agricultural landscape models [but see: Szymkowiak, Skierczyński & Kuczyński (2014), Elts, Tätte & Marja (2015) and Mõisja, Uuemaa & Oja (2016)]. The occurrence and diversity of these elements are most often the result of historical, cultural and natural processes; therefore, any list of the common point elements will be region specific and may vary depending on different farming systems (Poschlod & Braun-Reichert, 2016). However, SPELs occur worldwide and although they may look different (e.g. spiritual sites will differ depending on religion), they still belong to the same category of objects. Therefore, they may be important globally, across continents and cultures. This study aims to provide a new insight into spatial ecology by reviewing the available knowledge linking SPELs with the distribution and diversity of farmland birds. In our comprehensive study we: (*i*) define, identify and describe SPELs in the agricultural landscape from published studies worldwide; (*ii*) summarise theoretical and empirical knowledge of the role of SPELs for farmland birds; (*iii*) scan the knowledge and attitudes of field ornithologists relating to the importance of SPELs for birds based on their own experience, using horizon scanning; (*iv*) explore knowledge gaps in the associations of bird species with particular element types; and (*v*) propose future research areas that could broaden knowledge of the role of particular SPELs in supporting bird diversity. We also outline how the effects of SPELs should be included in biodiversity studies and in practical ecological conservation projects.

II. METHODS

(1) Definition of a singular point element in the agricultural landscape (SPEL)

In order to define the nature of objects that we describe herein, we propose the term singular point element in the agricultural landscape (SPEL). We define a SPEL as an object meeting all three of the following criteria: (*i*) its structure is clearly different (usually vertically) from the surrounding flat farmland habitat, i.e. in a satellite image it appears as a single point distinguishable from the surrounding landscape matrix; (*ii*) it is very small in size, often below the resolution of most publicly available land cover layers, so that its area is not measured or included in most official statistics concerning land use; (*iii*) its size is below the home range of all farmland bird species and, thus, does not provide all the resources needed by an individual. For some element types (particularly trees and shrubs), there is some difficulty in determining if it is actually singular, because they are often scattered in the landscape at different distances from each other. For practical reasons, one can propose a specific threshold distance between elements or use the height of a SPEL as a threshold value. Based on these criteria we can clearly distinguish SPELs from other landscape components such as remnant habitat patches or linear features (e.g. streams, hedgerows or ditches).

(2) Identification of SPELs in the agricultural landscape

Herein, we list and describe SPELs that meet the above-mentioned criteria. First, we used our collective field experience gathered through several research projects on bird ecology in farmland to identify SPELs which can act as a key elements of habitat for birds. Second, we screened the scientific literature for existing terms that referred to small landscape objects by searching in the *Web of Science* database. We used a combination of key words: [‘point’ OR ‘single’ OR ‘singular’ OR ‘individual’ OR ‘scattered’ OR ‘solitary’ OR ‘isolated’] AND [‘element’ OR ‘object’ OR ‘structure’ OR ‘feature’] AND [‘farmland’ OR ‘agricultural’ OR ‘agriculture’ OR ‘rural’ OR ‘field’] AND [‘bird’]. Then we refined the results of this search to include relevant research areas (zoology, biodiversity conservation, ecology, environmental sciences, biology, behavioural sciences, ornithology, and environmental studies). On the basis of our experience and the above-mentioned literature screening we completed a list of SPELs and examine the state of knowledge and application of various types in scientific research.

We identified 17 SPELs in the agricultural landscape (Fig. 1), varying in duration and naturalness (Fig. 2). They were: singular trees, singular shrubs, erratic boulders, puddles, electricity pylons, wind turbines, spiritual sites, hunting

Fig 1. Examples of singular point elements in a landscape (SPELs) in farmland. (A) tree, (B) shrub, (C) boulder, (D) puddle, (E) pylons, (F) spiritual site, (G) road sign, (H) post, (I) hunting platform, (J) pile of lime, (K) pile of manure, (L) haystack, (M) pile of stones, (N) scarecrows, and (O) pile of branches.

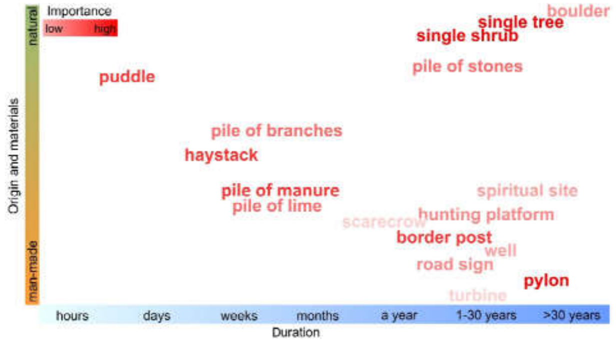


Fig 2. Variation in persistence time (*x*-axis), naturalness (*y*-axis) and the potential importance for birds of a particular singular point element in the landscape (SPEL; red colour intensity gradient).

platforms, fence and border posts, wells, road signs, scarecrows, piles of manure, piles of brushwood/branches, piles of stones/debris, piles of lime, and haystacks. Some may remain in a landscape for decades (e.g. singular trees, pylons, and wind turbines) or centuries (boulders and some spiritual sites), and may have historical or cultural value. Others appear temporarily (e.g. for several days/weeks/months) or at a specific time of year. SPELs may vary also in their degree of naturalness, from natural elements, to semi-natural (mostly related to field management), to man-made architectural structures (mostly associated with a modern landscape) (Fig. 2).

(3) Description of SPELs and their importance for birds

We performed 17 separate literature screenings using the *Web of Science* database to gather knowledge on the effects of 17 SPEL types on birds. As before, we used a combination of element definitions with landscape- and taxon-specific words, e.g. [‘manure’ OR ‘dung’] AND [‘farmland’ OR ‘agricultural’ OR ‘agriculture’ OR ‘rural’ OR ‘field’] AND [‘bird’]. Furthermore, we used a ‘snowball’ approach and included publications that were cited in the articles we retrieved from the database search. All the searches were conducted in April 2019. In total, we checked approximately 300 articles for relationships between SPELs and birds in the agricultural landscape. In Section III.2, we summarise the current knowledge for each SPEL type and their functional roles in supporting bird populations in farmland.

(4) Horizon scanning

We used the knowledge and experience possessed by field ornithologists to assess the results from our literature review. The method we used, horizon scanning, was developed to recognise knowledge gaps by using feedback from experts (Sutherland *et al.*, 2014). It also aims to uncover previously unrecognised scientific issues and unidentified threats and opportunities (Brown *et al.*, 2016).Using Google Forms we constructed an online survey in the Polish language which consisted of 13 principal questions and two optional ones (a list of all questions translated into English is available as online Supporting Information, Table S1). The questions were preceded by a short definition and illustration of SPELs. The first six questions assessed the respondent’s field experience (i.e. frequency of observations and observation habitats). The sequence of SPEL types in each question was randomly shuffled to avoid establishing patterns of answers. Because the target group was experts (experienced field ornithologists), we shared this survey on the internet among relevant leading institutes, universities, science clubs, organisations, and groups. We asked questions relating to bird observations on particular SPELs, the importance and functions of such elements for birds, and the possibility that SPELs mitigate certain negative impacts in agricultural landscapes. Respondents were also asked to list five bird species that most often use singular point elements based on their own observations. The survey was begun in January 2019 and data were collected until the end of October 2019. Summary statistics with charts were prepared using R software (R Core Team, 2016).

III. RESULTS

(1) Identification of SPELs in the literature

During literature screening, we found that authors used various phrases such as: ‘countryside elements’ in reference to “native vegetation, linear vegetation, plantation, scattered trees and pasture” (Haslem & Bennett, 2008, p. 191) or “linear roadside remnants, native vegetation patches, scattered trees and tree plantings” (Crane, Lindenmayer & Cunningham, 2014, p. 1); ‘landscape element’ in reference to “ditches, trees, and surrounding fields or rank vegetation” (Bosschieter & Goedhart, 2005, p. 460); ‘small-scale landscape element’ (Mõisja *et al.*, 2016) and ‘habitat element’ in reference to manure heaps (Šálek & Żmihorski, 2018). The term ‘point processes’ also appeared and is derived from statistical spatial modelling (Illian & Burslem, 2007). The most frequently repeated term is ‘point elements’ or ‘point objects’, referring to “habitat islands […], bedrock or stone piles, ponds, single trees” (Ihse, 1995, p. 26); “groves, trees, heaps of stones, boulders, etc.” (Mõisja *et al.*, 2016, p. 715); “kettle holes, isolated trees, tree groups, riparian woodlands” (Ungaro *et al.*, 2016, p. 400); “single tree, scattered trees, grove, boulder […], heap of stones, scattered boulders” (Elts *et al.*, 2015, p. 24). However, all the above studies referred only to certain selected elements, sometimes in combination with linear objects and land cover types. We did not find a study that provided a broader and more systematic assessment of point elements in their research methods. Some of the 17 SPELs we proposed above (Section II.2) were not considered in the literature we found.

(2) Description of SPELs and their roles for birds from the literature review

(*a*) Singular trees

Singular trees are very common and natural elements in the agricultural landscape, with a long persistence time; old trees can last in the landscape for several hundred years. This was the SPEL type most often mentioned as a point element in farmland.Singular trees are the only point elements that have been relatively well studied and are described as 'keystone structures' because of their disproportionate role in the ecosystem relative to the area occupied (Tews *et al.*, 2004; Manning, Fischer & Lindenmayer, 2006; Manning, Gibbons & Lindenmayer, 2009; Lindenmayer, 2017; Prevedello, Almeida-Gomes & Lindenmayer, 2018). Scattered trees in an open landscape are particularly valuable for their multifunctionality (DeMars, Rosenberg & Fontaine, 2010), because they are used for nesting, foraging, singing or roosting (see Fig. S1). A solitary tree was found to be frequently used as a song post by corn buntings *Miliaria calandra* L. (Mason & Macdonald, 2000; Szymkowiak *et al.*, 2014; Altewischer *et al.*, 2015), ortolan buntings *Emberiza hortulana* L. (Fonderflick, Thévenot & Guillaume, 2005; Elts *et al.*, 2015), and tree pipits *Anthus trivialis* L. (Schwarz, Trautner & Fartmann, 2018). Trees play an important role as perches for hunting predators, e.g. shrikes Laniidae (Vanhinsbergh & Evans, 2002; Morelli *et al.*, 2015*b*), the European roller *Coracias garrulus* L. (Rodríguez-Ruiz *et al.*, 2019), and buzzards *Buteo* spp. (Coates *et al.*, 2017) (Figs S2 and S3). Trees also act as perches for brood parasites like the common cuckoo *Cuculus canorus* L. (Tryjanowski & Morelli, 2015), and are a significant predictor of the occurrence of brood-parasitic interactions. In areas composed of fragmented patches of natural habitat within an open homogeneous matrix, scattered trees may act as stepping stones for birds, supporting gap-crossing decisions and improving landscape connectivity (Desrochers & Hannon, 1997; Grubb & Doherty Jr, 1999; Fischer & Lindenmayer, 2002; Robertson & Radford, 2009). Fruiting trees may in turn supply food resources for frugivorous birds, especially during spring migration and winter (Luck & Daily, 2003; Skórka *et al.*, 2006; Martin *et al.*, 2009; Godoi *et al.*, 2018; see Fig. S4).

There is strong evidence for a positive impact of scattered individual trees on the populations of many bird species within crop fields and pastures (Söderström *et al.*, 2001; Martin *et al.*, 2009; DeMars *et al.*, 2010; Fischer, Stott & Law, 2010*a*; Rivest *et al.*, 2013; Godoi *et al.*, 2018; Prevedello *et al.*, 2018). Sparse tree cover (up to 10%) was found to increase the probability of occurrence of the European roller within their wintering areas (Rodríguez-Ruiz *et al.*, 2019). In addition, for cavity-nesting birds, there is a strong positive relationship between the number of scattered trees (particularly old ones) and bird abundance during the breeding season (Manning, Lindenmayer & Barry, 2004; Carneiro *et al.*, 2012). Trees often grow along field borders and ditches and are associated with increased bird diversity and abundance compared to adjacent fields (Parish, Lakhani & Sparks, 1994). Moreover, tree size also has a positive effect on bird diversity (Di Giacomo & Lopez De Casenave, 2010; Le Roux *et al.*, 2018). Planting or retaining native trees is often associated with the colonisation of open areas by woodland birds and may, thereby, help to conserve this group (Barrett *et al.*, 2008; Haslem & Bennett, 2008; Martin *et al.*, 2009; Douglas *et al.*, 2014; Hartel *et al.*, 2014; Godoi *et al.*, 2018), while simultaneously increasing the heterogeneity of species composition in farmland. However, birds adapted to open landscapes may avoid the vicinity of scattered trees due to the presence of bird predators and brood parasites that use these trees as perches (Oien *et al.*, 1996; Coates *et al.*, 2017; Lautenbach *et al.*, 2017; Żmihorski *et al.*, 2018). Several grassland specialists, such as the calandra lark *Melanocorypha calandra* L., black-tailed godwit *Limosa limosa* L., and northern lapwing *Vanellus vanellus* L., avoid single trees and shrubs (Berg, Lindberg & Kallebrink, 1992; Morgado *et al.*, 2010; Żmihorski *et al.*, 2018).

(*b*) Singular shrubs

Singular shrubs are often present within fields, occurring as frequently as trees. They are natural elements and, like trees, may persist in the landscape for a long time (Fig. 2). Many studies have included the presence of shrubs in their research on the relationships between bird species abundance and habitat features.

Shrubs provide many important functions for birds (Fig. S5). They are major nesting sites, particularly for the common whitethroat *Sylvia communis* Latham and red-backed shrike *Lanius collurio* L. (Polak, 2012; Szymański & Antczak, 2013). Ground-nesting birds may site a nest under a shrub to prevent it from being destroyed by farm machinery. Shrubs may also serve as shelter for birds, particularly those that spend a significant period on the ground such as the common quail *Coturnix coturnix* L. or corncrake *Crex crex* L. (Budka & Osiejuk, 2013). Shrubs bearing berries (see Fig. S5B) are an important food resource for frugivorous birds (Godoi *et al.*, 2018). According to our observations, shrub species such as European dewberry *Rubus caesius* L., common elder *Sambucus nigra* L. or hawthorn *Crataegus* spp. influence the occurrence of certain bird species in the agricultural landscape during winter, for example, the Eurasian tree sparrow *Passer montanus* L. and migrating species, like the fieldfare *Turdus pilaris* L., and blackbird *Turdus merula* L. Shrubs may also play a role as song posts and hunting perches (Vanhinsbergh & Evans, 2002; Wuczyński, 2005; Brambilla, Reginato & Guidali, 2007*a*; Brambilla, Rubolini & Guidali, 2007*b*; Morelli *et al.*, 2015*b*). Thorny shrubs are used by shrikes to store prey and mark territorial borders (Antczak, Hromada & Tryjanowski, 2005; Antczak *et al.*, 2019).

Shrubs are one of the most important elements influencing the occurrence of farmland and non-farmland birds in open agricultural landscapes (Moreira *et al.*, 2005; Brambilla *et al.*, 2007*a*; Barrett *et al.*, 2008; Skórka, Lenda & Tryjanowski, 2010; Morelli, 2013). They are frequently present along field margins and ditches supporting a greater diversity of birds than the field interior (Kujawa, 2004; Di Giacomo & Lopez De Casenave, 2010). They are common elements of pastures contributing to increased colonisation of these areas by birds (Söderström *et al.*, 2001; Nikolov *et al.*, 2011; Rivest *et al.*, 2013; Godoi *et al.*, 2018). Interspersed shrubs were found to be a very important habitat component for the corn bunting, subalpine warbler *Sylvia cantillans* Pallas, red-backed shrike (Pärt & Söderström, 1999;

Brambilla *et al.*, 2007*b*; Tsiakiris *et al.*, 2009; Morelli, 2013), common whitethroat, lesser whitethroat *Sylvia curruca* L., tree sparrow, greenfinch *Chloris chloris* L., yellowhammer *Emberiza citrinella* L. (Pärt & Söderström, 1999), and corncrake (Budka & Osiejuk, 2013). An overall increase in bird species richness is most often associated with the early phase of succession and low bush cover, because higher shrub densities may have negative effects (Grant, Madden & Berkey, 2004; Skórka *et al.*, 2010). In addition, there are also specialist species (mainly ground foragers preferring short vegetation) that do not tolerate scrub encroachment in grasslands and abandoned fields (Pärt & Söderström, 1999; Morgado *et al.*, 2010; Orłowski, 2010).

(*c*) Erratic boulders

Boulders (sometimes called erratic boulders) and stones are characteristic elements of post-glacial landscapes (see Fig. S6) and are signs of previous glacier presence and movement (Gray, 2004). Usually, they are removed by farmers, but the largest often remain in fields. Boulders are rare in landscapes, but they are natural elements in the environment with very long persistence times (Fig. 2).Despite the presence of boulders in farmland, their relationship with birds has not been documented. Such elements are likely important for certain rare farmland species (Fitzsimons & Michael, 2017). They may serve as a perch for birds, particularly for sit-and-wait predators such as the European roller (Catry *et al.*, 2017), or as a singing post, for example, for the ortolan bunting (Fonderflick *et al.*, 2005; Elts *et al.*, 2015) and the rock bunting *Emberiza cia* L. (Sánchez, Václav & Prokop, 2009). Our field observations indicate that northern wheatear *Oenanthe oenanthe* L. and white wagtail *Motacilla alba* L. in the farmlands of southern Poland prefer the vicinity of boulders and stone piles. Moreover, we observed nests of the white wagtail, northern wheatear and African stonechat *Saxicola torquata* L. placed beside boulders and piles of stones.

(*d*) Puddles

Puddles (small pools of water) occur only after rain in small ground depressions created by machinery or cattle (see Fig. S7). Puddles usually last for short periods, from several hours to a few days. Puddles are natural elements in the landscape, although they often occur as a result of human activity. Puddles can serve a similar function for birds as temporary wetlands, which were highlighted as a 'disappearing' ecosystem with disproportionately high importance for biodiversity (Calhoun *et al.*, 2017). For farmland birds, puddles constitute a source of drinking water which is often limited in agricultural landscapes (Orłowski, 2005). Some insects reproduce rapidly in puddles (Paaijmans *et al.*, 2008) and, therefore, puddles may periodically provide important food resources (Faria, Albertoni & Bugoni, 2018). The yellow wagtail *Motacilla flava* L. and white wagtail often forage at puddles (see Fig. S7B). Lapwings and great egrets *Ardea alba* L. also forage in areas containing shallow pools of water (Fidorra *et al.*, 2016; Schmidt *et al.*, 2017). Yellowhammers and sparrows have been observed to use puddles for bathing.

Flooded areas are associated with a higher abundance of yellow wagtails (Bradbury & Bradter, 2004). Puddles are also valuable to rare and non-farmland bird species during migration (Faria *et al.*, 2018). Water resources are very important for birds, particularly certain species groups including waders, which show strong preferences for wetlands (Gunnarsson *et al.*, 2006; Eglington *et al.*, 2008 Fidorra *et al.*, 2016). In our studies located near Tarnów, Poland, between 2010 and 2014 more than half of all observations of the common snipe *Gallinago gallinago* L. were recorded in periodic puddles. Several other species were recorded foraging at puddles during their spring and autumn migrations at this farmland site including the great egret and common greenshank *Tringa nebularia* Gunnerus (see Fig. S7A). These species are more abundant in fields on wet days when puddles are present compared to dry days. Thus, the presence of puddles is most likely a driver of many important ecological processes in farmland such as inter-habitat long-distance dispersal of plant seeds and invertebrates (Green *et al.*, 2008; van Leeuwen *et al.*, 2012).

(*e*) Electricity pylons

Electricity pylons are widespread elements in the modern landscape (see Fig. S8). Because they are evenly distributed along power lines, they can be the most frequent SPELs in highly developed areas. This man-made element is also long-lasting (Fig. 2).

Pylons may affect the species richness of breeding birds positively in intensive farmland. Tryjanowski *et al.* (2014) found significantly more breeding birds species under pylons compared to in open fields. This is because small areas of grass and/or shrubs are often located underneath a pylon, which may be used by birds as breeding sites (see Fig. S9). Pylons that have shrubs underneath were found to support a high bird species richness, indicating that different SPELs can have additive effects on farmland birds. Electricity poles may also be used as nesting sites for certain species such as ravens *Corvus corax* L. (Tryjanowski, 2001) and white storks *Ciconia ciconia* L. (Infante & Peris, 2003; Janiszewski, Minias & Wojciechowski, 2015). Some species, for example the American kestrel *Falco sparverius* L. (Crouch, Benson & Brennan, 2018), use electricity poles as roosting sites, particularly during the non-breeding season. Moreover, pylons are important singing sites for some species (Mason & Macdonald, 2000; Fonderflick *et al.*, 2005; Elts *et al.*, 2015) and perching sites for birds of prey such as buzzards and common kestrels *Falco tinnunculus* L. (Fig. S10) as well as the European roller (Rodríguez-Ruiz *et al.*, 2019). The use of pylons as perches by fruit-eating birds results in seed deposition and supports the succession of fleshy-fruited plants, which can be native or non-native (Kurek, Sparks & Tryjanowski, 2015; Dylewski *et al.*, 2017).

Pylons are associated with many positive, and also negative effects on birds (Biasotto & Kindel, 2018). They also may cause significant mortalities in migrating birds due to collisions and electrocution (Dwyer *et al.*, 2016; Bernardino *et al.*, 2018). In Canada, collisions with electricity lines are a main industrial-related cause of bird mortality (Calvert *et al.*, 2013). Collisions with electricity lines affect many species migrating at night, and particularly larger birds (Bevanger, 1998). Habitat models show that there are also species (e.g. the reed bunting *Emberiza schoeniclus* L., black-tailed godwit, little bustard *Tetrax tetrax* L., and lesser prairie-chicken *Tympanuchus pallidicinctus* Ridgway) which avoid nesting or roosting in areas with power lines (Milsom *et al.*, 2000; Gruar, Barritt & Peach, 2006; Silva *et al.*, 2010; Santiago-Quesada *et al.*, 2014; Plumb *et al.*, 2019). Moreover, predator activity near pylons and power lines may induce certain prey species to avoid nesting close to power lines (Dinkins *et al.*, 2014). However, no study has investigated the relative gains and costs of pylons in relation to the conservation of farmland birds.

(*f*) Wind turbines

Windmills producing 'green energy' are point elements with a relatively short history, but they are becoming more popular in agricultural areas (Global Wind Energy Council, 2017). These elements are artificial and their durability is strictly defined as not exceeding 30 years. The construction phase is also associated with large land transformations.

No studies show that windmills perform any functions for birds, but some studies show certain positive effects. Uncultivated areas around turbines are usually successively overgrown by herbaceous vegetation, supporting higher diversities of plants and pollinating insects within large arable fields (Pustkowiak *et al.*, 2018). This may provide birds with additional food and nesting places.

Windmills are mainly associated with threats to aerially mobile wildlife, particularly birds and bats, due to collision risks (Rydell *et al.*, 2010; Graff *et al.*, 2016) although smaller turbines are associated with a lower risk (Minderman *et al.*, 2015). Territorial singing behaviours may also be disturbed by the noise that windmills generate (Zwart *et al.*, 2016). The proximity of wind turbines can negatively affect certain bird species' distributions (Stevens *et al.*, 2013; Rosin *et al.*, 2016). However, they may have neutral or even positive effects on other species (reduced predation rate due to displacement of raptors is one possible explanation for this pattern; Winder *et al.*, 2014).

(*g*) Spiritual sites

Spiritual sites are occasionally found in eastern European landscapes. They are built mostly near roads or dirt tracks and are composed of a small monument to a Christian saint or a crucifix accompanied by decorative plants (Fig. S11). Many spiritual sites have existed for centuries.Plants (e.g. *Thuja* spp.) at spiritual sites may provide nesting, shelter or a source of food for birds. In southern Poland we observed common linnets *Linaria cannabina* L. on over half of all spiritual sites surveyed. We also found nests of the great tit *Parus major* L., greenfinch and common redstart *Phoenicurus phoenicurus* L. inside such sites. Blackbirds and song thrushes *Turdus philomelos* C. L. Brehm were seen regularly around spiritual sites. However, there are no empirical data in the literature on the impact of these elements on birds.

(*h*) Hunting platforms

Hunting platforms are occasionally found within fields and on the edges of forests. These man-made structures remain in the landscape for long periods (Fig. 2).Hunting platforms can also function as hunting sites for some predatory bird species. In rare cases, species such as the white stork may build nests on these structures (Tobolka *et al.*, 2013). We observed hunting platforms being used by grey shrike *Lanius excubitor* L., red-backed shrike (Fig. S12) and buzzards. Nonetheless, we did not find any evidence in the literature relating to the importance of hunting platforms for farmland birds.

(*i*) Fence and border posts

Fences are very common in the agricultural landscape and are mainly regarded as linear structures, but solitary posts are often used to border fields (Fig. S13). These artificial elements may appear temporarily in the landscape, but those that have a solid construction persist for much longer.Fence posts are widely used by birds as a perch (Catry *et al.*, 2017), or as a lookout for predators, and are often used by crows (Preston, 1957; Elliot, 1985), shrikes (Morelli *et al.*, 2015*b*) and owls (Manning & Garton, 2012). These SPELs were found to be substantial elements in the habitat of species that require a song post, e.g. the corn bunting (Mason & Macdonald, 2000). They may also affect the movements of predatory mammals (Hayward & Kerley, 2009) and thus may impact the breeding success and foraging rates of birds.

(*j*) Wells

We define wells as concrete rings in agricultural landscapes, and as a type of infrastructure. Wells are common artificial elements in fields (Fig. S14), that usually persist in a landscape for long periods (Fig. 2).To our knowledge, only one study to date has included wells in their research on bird diversity in landscapes. This study linked greater bird diversity in intensively grazed grasslands with a greater diversity of various structures, including wells (Báldi, Batáry & Erdos, 2005). Wells are often accompanied by other pieces of infrastructure, such as water cranes, which can also be used as lookouts and singing sites by birds. In-field wells are generally used to water crops or provide water to livestock. It is usually humid in their vicinity, which attracts invertebrates and thus they are likely to provide birds with both food and a source of water. We have observed that such structures are used by small birds, like wagtails or northern wheatears.

(*k*) Road signs

Road signs are becoming more common in agricultural landscapes (Cooke *et al.*, 2020) that are increasingly intersected by a developing network of smaller roads (Fig. S15). The persistence time of these man-made structures may vary, but they tend to be relatively long-lasting (Fig. 2).

Road signs may act as a perch and serve similar functions as fence posts (i.e. singing and roosting sites, and predator lookouts). We did not find any studies referring to the importance of these structures for birds. However, road signs are associated with roads, which generally have negative impacts on birds (Benítez-López, Alkemade & Verweij, 2010; Morelli *et al.*, 2015*a*). Because roads are often densely distributed in farmland, their effect should be considered when investigating the importance of road signs for birds.

(*l*) Scarecrows

Scarecrows are used by farmers to frighten birds from a field (Fig. S16). They have a centuries-old tradition and have a cultural value. Scarecrows are mostly present within smaller fields in more-traditional landscapes. They are very rare in intensive farming systems. Their persistence time within fields is most likely very short.Interestingly, there is no evidence relating to the relationship between birds and scarecrows, including regarding their effectiveness in deterring birds. If birds are not deterred by scarecrows, they may use them as a perch (e.g. for singing or hunting).

(*m*) Piles of manure

Livestock manure is a natural substrate that requires storage and these practices vary depending on the legislation in a particular country. Piles of manure often occur in the agricultural landscape around farms involved in animal production. Manure is also used as a natural soil fertiliser. Therefore, persistence of such elements in a field may vary from weeks to months.Livestock manure is a habitat for a diversity of invertebrates and can represent a good food resource for insectivorous birds like shrikes (Vanhinsbergh & Evans, 2002), lapwings (Kamp *et al.*, 2009), swallows (Orłowski & Karg, 2011) and wagtails (see Fig. S17). It was reported that stone-curlews *Burhinus* spp. nesting along riverbanks forage on heaps of manure within fields during the night (Caccamo *et al.*, 2011). Granivorous birds also benefit from the presence of manure because it contains grass seeds derived from animal fodder (Orłowski, Czarnecka & Goławski, 2014). Some bird species also collect manure and use it as a nest-building material but the reason for doing so is unclear. Black lark *Melanocorypha yeltoniensis* J. R. Forster females build extensive dung ‘pavements’ around nests which probably serve as protection from trampling by grazing livestock or in temperature regulation inside the nest (Fijen *et al.*, 2015). White storks have been observed carrying fresh cattle dung to the nest during incubation and after hatching, which may influence nestling thermoregulation (Tortosa & Villafuerte, 1999). Piles of manure, which have higher temperatures, play very important roles during winter, because birds gather on them to keep warm (Šálek & Żmihorski, 2018). These SPELs attract higher numbers of individual birds than stubbles during winter, particularly when snow depth is high (Goławski & Kasprzykowski, 2011). They are occupied by many common and declining bird species such as yellowhammers, corn buntings, tree sparrows, common chaffinches *Fringilla coelebs* L. and corvids (Goławski & Kasprzykowski, 2011; Kasprzykowski & Goławski, 2012; Šálek & Żmihorski, 2018). The number of dung heaps has been correlated with barn swallow *Hirundo rustica* L. nestling survival (Grüebler, Korner-Nievergelt & Von Hirschheydt, 2010). European kestrels and common buzzards *Buteo buteo* have been observed using piles of manure as hunting perches (Goławski & Kasprzykowski, 2011).

(*n*) Piles of brushwood/branches

Fallen branches are natural structures. However, they are sometimes stored by farmers in piles at field margins. Such elements are not common in the agricultural landscape and their persistence time in fields is mostly short, varying from weeks to months. However, anecdotal observations by the authors of this review indicate that some piles of branches can be present for several years in field margins.The function and importance of piles of branches for birds remains unknown according to the literature. However, we observed the Eurasian wren *Troglodytes troglodytes* L. in piles of branches during winter in Poland, and we also found blackbird and red-backed shrike nests inside piles. Thus, they may provide shelter for small birds that are more likely to feed near brushwood piles (Pearson, 1991) or can potentially be a source of food and nesting sites.

(*o*) Piles of stones/debris

Stones usually impede soil cultivation, so farmers remove them from the field and store them in piles at field margins. They are a natural and common landscape element that usually lasts for a long period of time.

As for boulders, piles of stones or debris may be used as perches and singing posts, as observed for the burrowing owl *Athene cunicularia* Molina (Manning & Garton, 2012) and yellow wagtail (Fig. S18). Contrary to boulders, piles of stones and debris provide many holes and indentations, which can be used by a variety of invertebrates, amphibians, small reptiles and mammals, making these sites as attractive for foraging as dry-stone walls in hilly agricultural areas (Manenti, 2014). Thrushes use stones as anvils to break snail shells (Kwieciński *et al.*, 2019), while northern wheatear often builds nests in crevices between rocks and stones (Arlt & Pärt, 2008). Larger amounts of rocky substrates can attract species like the stone curlew *Burhinus oedicnemus* L. (Green, Tyler & Bowden, 2000). Stone walls were found to increase the abundance of the common redstart (Assandri *et al.*, 2018). However, some studies show that heaps of stones can act as potential habitats for parasites and vectors of dangerous diseases (Bautista *et al.*, 1999).

(*p*) Piles of lime

Liming is a common practice on acidic soils which aims to increase soil pH and improve certain soil properties such as N and P availability for plants (Holland *et al.*, 2018). Because lime is often stored in piles in a field, there is also a landscape aspect of this practice. Piles of lime may appear locally at a specific time of year, and persist in the landscape for various periods from weeks to months.Piles of lime can be used as singing or hunting perches by many bird species, for example the yellow wagtail (Fig. S19). However, we did not find any studies analysing the relationship between piles of lime and bird populations.

(*q*) Haystacks

Haystacks are piles of mown and dried grass or cereals and they are common elements during the summer in agricultural landscapes (Fig. S20). Haystacks usually last within fields for several weeks (Fig. 2), but sometimes they are left in one place for a longer time period.Haystacks can act as perching sites for birds of prey, improving their ability to detect some prey species. Thus, they may mediate predator–prey interactions in farmland (Manning & Garton, 2012). Haystacks may provide foraging resources for predatory birds because they are often inhabited by animals such as rodents (Singleton, 1985). Some granivorous bird species may forage on cut herbs within haystacks. Tryjanowski (1995) noted higher bird densities within fallow lands that contained haystacks and piles of manure, implying that these elements may be significant food sources. There have also been observations of white wagtails and common linnets nesting in haystacks (Tryjanowski *et al.*, 2009). Some species (e.g. white storks) gather on these elements during the autumn migration (S. Pustkowiak, unpublished data).

(3) Horizon scanning: evaluation of SPELs

Our questionnaire was completed by 163 specialists in ornithology, whose average number of bird-watching years was 14 (range: 1–50). Most respondents carried out observations at least once per week. Over half of respondents declared that they had a biology-related education (e.g. biology, environmental protection, forestry, or ecology), with one-quarter working as professional ornithologists. Agricultural areas were their most frequent bird-observation habitat.

When ornithologists were asked to indicate the elements on which they observed a bird at least once (question 7), most of them marked electricity pylons (152/163), trees (150/163), shrubs (149/163) and haystacks (145/163). A lower number of respondents marked wells (39/163), scarecrows (31/163) and wind turbines (7/163). No elements scored zero (see Fig. S21). The pattern of answers to question 11 (‘How often do you observe birds on particular types of singular point elements in the agricultural landscape?’) was similar to that for question 7. Again, respondents most often (answers ‘very often’ and ‘quite often’) observed birds on singular trees, shrubs, pylons, puddles, fence posts and haystacks (Fig. 3). The elements on which birds were reported to have been observed rarely or never by most respondents were wind turbines, wells and scarecrows. When we asked about the importance of particular SPELs for birds, most specialists indicated a clear positive impact of singular trees (90%), shrubs (87%), puddles (83%), haystacks (64%), piles of manure (52%), and piles of stones (51%, Fig. S22) on birds. The element that, in the experts’ opinions, was distinguished by the most negative impacts on birds was wind turbines (62% ‘negative’, 18% ‘moderately negative’). Negative effects were also assigned (although to a much lesser extent) to pylons, hunting platforms and scarecrows. For the other elements, the total proportion of responses that were ‘negative’ or ‘moderately negative’ did not exceed 10%. Two-thirds of respondents thought that SPELs are most important for birds during the breeding season (67.5%). A much lower proportion of respondents indicated that SPELs were important during other parts of year (winter season 17.8%, autumn migration 11%, or spring migration 3.7%). Of all SPELs, trees and shrubs were assigned all the proposed functions (nesting, foraging, roosting, singing, and hunting) in similar proportions by respondents (Fig. 4). After trees and shrubs, pylons, piles of stones, chapels/crucifixes and hunting platforms scored highest as potential nesting sites. Two types of elements that were perceived as being important for foraging were piles of manure (136/163) and puddles (112/163). Wind turbines received the lowest scores in all the proposed functions.

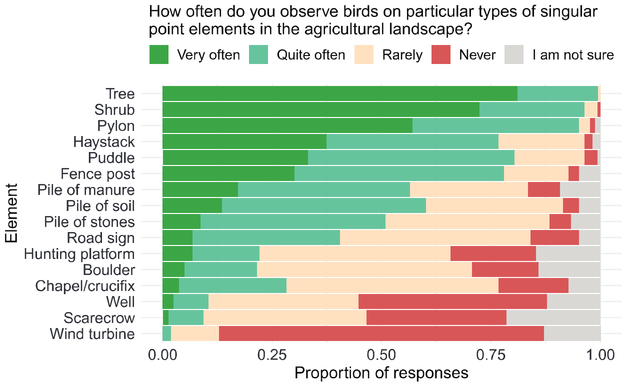


Fig 3. The frequency of bird observations on particular types of singular point elements in the landscape (SPELs) reported in the horizon-scanning survey in response to question 11.

Experts also suggested that SPELs may mitigate impacts from other negative phenomena. According to the answers we received, most respondents think that SPELs may mitigate some negative landscape alterations (such as the decline of semi-natural habitats, the increase in arable area or

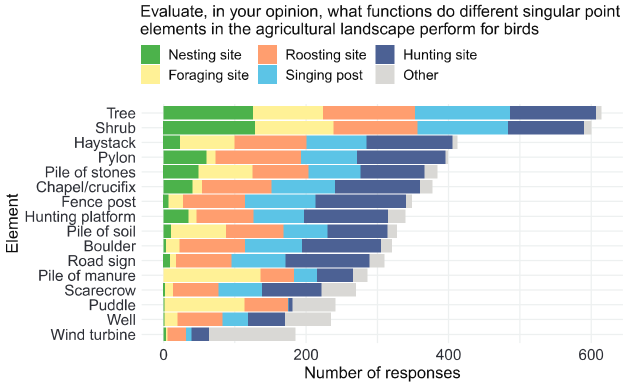


Fig 4. The answers to question 10 in our online survey showing the opinion of respondents regarding the functions of single point elements in the landscape (SPELs) for birds.

cropland homogenisation) but not effects related to intensive field management (such as the excessive use of pesticides or fertilisers, or an increase in the area of GMO crops) or to the invasion of alien plant species (see Fig. S23). However, these results should be taken with caution because of potential confirmation bias. Nonetheless, such beliefs expressed by specialists with experience in observing bird behaviour may constitute a good starting point to formulate scientific hypotheses for future research. It is reasonable to suggest that future studies should test empirically whether SPELs can mitigate such negative effects.

Finally, each respondent was asked to list five bird species that they thought used point elements most often. In total, respondents listed 71 species and 12 taxa/groups (see Table S2). The ten most frequently mentioned species were: common buzzard, red-backed shrike, yellowhammer, European kestrel, corn bunting, grey shrike, yellow wagtail, common starling *Sturnus vulgaris* L., Eurasian skylark *Alauda arvensis* L. and white stork.

IV. DISCUSSION

We distinguished 17 types of SPEL with different origins and persistence times that could potentially affect farmland birds. Based on our literature review, horizon scanning among ornithologists, and our own observations we listed several functions provided by SPELs for birds (Table 1). We conclude that SPELs occurring in the agricultural landscape play an important role for birds, but there are also many knowledge gaps that should be filled with empirical data. Below, we discuss the ecological mechanisms behind these effects and provide management recommendations based on our results.Our definition of a SPEL, and our list of 17 such elements, may be subjective, and others may exist in regions with different farming systems that may be potentially used by birds. Out of the publications collected herein, two-thirds (65%) were from Europe, and 20% from North America, but some were from Australia (Fischer & Lindenmayer, 2002; Manning *et al.*, 2004; Barrett *et al.*, 2008; Haslem & Bennett, 2008; Robertson & Radford, 2009; Fischer *et al.*, 2010*a*; Le Roux *et al.*, 2018), South America (Di Giacomo & Lopez De Casenave, 2010; Carneiro *et al.*, 2012; Faria *et al.*, 2018; Godoi *et al.*, 2018), Africa (Martin *et al.*, 2009; Douglas *et al.*, 2014; Rodríguez-Ruiz *et al.*, 2019) and Asia (Kamp *et al.*, 2009; Fijen *et al.*, 2015). We attempted, however, to list the most common SPELs occurring in the farmland of central Europe. Our search method may not have detected all relevant publications, because information about the use of SPELs by birds often appears as short commentaries within main texts on other subjects. Research papers also use different terms to refer to SPELs (e.g. countryside/landscape/habitat elements, point elements/objects) and include different types of elements in their studies. However, we conclude from our review of the literature that while some studies on farmland birds do include certain SPELs in their analyses, in most cases the presence of SPELs was ignored. There is poor understanding of the ecological functions of spiritual sites, piles of stones, boulders, hunting platforms, wells, road signs, piles of lime, piles of brushwood/branches, haystacks, and scarecrows. Comprehensive empirical data about the contribution of these various SPELs to habitat quality of farmland birds is therefore needed. The concept of small natural features (SNFs) proposed by Hunter *et al.* (2016) could be extended to other natural point elements, and a synthesis of knowledge about the role of small landscape features (including patches, lines and points) in the ecosystem, both natural and man-made, could be attempted.

Some studies suggest that SPELs may substantially increase the species richness and abundance of farmland birds by providing nest sites and perches and supporting activities like foraging, roosting, hunting, signalling and movement (Table 1). Each of these activities are crucial for the persistence of a population in environments with limited resources. They facilitate the spread of individuals and also affect the dynamics of intra-and inter-species interactions within farmland and with other ecosystems. For example, in relation to climate change, maintaining landscape connectivity (e.g. through scattered trees and shrubs) may be key to supporting the movements of organisms through ecological networks and allowing them to adapt their ranges to varying environmental conditions (Manning *et al.*, 2009). SPELs may also affect adjacent vegetation because they are associated with limited mowing, soil cultivation and the use of chemicals in their immediate vicinity which may contribute to habitat restoration by increasing floristic and structural diversity (López-Sánchez *et al.*, 2016; Pustkowiak *et al.*, 2018). The presence of SPELs may also increase the occurrence of other phenomena such as soil fertilisation from animal droppings (Julig *et al.*, 2013) and the dispersal of seeds by frugivorous birds (Galindo-González, Guevara & Sosa, 2000; Luck & Daily, 2003; Athie & Dias, 2016; Guidetti *et al.*, 2016). These

Table 1. List of functions that singular point elements in the agricultural landscape (SPELs) perform based on our literature review and on our own observations

SPEL type	Function for birds	References
Singular trees	Nesting	Carneiro *et al.* (2012); DeMars *et al.* (2010); Di Giacomo & Lopez De Casenave (2010); Hartel *et al.* (2014); Le Roux *et al.* (2018); Manning *et al.* (2004); Parish *et al.* (1994); Tews *et al.* (2004)
	Foraging	Douglas *et al.* (2014); Godoi *et al.* (2018); Luck & Daily (2003); Martin *et al.* (2009); Skórka *et al.* (2006)
	Hunting	Coates *et al.* (2017); Morelli *et al.* (2015*b*); Rodríguez-Ruiz *et al.* (2019); Vanhinsbergh & Evans (2002)
	Song post	Altewischer *et al.* (2015); Elts *et al.* (2015); Fonderflick *et al.* (2005); Mason & Macdonald (2000); Schwarz *et al.* (2018); Szymkowiak *et al.* (2014)
	Migration	Desrochers & Hannon (1997); Fischer & Lindenmayer (2002); Grubb & Doherty Jr (1999); Robertson & Radford (2009)
Singular shrubs	Nesting	Di Giacomo & Lopez De Casenave (2010); Kujawa (2004); Pärt & Söderström (1999); Polak (2012); Szymański & Antczak (2013); Tsiakiris *et al.* (2009)
	Foraging	Godoi *et al.* (2018); Z. Kwieciński, S. Pustkowiak & Z.M. Rosin, unpublished data
	Hunting	Antczak *et al.* (2005, 2019); Brambilla *et al.* (2007*b*); Morelli *et al.* (2015*b*); Vanhinsbergh & Evans (2002); Wuczyński (2005)
	Song post	Brambilla *et al.* (2007*a*)
	Shelter	Budka & Osiejuk (2013)
Erratic boulders	Nesting	Z. Kwieciński & P. Skórka, unpublished data
	Hunting	Catry *et al.* (2017)
	Song post	Elts *et al.* (2015); Fonderflick *et al.* (2005); Sánchez *et al.* (2009)
Puddles	Foraging	Faria *et al.* (2018); Fidorra *et al.* (2016); Schmidt *et al.* (2017); Z. Kwieciński, S. Pustkowiak, Z.M. Rosin & P. Skórka, unpublished data
	Water source	Orłowski (2005)
Electricity pylons	Nesting	Janiszewski *et al.* (2015); Infante & Peris (2003); Tryjanowski (2001); Tryjanowski *et al.* (2014)
	Foraging	Tryjanowski *et al.* (2014)
	Hunting	Rodríguez-Ruiz *et al.* (2019); Z. Kwieciński, S. Pustkowiak & Z.M. Rosin, unpublished data
	Song post	Elts *et al.* (2015); Fonderflick *et al.* (2005); Mason & Macdonald (2000)
	Roosting	Crouch *et al.* (2018)
Wind turbines	None identified	
Spiritual sites	Nesting	Z. Kwieciński, P. Skórka & M. Lenda, unpublished data
	Foraging	Z. Kwieciński & Z.M. Rosin, unpublished data
Hunting platforms	Nesting	Tobolka *et al.* (2013)
	Hunting	Z. Kwieciński, unpublished data
Fence/border posts	Hunting	Catry *et al.* (2017); Elliot (1985); Manning & Garton (2012); Morelli *et al.* (2015*b*); Preston (1957)
	Song post	Mason & Macdonald (2000)
Wells	Hunting	Z. Kwieciński & S. Pustkowiak, unpublished data
Road signs	None identified	
Scarecrows	None identified	
Piles of manure	Foraging	Caccamo *et al.* (2011); Goławski & Kasprzykowski (2011); Grüebler *et al.* (2010); Kamp *et al.* (2009); Kasprzykowski & Goławski (2012); Orłowski *et al.* (2014); Orłowski & Karg (2011); Šálek & Żmihorski (2018); Vanhinsbergh & Evans (2002); Z. Kwieciński, S. Pustkowiak & Z.M. Rosin, unpublished data
	Hunting	Goławski & Kasprzykowski (2011)
	Roosting	Fijen *et al.* (2015); Goławski & Kasprzykowski (2011); Kasprzykowski & Goławski (2012); Tortosa & Villafuerte (1999); Šálek & Żmihorski (2018)
Piles of branches	Nesting	Z. Kwieciński, Z.M. Rosin & P. Skórka, unpublished data
	Shelter	Pearson (1991)
Piles of stones/debris	Nesting	Arlt & Pärt (2008)
	Foraging	Kwieciński *et al.* (2019); Vanhinsbergh & Evans (2002)
	Hunting	Manning & Garton (2012); Z. Kwieciński, S. Pustkowiak & P. Skórka, unpublished data
Piles of lime	Hunting	Z. Kwieciński, unpublished data
	Song post	Z. Kwieciński & S. Pustkowiak, unpublished data
Haystacks	Nesting	Tryjanowski *et al.* (2009)
	Foraging	Z. Kwieciński, unpublished data
	Hunting	Manning & Garton (2012)
	Roosting	Z. Kwieciński, S. Pustkowiak & Z.M. Rosin, unpublished data

processes associated with SPEL may then contribute to the creation of new valuable microhabitats for many different organisms (Lentini *et al.*, 2012; Gallé *et al.*, 2017; Pustkowiak *et al.*, 2018).

The horizon-scanning survey directed to ornithologists returned much positive feedback on the relationships between SPELs and birds, including many species of conservation concern. The elements that clearly emerged as most important were trees and shrubs. The frequency of bird observations on these elements was high, their positive impact on birds was clearly emphasised and they were observed to provide numerous functions, including nesting. Most respondents reported bird observations on electricity pylons and pylons were thought to be potential nesting sites, but their other functions were not thought to be positive. The most controversial elements were wind turbines, because their impact on birds is seen as negative and without important functions for birds. The frequency of bird observations at a given SPEL may be related to the commonness of that particular element in the landscape, which should be verified by field studies. Our study has highlighted the importance of some elements such as haystacks, puddles, piles of manure, piles of stones and fence posts for birds. For some of these elements, empirical studies about their impacts on birds are lacking. The vast majority of respondents emphasised the importance of SPELs in the breeding season. However, systematic field research is needed to assess accurately which elements are used in different seasons by particular species. An important finding was the view that SPELs could mitigate some negative changes in the landscape due to agricultural intensification. This requires verification using landscape-management methods.

Despite many examples of the positive impacts of SPELs on birds there are also some negative effects. The presence of perches used by predators may have a negative impact on prey populations, particularly ground-nesting birds (Berg *et al.*, 1992). Further research should consider how to minimise threats to wildlife posed by certain man-made elements such as electricity pylons (Tintó, Real & Mañosa, 2010) and wind turbines (Wang, Wang & Smith, 2015). Furthermore, some SPELs are controversial in a broader context; for example, piles of manure support bird populations (Šálek & Żmihorski, 2018) but also lead to greenhouse gas emissions and the eutrophication of water and soil.

SPELs may have other benefits besides increasing bird diversity. Many SPELs perform numerous functions for the environment and for humans by providing cultural and aesthetic ecosystem services and enhancing landscape attractiveness (Ungaro *et al.*, 2016). They are often created and/or maintained by people, and their persistence depends on perceptions of their value and function as well as on agricultural practices (Hunter *et al.*, 2016; Rolo *et al.*, 2020). However, many elements are disappearing from agricultural landscapes. Studies of aerial photographs from Sweden reported a substantial decrease in the number of SPELs in intensive-agriculture landscapes between 1938 and 1986 (Ihse, 1995). Scattered trees, especially mature trees, are vanishing from fields and this decline will accelerate the loss of bird diversity, potentially contributing to disorder in many ecosystem services (Ozolins, Brack & Freudenberger, 2001; Gibbons *et al.*, 2008; Fischer *et al.*, 2010*b*). SPELs are most often removed because they impede field management (Ozolins *et al.*, 2001). Questionnaire surveys have revealed that farmers appreciate mature and old trees for their value, both tangible (e.g. timber or shade for livestock) and intangible (e.g. cultural), as well as for their provision of fruits for birds (Harvey & Haber, 1999; Hartel, Réti & Craioveanu, 2017). Landholders are also aware of the rapid decline of scattered trees. However, they are still less engaged in the regeneration and protection of single trees than in the protection of trees growing in patches or lines (Schirmer, Clayton & Sherren, 2012). Knowledge of the cultural and socio-economic drivers affecting management of SPELs will be crucial for effective action against their loss.

(1) Further research and practical recommendations

We propose the following research and methodological recommendations to allow a greater understanding of the importance of SPELs for farmland birds.Firstly, it was demonstrated that bird species richness doubled with the presence of one tree compared to treeless sites (Fischer *et al.*, 2010*a*). Thus, future research could measure the impact of SPELs by adding an individual element of a particular type to the landscape and estimating the ecological benefits to bird communities. Experiments that add elements (e.g. planting shrubs) to landscape plots and compare these to control landscapes will be necessary to disentangle the presence of SPELs from other habitat features (Josefsson *et al.*, 2020). Moreover, one may predict a non-linear response of birds to SPELs, such as a positive effect at low SPEL densities and no effect at high SPEL densities (Fischer *et al.*, 2010*a*). Determining the quantity and quality of SPELs that have the strongest positive impact on birds would allow effective management of SPELs in agricultural landscapes to achieve the highest possible gains in terms of bird species diversity.

Second, the sustainability of ecosystem functioning is determined by species interactions forming so-called social networks (Delmas *et al.*, 2019). SPELs may also increase the permeability and suitability of farmland for non-farmland species, which may potentially modify species interactions and ecosystem processes within fields (Moreira *et al.*, 2005; Faria *et al.*, 2018). It is therefore important to study how SPELs affect social networks in farmland birds. This could be done by investigating species interactions at sites with varying numbers of SPELs.

Third, most research on farmland birds has focused on the breeding season, and this is also true in the case of SPELs. However, our review indicates that the roles of SPELs may also be significant during other phenological periods. For example, the role of fruiting shrubs as refuelling sites for migrating and wintering farmland birds will be particularly worth investigating (Skórka *et al.*, 2006).

Fourth, many models describe the spatial pattern of biodiversity using land-use metrics such as crop diversity, farming intensity, land-use cover, landscape homogeneity, etc. (Walz, 2011). However, commonly available spatial data do not include SPELs. This is probably because SPELs are too small to be visible in low-resolution spatial layers, as is the case for the Corine Land Cover Minimum Mapping Unit of 25 ha (European Environment Agency, 2017). In this regard, most studies on relationships between bird diversity and landscape heterogeneity will not capture the effects of so-called biodiversity hot-spots based on the presence of 'keystone structures' (Tews *et al.*, 2004). However, some SPELs are visible on satellite images, some, like trees (Nevalainen *et al.*, 2017), shrubs (Cao *et al.*, 2019) and pylons (Qiao, Sun & Zhang, 2020), can be detected by remote sensing, and data can also be obtained from specific sources (e.g. the power network or the wind turbine network). On the other hand, some singular point elements appear only temporarily within a field. Thus, to improve the predictive power of models explaining spatial and temporal patterns of bird richness in agricultural landscapes, we recommend that both the number and type of SPELs are assessed, in addition to other habitat measures during bird surveys.

Fifth, farmland agri-environment-climate schemes (AES) contain tools aimed at bird conservation (Żmihorski *et al.*, 2016) and provide payments to farmers who adopt the bird-friendly farming practices outlined in the program. In the Polish AES some measures obligate farmers to preserve "non-agricultural landscape elements constituting wildlife refuges", which may encompass SPELs (Ministry of Agriculture and Rural Development, 2019, p. 320). Extending AES to include the SPELs that most effectively support bird diversity would make them a successful and low-conflict tool in achieving conservation goals. Broader studies on SPELs on other continents, including tests of the hypotheses derived from our horizon scanning would help to understand their role in various regions and landscapes for use in local and national policies.

Finally, studies on other taxa are greatly needed in order to understand better the complex roles of SPELs in farmland. For example, Pustkowiak *et al.* (2018) demonstrated that wind turbines had a positive role in the conservation of invertebrates in farmland while Šálek, Václav & Sedláček (2020) showed that small mammals benefit from vegetation developing under power pylons. Both invertebrates and small mammals are used by many birds as food, thus a complete analysis of the effects of SPELs on birds needs to take other groups into account as well.

V. CONCLUSIONS

(1) Agricultural landscapes contain a variety of SPELs with different historical backgrounds and temporal dynamics. Some of these elements are common worldwide, but are ignored in official data concerning land use and thus overlooked in analyses of spatial patterns in bird diversity.

(2) SPELs provide numerous functions to farmland birds, but there is a need for empirical evidence on the relationships between many SPELs and bird species in different farming systems.

(3) SPELs appear to be an important component of habitats, particularly in modern homogenised farmland landscapes. SPELs add to the structural complexity of a habitat, providing specific microhabitats and maintaining many ecosystem processes while the production function of cropland remains unaffected.

(4) Because SPELs may shape the distribution of farmland birds, their effects should be incorporated into models of habitat suitability.

(5) Considering the small area occupied by point elements, they have the potential to be an effective and low-conflict tool in increasing bird diversity.

VI. ACKNOWLEDGEMENTS

We thank Dorota Kotowska and Rafał Martyka for helpful comments during conceptualisation of this study. This work was partially financed by a Sonata Bis 4 grant – 2014/14/E/NZ8/00165 from the National Science Centre, Poland and through grant funding for PhD students and young scientists received from the Institute of Botany, Polish Academy of Sciences (Kraków, Poland). Z.M.R. was supported by the Ministry of Science and Higher Education of Poland: program "Mobilność Plus" (no. 1654/MOB/V/2017/0).

VII. REFERENCES

Altewischer, A., Buschewski, U., Ehrke, C., Fröhlich, J., Gärtner, A., Giese, P., Günter, F., Heitmann, N., Hestermann, M., Hoffmann, H., Kleinschmidt, F., Kniepkamp, B., Linke, W., Mayland-Quellhorst, T., Pape, J., et al. (2015). Habitat preferences of male corn buntings *Emberiza calandra* in North-Eastern Germany. *Acta Ornithologica* **50**, 1–11.

Ansell, D., Gibson, F. & Salt, D. (2016). *Learning from Agri-Environment Schemes in Australia. Investing in Biodiversity and Other Ecosystem Services on Farms*. Canberra: ANU Press.

Antczak, M., Ekner-Grzyb, A., Majláth, I., Majláthová, V., Bona, M., Hromada, M. & Tryjanowski, P. (2019). Do males pay more? A male-biased predation of common lizard (*Zootoca vivipara*) by great grey shrike (*Lanius excubitor*). *Acta Ethologica* **22**, 155–162.

Antczak, M., Hromada, M. & Tryjanowski, P. (2005). Frogs and toads in the food of the great Grey shrike (*Lanius excubitor*): larders and skinning as two ways to consume dangerous prey. *Animal Biology* **55**, 227–233.

Arlt, D. & Pärt, T. (2008). Post-breeding information gathering and breeding territory shifts in northern wheatears. *Journal of Animal Ecology* **77**, 211–219.

Assandri, G., Bogliani, G., Pedrini, P. & Brambilla, M. (2018). Beautiful agricultural landscapes promote cultural ecosystem services and biodiversity conservation. *Agriculture, Ecosystems and Environment* **256**, 200–210.

Athie, S. & Dias, M. M. (2016). Use of perches and seed dispersal by birds in an abandoned pasture in the Porto Ferreira state park, southeastern Brazil. *Brazilian Journal of Biology* **76**, 80–92.

Báldi, A., Batáry, P. & Erdos, S. (2005). Effects of grazing intensity on bird assemblages and populations of Hungarian grasslands. *Agriculture, Ecosystems and Environment* **108**, 251–263.

Barrett, G. W., Freudenberger, D., Drew, A., Stol, J., Nicholls, A. O. & Cawsey, E. M. (2008). Colonisation of native tree and shrub plantings by woodland birds in an agricultural landscape. *Wildlife Research* **35**, 19–32.

Batáry, P., Báldi, A., Kleijn, D. & Tscharntke, T. (2011a). Landscape-moderated biodiversity effects of Agri-environmental management: a meta-analysis. *Proceedings of the Royal Society B: Biological Sciences* **278**, 1894–1902.

Batáry, P., Fischer, J., Báldi, A., Crist, T. O. & Tscharntke, T. (2011b). Does habitat heterogeneity increase farmland biodiversity? *Frontiers in Ecology and the Environment* **9**, 152–153.

Bautista, N. L., García De La Torre, G. S., De Haro Arteaga, I. & Salazar Schettino, P. M. (1999). Importance of *Triatoma pallidipennis* (*Hemiptera*: *Reduviidae*) as a vector of *Trypanosoma cruzi* (*Kinetoplastida*: *Trypanosomatidae*) in the state of Morelos, Mexico, and possible ecotopes. *Journal of Medical Entomology* **36**, 233–235.

Benítez-López, A., Alkemade, R. & Verweij, P. A. (2010). The impacts of roads and other infrastructure on mammal and bird populations: a meta-analysis. *Biological Conservation* **143**, 1307–1316.

Berg, A., Lindberg, T. & Kallebrink, K. G. (1992). Hatching success of lapwings on farmland: differences between habitats and colonies of different sizes. *Journal of Animal Ecology* **61**, 469–476.

Bernardino, J., Bevanger, K., Barrientos, R., Dwyer, J. F., Marques, A. T., Martins, R. C., Shaw, J. M., Silva, J. P. & Moreira, F. (2018). Bird collisions with power lines: state of the art and priority areas for research. *Biological Conservation* **222**, 1–13.

Bevanger, K. (1998). Biological and conservation aspects of bird mortality caused by electricity power lines: a review. *Biological Conservation* **86**, 67–76.

Biasotto, L. D. & Kindel, A. (2018). Power lines and impacts on biodiversity: a systematic review. *Environmental Impact Assessment Review* **71**, 110–119.

Bosschieter, L. & Goedhart, P. W. (2005). Gap crossing decisions by reed warblers (*Acrocephalus scirpaceus*) in agricultural landscapes. *Landscape Ecology* **20**, 455–468.

Bradbury, R. B. & Bradter, U. (2004). Habitat associations of yellow wagtails *Motacilla flava flavissima* on lowland wet grassland. *Ibis* **146**, 241–246.

Brambilla, M., Reginato, F. & Guidali, F. (2007a). Habitat use by Moltoni's warbler *Sylvia cantillans moltonii* in Italy. *Ornis Fennica* **84**, 91–96.

Brambilla, M., Rubolini, D. & Guidali, F. (2007b). Between land abandonment and agricultural intensification: habitat preferences of red-backed shrikes *Lanius collurio* in low-intensity farming conditions. *Bird Study* **54**, 160–167.

Brown, M. J. F., Dicks, L. V., Paxton, R. J., Baldock, K. C. R., Barron, A. B., Chauzat, M.-P., Freitas, B. M., Goulson, D., Jepsen, S., Kremen, C., Li, J., Neumann, P., Pattemore, D. E., Potts, S. G., Schweiger, O., et al. (2016). A horizon scan of future threats and opportunities for pollinators and pollination. *PeerJ* **4**, e2249.

Budka, M. & Osiejuk, T. S. (2013). Habitat preferences of corncrake (*Crex crex*) males in agricultural meadows. *Agriculture, Ecosystems and Environment* **171**, 33–38.

Caccamo, C., Pollonara, E., Baldaccini, N. E. & Giunchi, D. (2011). Diurnal and nocturnal ranging behaviour of stone-curlews *Burhinus oedicnemus* nesting in river habitat. *Ibis* **153**, 707–720.

Calhoun, A. J. K., Mushet, D. M., Bell, K. P., Boix, D., Fitzsimons, J. A. & Isselin-Nondedeu, F. (2017). Temporary wetlands: challenges and solutions to conserving a 'disappearing' ecosystem. *Biological Conservation* **211**, 3–11.

Calvert, A. M., Bishop, C. A., Elliot, R. D., Krebs, E. A., Kydd, T. M., Machtans, C. S. & Robertson, G. J. (2013). A synthesis of human-related avian mortality in Canada. *Avian Conservation and Ecology* **8**, 11.

Cao, X., Liu, Y., Cui, X., Chen, J. & Chen, X. (2019). Mechanisms, monitoring and modeling of shrub encroachment into grassland: a review. *International Journal of Digital Earth* **12**, 625–641.

Carneiro, A. P. B., Jiménez, J. E., White, T. H. Jr. & Soto-Gamboa, M. R. (2012). Distribution of slender-billed parakeets (*Enicognathus leptorhynchus*) in a fragmented agricultural landscape of southern Chile. *Ornitologia Neotropical* **23**, 201–213.

Catry, I., Marcelino, J., Franco, A. M. A. & Moreira, F. (2017). Landscape determinants of European roller foraging habitat: implications for the definition of Agri-environmental measures for species conservation. *Biodiversity and Conservation* **26**, 553–566.

Coates, P. S., Prochazka, B. G., Ricca, M. A., Gustafson, K. B., Ziegler, P. & Casazza, M. L. (2017). Pinyon and juniper encroachment into sagebrush ecosystems impacts distribution and survival of greater sage-grouse. *Rangeland Ecology & Management* **70**, 25–38.

Cooke, S. C., Balmford, A., Donald, P. F., Newson, S. E. & Johnston, A. (2020). Roads as a contributor to landscape-scale variation in bird communities. *Nature Communications* **11**, 1–10.

Crane, M. J., Lindenmayer, D. B. & Cunningham, R. B. (2014). The value of countryside elements in the conservation of a threatened arboreal marsupial *Petaurus norfolcensis* in agricultural landscapes of South-Eastern Australia—the disproportional value of scattered trees. *PLoS One* **9**, e107178.

Crouch, C. G., Benson, R. H. & Brennan, L. A. (2018). American kestrel nonbreeding roost use and behavior in South Texas. *Journal of Raptor Research* **52**, 370–378.

Delmas, E., Besson, M., Brice, M. H., Burkle, L. A., Dalla Riva, G. V., Fortin, M.-J., Gravel, D., Guimarães, P. R., Hembry, D. H., Newman, E. A., Olesen, J. M., Pires, M. M., Yeakel, J. D. & Poisot, T. (2019). Analysing ecological networks of species interactions. *Biological Reviews* **94**, 16–36.

DeMars, C. A., Rosenberg, D. K. & Fontaine, J. B. (2010). Multi-scale factors affecting bird use of isolated remnant oak trees in agro-ecosystems. *Biological Conservation* **143**, 1485–1492.

Desrochers, A. & Hannon, S. J. (1997). Gap crossing decisions by forest songbirds during the post-fledging period. *Conservation Biology* **11**, 1204–1210.

Di Giacomo, A. S. & Lopez De Casenave, J. (2010). Use and importance of crop and field-margin habitats for birds in a neotropical agricultural ecosystem. *The Condor* **112**, 283–293.

Dinkins, J. B., Conover, M. R., Kirol, C. P., Beck, J. L. & Frey, S. N. (2014). Greater sage-grouse (*Centrocercus urophasianus*) select habitat based on avian predators, landscape composition, and anthropogenic features. *The Condor: Ornithological Applications* **116**, 629–642.

Donald, P. F., Green, R. E. & Heath, M. F. (2001). Agricultural intensification and the collapse of Europe's farmland bird populations. *Proceedings of the Royal Society of London Series B: Biological Sciences* **268**, 25–29.

Douglas, D. J. T., Nalwanga, D., Katebaka, R., Atkinson, P. W., Pomeroy, D. E., Nkuutu, D. & Vickery, J. A. (2014). The importance of native trees for forest bird conservation in tropical farmland. *Animal Conservation* **17**, 256–264.

Dudley, N., Shadie, P. & Stolton, S. (2013). Guidelines for applying protected area management categories including IUCN WCPA best practice guidance on recognising protected areas and assigning management categories and governance types. In Gland, Switzerland: IUCN. x, 86p. + iv, 31p.: ill.

Dwyer, J. F., Harness, R. E., Gerber, B. D., Landon, M. A., Petersen, P., Austin, D. D., Woodbridge, B., Williams, G. E. & Eccleston, D. (2016). Power pole density informs spatial prioritization for mitigating avian electrocution. *The Journal of Wildlife Management* **80**, 634–642.

Dylewski, Ł., Kurek, P., Wiatrowska, B., Jerzak, L. & Tryjanowski, P. (2017). Man-made perching sites—electricity pylons accelerate fleshy-fruited plants succession in farmlands. *Flora* **231**, 51–56.

Eglington, S. M., Gill, J. A., Bolton, M., Smart, M. A., Sutherland, W. J. & Watkinson, A. R. (2008). Restoration of wet features for breeding waders on lowland grassland. *Journal of Applied Ecology* **45**, 305–314.

Elliot, R. D. (1985). The exclusion of avian predators from aggregations of nesting lapwings (*Vanellus vanellus*). *Animal Behaviour* **33**, 308–314.

Elts, J., Tätte, K. & Marja, R. (2015). What are the important landscape components for habitat selection of the ortolan bunting *Emberiza hortulana* in northern limit of range? *European Journal of Ecology* **1**, 13–25.

European Environment Agency (2017). CLC2018 Technical Guidelines.

European Network for Rural Development (2016). RDPs 2014–2020: key facts & figures. Rural development priority 4: restoring, preserving and enhancing ecosystems related to agriculture and forestry.

Faria, F. A., Albertoni, E. F. & Bugoni, L. (2018). Trophic niches and feeding relationships of shorebirds in southern Brazil. *Aquatic Ecology* **52**, 281–296.

Fidorra, J. C., Frederick, P. C., Evers, D. C. & Meyer, K. D. (2016). Selection of human-influenced and natural wetlands by great egrets at multiple scales in the southeastern USA. *The Condor: Ornithological Applications* **118**, 46–56.

Fijen, T. P. M., Kamp, J., Lameris, T. K., Pulikova, G., Urazaliev, R., Kleijn, D. & Donald, P. F. (2015). Functions of extensive animal dung 'pavements' around the nests of the black lark (*Melanocorypha yeltoniensis*). *The Auk: Ornithological Advances* **132**, 878–892.

Fischer, J. & Lindenmayer, D. B. (2002). The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 2. Paddock trees as stepping stones. *Biodiversity and Conservation* **11**, 833–849.

Fischer, J., Stott, J. & Law, B. S. (2010a). The disproportionate value of scattered trees. *Biological Conservation* **143**, 1564–1567.

Fischer, J., Zerger, A., Gibbons, P., Stott, J. & Law, B. S. (2010b). Tree decline and the future of Australian farmland biodiversity. *Proceedings of the National Academy of Sciences of the United States of America* **107**, 19597–19602.

Fitzsimons, J. A. & Michael, D. R. (2017). Rocky outcrops: a hard road in the conservation of critical habitats. *Biological Conservation* **211**, 36–44.

Fonderflick, J., Thévenot, M. & Guillaume, C. P. (2005). Habitat of the Ortolan bunting *Emberiza hortulana* on the Causse Méjean (Lozère, southern France). *Vie et Milieu* **55**, 109–120.

Galindo-González, J., Guevara, S. & Sosa, V. J. (2000). Bat-and bird-generated seed rains at isolated trees in pastures in a tropical rainforest. *Conservation Biology* **14**, 1693–1703.

Gallé, R., Urák, I., Nikolett, G.-S. & Hartel, T. (2017). Sparse trees and shrubs confers a high biodiversity to pastures: case study on spiders from Transylvania. *PLoS One* **12**, e0183465.

Gibbons, P., Lindenmayer, D. B., Fischer, J., Manning, A. D., Weinberg, A., Seddon, J., Ryan, P. & Barrett, G. (2008). The future of scattered trees in agricultural landscapes. *Conservation Biology* **22**, 1309–1319.

Global Wind Energy Council (2017). Global Wind Energy Report: Annual Market Update 2017.

Godoi, M. N., Laps, R. R., Ribeiro, D. B., Aoki, C. & de Souza, F. L. (2018). Bird species richness, composition and abundance in pastures are affected by vegetation structure and distance from natural habitats: a single tree in pastures matters. *Emu - Austral Ornithology* **118**, 201–211.

Goławski, A. & Kasprzykowski, Z. (2011). The significance of cereal stubble and manure heaps for birds wintering in the farmland of eastern Poland. *Ardeola* **58**, 277–286.

Graff, B. J., Jenks, J. A., Stafford, J. D., Jensen, K. C. & Grovenburg, T. W. (2016). Assessing spring direct mortality to avifauna from wind energy facilities in the Dakotas. *The Journal of Wildlife Management* **80**, 736–745.

Grant, T. A., Madden, E. & Berkey, G. B. (2004). Tree and shrub invasion in northern mixed-grass prairie: implications for breeding grassland birds. *Wildlife Society Bulletin* **32**, 807–818.

Gray, M. (2004). *Geodiversity: Valuing and Conserving Abiotic Nature*. Chichester: John Wiley & Sons.

Green, A. J., Jenkins, K. M., Bell, D., Morris, P. J. & Kingsford, R. T. (2008). The potential role of waterbirds in dispersing invertebrates and plants in arid Australia. *Freshwater Biology* **53**, 380–392.

Green, R. E., Tyler, G. A. & Bowden, C. G. R. (2000). Habitat selection , ranging behaviour and diet of the stone curlew (*Burhinus oedicnemus*) in southern England. *Journal of Zoology* **250**, 161–183.

Gregory, R. D., Van Strien, A., Vorisek, P., Gmelig Meyling, A. W., Noble, D. G., Foppen, R. P. B. & Gibbons, D. W. (2005). Developing indicators for European birds. *Philosophical Transactions of the Royal Society B: Biological Sciences* **360**, 269–288.

Gruar, D., Barritt, D. & Peach, W. J. (2006). Summer utilization of oilseed rape by reed buntings *Emberiza schoeniclus* and other farmland birds. *Bird Study* **53**, 47–54.

Grubb, T. C. & Doherty, P. F. Jr. (1999). On home-range gap-crossing. *The Auk* **116**, 618–628.

Grüebler, M. U., Korner-Nievergelt, F. & Von Hirschheydt, J. (2010). The reproductive benefits of livestock farming in barn swallows *Hirundo rustica*: quality of nest site or foraging habitat? *Journal of Applied Ecology* **47**, 1340–1347.

Guidetti, B. Y., Amico, G. C., Dardanelli, S. & Rodriguez-cabal, M. A. (2016). Artificial perches promote vegetation restoration. *Plant Ecology* **217**, 935–942.

Gunnarsson, T. G., Gill, J. A., Appleton, G. F., Gíslason, H., Gardarsson, A., Watkinson, A. R. & Sutherland, W. J. (2006). Large-scale habitat associations of birds in lowland Iceland: implications for conservation. *Biological Conservation* **128**, 265–275.

Hartel, T., Hanspach, J., Abson, D. J., Máthé, O., Moga, C. I. & Fischer, J. (2014). Bird communities in traditional wood-pastures with changing management in Eastern Europe. *Basic and Applied Ecology* **15**, 385–395.

Hartel, T., Réti, K.-O. & Craioveanu, C. (2017). Valuing scattered trees from wood-pastures by farmers in a traditional rural region of Eastern Europe. *Agriculture, Ecosystems and Environment* **236**, 304–311.

Harvey, C. A. & Haber, W. A. (1999). Remnant trees and the conservation of biodiversity in Costa Rican pastures. *Agroforestry Systems* **44**, 37–68.

Haslem, A. & Bennett, A. F. (2008). Countryside elements and the conservation of birds in agricultural environments. *Agriculture, Ecosystems and Environment* **125**, 191–203.

Hayward, M. W. & Kerley, G. I. H. (2009). Fencing for conservation: restriction of evolutionary potential or a riposte to threatening processes? *Biological Conservation* **142**, 1–13.

Hiron, M., Berg, Å., Eggers, S., Josefsson, J. & Pärt, T. (2013). Bird diversity relates to Agri-environment schemes at local and landscape level in intensive farmland. *Agriculture, Ecosystems and Environment* **176**, 9–16.

Hobbs, R. J., Higgs, E. & Harris, J. A. (2009). Novel ecosystems: implications for conservation and restoration. *Trends in Ecology and Evolution* **24**, 599–605.

Holland, J. E., Bennett, A. E., Newton, A. C., White, P. J., McKenzie, B. M., George, T. S., Pakeman, R. J., Bailey, J. S., Fornara, D. A. & Hayes, R. C. (2018). Liming impacts on soils, crops and biodiversity in the UK: a review. *Science of the Total Environment* **610–611**, 316–332.

Hunter, M. L. Jr. (2016). Conserving small natural features with large ecological roles: an introduction and definition. *Biological Conservation* **211**, 1–2.

Hunter, M. L. Jr., Acuña, V., Bauer, D. M., Bell, K. P., Calhoun, A. J. K., Felipe-Lucia, M. R., Fitzsimons, J. A., González, E., Kinnison, M., Lindenmayer, D., Lundquist, C. J., Medellin, R. A., Nelson, E. J. & Poschlod, P. (2016). Conserving small natural features with large ecological roles: a synthetic overview. *Biological Conservation* **211**, 88–95.

Ihse, M. (1995). Swedish agricultural landscapes—patterns and changes during the last 50 years, studied by aerial photos. *Landscape and Urban Planning* **31**, 21–37.

Illian, J. & Burslem, D. (2007). Contributions of spatial point process modelling to biodiversity theory. *Journal de la Société Française de Statistique* **148**, 9–29.

Infante, O. & Peris, S. (2003). Bird nesting on electric power supports in northwestern Spain. *Ecological Engineering* **20**, 321–326.

Janiszewski, T., Minias, P. & Wojciechowski, Z. (2015). Selective forces responsible for transition to nesting on electricity poles in the white stork *Ciconia ciconia*. *Ardea* **103**, 39–50.

Josefsson, J., Hiron, M., Arlt, D., Auffret, A. G., Berg, Å., Chevalier, M., Glimskär, A., Hartman, G., Kačergytė, I., Klein, J., Knape, J., Laugen, A. T., Low, M., Paquet, M., Pasanen-Mortensen, M., et al. (2020). Improving scientific rigour in conservation evaluations and a plea deal for transparency on potential biases. *Conservation Letters* **13**, 1–8.

Julig, P. J., Mahaney, W. C., Kalm, V. & Earl-Goulet, J. R. (2013). Geoarchaeological importance of sub-Arctic bird perches dated by lee side turf mound accumulation and identified by lichen plumes. *Polar Record* **49**, 373–380.

Kamp, J., Sheldon, R. D., Koshkin, M. A., Donald, P. F. & Biedermann, R. (2009). Post - soviet steppe management causes pronounced synanthropy in the globally threatened sociable lapwing *Vanellus gregarius*. *Ibis* **15**, 452–463.

Kasprzykowski, Z. & Goławski, A. (2012). Habitat preferences of granivorous passerine birds wintering on farmland in eastern Poland. *Bird Study* **59**, 52–57.

Kleijn, D., Rundlöf, M., Scheper, J., Smith, H. G. & Tscharntke, T. (2011). Does conservation on farmland contribute to halting the biodiversity decline? *Trends in Ecology & Evolution* **26**, 474–481.

Kujawa, K. (2004). Importance of young shelterbelts for breeding avifauna in agricultural landscape (Turew area, West Poland). *Polish Journal of Ecology* **52**, 433–443.

Kurek, P., Sparks, T. H. & Tryjanowski, P. (2015). Electricity pylons may be potential foci for the invasion of black cherry *Prunus serotina* in intensive farmland. *Acta Oecologica* **62**, 40–44.

Kwieciński, Z., Rosin, Z. M., Jankowiak, Ł., Sparks, T. H. & Tryjanowski, P. (2019). Thrush anvils are calcium source hotspots for many bird species. *Biological Journal of the Linnean Society* **128**, 603–610.

Lautenbach, J. M., Plumb, R. T., Robinson, S. G., Hagen, C. A., Haukos, D. A. & Pitman, J. C. (2017). Lesser prairie-chicken avoidance of trees in a grassland landscape. *Rangeland Ecology & Management* **70**, 78–86.

Lentini, P. E., Martin, T. G., Gibbons, P., Fischer, J. & Cunningham, S. A. (2012). Supporting wild pollinators in a temperate agricultural landscape: maintaining mosaics of natural features and production. *Biological Conservation* **149**, 84–92.

Le Roux, D. S., Ikin, K., Lindenmayer, D. B., Manning, A. D. & Gibbons, P. (2014). The future of large old trees in urban landscapes. *PLoS One* **9**, e99403.

Le Roux, D. S., Ikin, K., Lindenmayer, D. B., Manning, A. D. & Gibbons, P. (2018). The value of scattered trees for wildlife: contrasting effects of landscape context and tree size. *Diversity and Distributions* **24**, 69–81.

Lindenmayer, D. B. (2017). Conserving large old trees as small natural features. *Biological Conservation* **211**, 51–59.

López-Sánchez, A., San Miguel, A., López-Carrasco, C., Huntsinger, L. & Roig, S. (2016). The important role of scattered trees on the herbaceous diversity of a grazed Mediterranean dehesa. *Acta Oecologica* **76**, 31–38.

Luck, G. W. & Daily, G. C. (2003). Tropical countryside bird assemblages: richness, composition, and foraging differ by landscape context. *Ecological Applications* **13**, 235–247.

Manenti, R. (2014). Dry stone walls favour biodiversity: a case-study from the Appennines. *Biodiversity and Conservation* **23**, 1879–1893.

Manning, A. D., Fischer, J. & Lindenmayer, D. B. (2006). Scattered trees are keystone structures–implications for conservation. *Biological Conservation* **132**, 311–321.

Manning, A. D., Gibbons, P. & Lindenmayer, D. B. (2009). Scattered trees: a complementary strategy for facilitating adaptive responses to climate change in modified landscapes? *Journal of Applied Ecology* **46**, 915–919.

Manning, A. D., Lindenmayer, D. B. & Barry, S. C. (2004). The conservation implications of bird reproduction in the agricultural 'matrix': a case study of the vulnerable superb parrot of South-Eastern Australia. *Biological Conservation* **120**, 363–374.

Manning, J. A. & Garton, E. O. (2012). A sightability model for correcting visibility and availability biases in standardized surveys of breeding burrowing owls in southwest agroecosystem environments. *The Journal of Wildlife Management* **76**, 65–74.

Martin, E. A., Ratsimisetra, L., Laloë, F. & Carrière, S. M. (2009). Conservation value for birds of traditionally managed isolated trees in an agricultural landscape of Madagascar. *Biodiversity and Conservation* **18**, 2719–2742.

Mason, C. F. & Macdonald, S. M. (2000). Corn bunting *Miliaria calandra* populations, landscape and land-use in an arable district of eastern England. *Bird Conservation International* **10**, 169–186.

Milsom, T. P., Langton, S. D., Parkin, W. K., Peel, S., Bishop, J. D., Hart, J. D. & Moore, N. P. (2000). Habitat models of bird species' distribution: an aid to the management of coastal grazing marshes. *Journal of Applied Ecology* **37**, 706–727.

Minderman, J., Fuentes-Montemayor, E., Pearce-Higgins, J. W., Pendlebury, C. J. & Park, K. J. (2015). Estimates and correlates of bird and bat mortality at small wind turbine sites. *Biodiversity and Conservation* **24**, 467–482.

Ministry of Agriculture and Rural Development (2019). Rural Development Programme for 2014–2020. 1–839.

Mõisja, K., Uuemaa, E. & Oja, T. (2016). Integrating small-scale landscape elements into land use/cover: the impact on landscape metrics' values. *Ecological Indicators* **67**, 714–722.

Moreira, F., Beja, P., Morgado, R., Reino, L., Gordinho, L., Delgado, A. & Borralho, R. (2005). Effects of field management and landscape context on grassland wintering birds in southern Portugal. *Agriculture, Ecosystems & Environment* **109**, 59–74.

Morelli, F. (2013). Relative importance of marginal vegetation (shrubs, hedgerows, isolated trees) surrogate of HNV farmland for bird species distribution in Central Italy. *Ecological Engineering* **57**, 261–266.

Morelli, F., Jerzak, L., Pruscini, F., Santolini, R., Benedetti, Y. & Tryjanowski, P. (2015a). Testing bird response to roads on a rural environment: a case study from Central Italy. *Acta Oecologica* **69**, 146–152.

Morelli, F., Mróz, E., Pruscini, F., Santolini, R., Goławski, A. & Tryjanowski, P. (2015b). Habitat structure, breeding stage and sex affect hunting success of breeding red-backed shrike (*Lanius collurio*). *Ethology Ecology & Evolution* **28**, 136–147.

Morgado, R., Beja, P., Reino, L., Gordinho, L., Delgado, A., Borralho, R. & Moreira, F. (2010). Calandra lark habitat selection: strong fragmentation effects in a grassland specialist. *Acta Oecologica* **36**, 63–73.

Nevalainen, O., Honkavaara, E., Tuominen, S., Viljanen, N., Hakala, T., Yu, X., Hyyppä, J., Saari, H., Pölönen, I., Imai, N. N. & Tommaselli, A. M. G. (2017). Individual tree detection and classification with UAV-based photogrammetric point clouds and hyperspectral imaging. *Remote Sensing* **9**, 185.

Nikolov, S. C., Demerdzhiev, D. A., Popgeorgiev, G. S. & Plachiyski, D. G. (2011). Bird community patterns in sub–Mediterranean pastures: the effects of shrub cover and grazing intensity. *Animal Biodiversity and Conservation* **34**, 11–21.

Oien, I. J., Honza, M., Moksnes, A. & Roskaft, E. (1996). The risk of parasitism in relation to the distance from reed warbler nests to cuckoo perches. *Journal of Animal Ecology* **65**, 147–153.

Orłowski, G. (2005). Factors affecting road mortality of the barn swallows *Hirundo rustica* in farmland. *Acta Ornithologica* **40**, 117–125.

Orłowski, G. (2010). Effect of boundary vegetation and landscape features on diversity and abundance of breeding bird communities of abandoned crop fields in Southwest Poland. *Bird Study* **57**, 175–182.

Orłowski, G., Czarnecka, J. & Goławski, A. (2014). Winter diet of yellowhammers *Emberiza citrinella* on contemporary farmland: the different contribution of forbs, wild grasses and cereals in semi-natural and agricultural habitats. *Bird Study* **61**, 484–495.

Orłowski, G. & Karg, J. (2011). Diet of nestling barn swallows *Hirundo rustica* in rural areas of Poland. *Open Life Sciences* **6**, 1023–1035.

Ozolins, A., Brack, C. & Freudenberger, D. (2001). Abundance and decline of isolated trees in the agricultural landscapes of Central New South Wales, Australia. *Pacific Conservation Biology* **7**, 195–203.

Paaijmans, K. P., Takken, W., Githeko, A. K. & Jacobs, A. F. G. (2008). The effect of water turbidity on the near-surface water temperature of larval habitats of the malaria mosquito *Anopheles gambiae*. *International Journal of Biometeorology* **52**, 747–753.

Parish, T., Lakhani, K. & Sparks, T. (1994). Modelling the relationship between bird population variables and hedgerow and other field margin attributes. I. Species richness of winter, summer and breeding birds. *Journal of Applied Ecology* **31**, 764–775.

Pärt, T. & Söderström, B. (1999). The effects of management regimes and location in landscape on the conservation of farmland birds breeding in semi-natural pastures. *Biological Conservation* **90**, 113–123.

Pearson, S. M. (1991). Food patches and the spacing of individual foragers. *The Auk* **108**, 355–362.

Plumb, R. T., Lautenbach, J. M., Robinson, S. G., Haukos, D. A., Winder, V. L., Hagen, C. A., Sullins, D. S., Pitman, J. C. & Dahlgren, D. K. (2019). Lesser prairie-chicken space use in relation to anthropogenic structures. *Journal of Wildlife Management* **83**, 216–230.

Polak, M. (2012). Habitat preferences of the sympatric barred warbler (*Sylvia nisoria*) and the red-backed shrike (*Lanius collurio*) breeding in Central Poland. *Annales Zoologici Fennici* **49**, 355–363.

Poschlod, P. & Braun-Reichert, R. (2016). Small natural features with large ecological roles in ancient agricultural landscapes of Central Europe - history, value, status, and conservation. *Biological Conservation* **211**, 60–68.

Preston, F. W. (1957). The look-out perch as a factor in predation by crows. *The Wilson Bulletin* **69**, 368–370.

Prevedello, J. A., Almeida-Gomes, M. & Lindenmayer, D. B. (2018). The importance of scattered trees for biodiversity conservation: a global meta-analysis. *Journal of Applied Ecology* **55**, 205–214.

Pustkowiak, S., Banaszak-Cibicka, W., Mielczarek, Ł. E., Tryjanowski, P. & Skórka, P. (2018). The association of windmills with conservation of pollinating insects and wild plants in homogeneous farmland of western Poland. *Environmental Science and Pollution Research* **25**, 6273–6284.

Qiao, S., Sun, Y. & Zhang, H. (2020). Deep learning based electric pylon detection in remote sensing images. *Remote Sensing* **12**, 1857.

R Core Team (2016). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna.

Redlich, S., Martin, E. A., Wende, B. & Steffan-dewenter, I. (2018). Landscape heterogeneity rather than crop diversity mediates bird diversity in agricultural landscapes. *PLoS One* **13**, 1–14.

Renwick, A. R., Vickery, J. A., Potts, S. G., Bolwig, S., Nalwanga, D., Pomeroy, D. E., Mushabe, D. & Atkinson, P. W. (2014). Achieving production and conservation simultaneously in tropical agricultural landscapes. *Agriculture, Ecosystems and Environment* **192**, 130–134.

Rivest, D., Paquette, A., Moreno, G. & Messier, C. (2013). A meta-analysis reveals mostly neutral influence of scattered trees on pasture yield along with some contrasted effects depending on functional groups and rainfall conditions. *Agriculture, Ecosystems & Environment* **165**, 74–79.

Robertson, O. J. & Radford, J. Q. (2009). Gap-crossing decisions of forest birds in a fragmented landscape. *Austral Ecology* **34**, 435–446.

Rodríguez-Ruiz, J., Mougeot, F., Parejo, D., De La Puente, J., Bermejo, A. & Avilés, J. M. (2019). Important areas for the conservation of the European roller *Coracias garrulus* during the non-breeding season in southern Africa. *Bird Conservation International* **29**, 159–175.

Rolo, V., Hartel, T., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., Mirck, J., Palma, J. H. N., Pantera, A., Paulo, J. A., Pulido, F. J., Seddaiu, G., Thenail, C., Varga, A., Viaud, V., et al. (2020). Challenges and innovations for improving the sustainability of European agroforestry systems of high nature and cultural value: stakeholder perspectives. *Sustainability Science* **15**, 1301–1315.

Rosin, Z. M., Skórka, P., Szymański, P., Tobolka, M., Luczak, A. & Tryjanowski, P. (2016). Constant and seasonal drivers of bird communities in a wind farm: implications for conservation. *PeerJ* **4**, e2105.

Rydell, J., Bach, L., Dubourg-Savage, M.-J., Green, M., Rodrigues, L. & Hedenström, A. (2010). Bat mortality at wind turbines in northwestern Europe. *Acta Chiropterologica* **12**, 261–274.

Šálek, M., Hula, V., Kipson, M., Daňková, R., Niedobová, J. & Gamero, A. (2018). Bringing diversity back to agriculture: smaller fields and non-crop elements enhance biodiversity in intensively managed arable farmlands. *Ecological Indicators* **90**, 65–73.

Šálek, M., Václav, R. & Sedláček, F. (2020). Uncropped habitats under power pylons are overlooked refuges for small mammals in agricultural landscapes. *Agriculture, Ecosystems and Environment* **290**, 106777.

Šálek, M. & Żmihorski, M. (2018). Manure heaps attract farmland birds during winter. *Bird Study* **65**, 426–430.

Sánchez, S., Václav, R. & Prokop, P. (2009). An inter-regional approach to intraspecific variation in habitat association: rock buntings *Emberiza cia* as a case study. *Ibis* **151**, 88–98.

Santiago-Quesada, F., Masero, J. A., Albano, N. & Sánchez-Guzmán, J. M. (2014). Roost location and landscape attributes influencing habitat selection of migratory waterbirds in rice fields. *Agriculture, Ecosystems and Environment* **188**, 97–102.

Schirmer, J., Clayton, H. & Sherren, K. (2012). Reversing scattered tree decline on farms: implications of landholder perceptions and practice in the Lachlan catchment, New South Wales. *Australasian Journal of Environmental Management* **19**, 91–107.

Schmidt, J. U., Eilers, A., Schimkat, M., Krause-Heiber, J., Timm, A., Siegel, S., Nachtigall, W. & Kleber, A. (2017). Factors influencing the success of within-field AES fallow plots as key sites for the northern lapwing *Vanellus vanellus* in an industrialised agricultural landscape of Central Europe. *Journal for Nature Conservation* **35**, 66–76.

Schwarz, C., Trautner, J. & Fartmann, T. (2018). Common pastures are important refuges for a declining passerine bird in a pre-alpine agricultural landscape. *Journal of Ornithology* **159**, 945–954.

Silva, J. P., Santos, M., Queirós, L., Leitão, D., Moreira, F., Pinto, M., Leqoc, M. & Cabral, J. A. (2010). Estimating the influence of overhead transmission power lines and landscape context on the density of little bustard *Tetrax tetrax* breeding populations. *Ecological Modelling* **221**, 1954–1963.

Singleton, G. R. (1985). A demographic and gentic study of house mice, *Mus musulus*, colonizing pasture haystacks on a cereal farm. *Australian Journal of Zoology* **33**, 437–450.

Skórka, P., Babiarz, T., Skórka, J. & Wöjcik, J. D. (2006). Winter territoriality and fruit defence by the fieldfare (*Turdus pilaris*). *Journal of Ornithology* **147**, 371–375.

Skórka, P., Lenda, M., Moroń, D. & Tryjanowski, P. (2013). New methods of crop production and farmland birds: effects of plastic mulches on species richness and abundance. *Journal of Applied Ecology* **50**, 1387–1396.

Skórka, P., Lenda, M. & Tryjanowski, P. (2010). Invasive alien goldenrods negatively affect grassland bird communities in Eastern Europe. *Biological Conservation* **143**, 856–861.

Söderström, B., Svensson, B., Vessby, K. & Glimskär, A. (2001). Plants, insects and birds in semi-natural pastures in relation to local habitat and landscape factors. *Biodiversity and Conservation* **10**, 1839–1863.

Stanton, R. L., Morrissey, C. A. & Clark, R. G. (2018). Analysis of trends and agricultural drivers of farmland bird declines in North America: a review. *Agriculture, Ecosystems and Environment* **254**, 244–254.

Stevens, T. K., Hale, A. M., Karsten, K. B. & Bennett, V. J. (2013). An analysis of displacement from wind turbines in a wintering grassland bird community. *Biodiversity and Conservation* **22**, 1755–1767.

Sutherland, W. J., Aveling, R., Brooks, T. M., Clout, M., Dicks, L. V., Fellman, L., Fleishman, E., Gibbons, D. W., Keim, B., Lickorish, F., Monk, K. A., Mortimer, D., Peck, L. S., Pretty, J., Rockström, J., et al. (2014). A horizon scan of global conservation issues for 2014. *Trends in Ecology and Evolution* **29**, 15–22.

Szymański, P. & Antczak, M. (2013). Structural heterogeneity of linear habitats positively affects barred warbler *Sylvia nisoria*, common whitethroat *Sylvia communis* and lesser whitethroat *Sylvia curruca* in farmland of Western Poland. *Bird Study* **60**, 484–490.

Szymkowiak, J., Skierczyński, M. & Kuczyński, L. (2014). Are buntings good indicators of agricultural intensity? *Agriculture, Ecosystems and Environment* **188**, 192–197.

Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M. C., Schwager, M. & Jeltsch, F. (2004). Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of Biogeography* **31**, 79–92.

Thomas, J. A., Telfer, M. G., Roy, D. B., Preston, C. D., Greenwood, J. J. D., Asher, J., Fox, R., Clarke, R. T. & Lawton, J. H. (2004). Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science* **303**, 1879–1881.

Tintó, A., Real, J. & Mañosa, S. (2010). Predicting and correcting electrocution of birds in Mediterranean areas. *Journal of Wildlife Management* **74**, 1852–1862.

Tobolka, M., Kuźniak, S., Zolnierowicz, K. M., Sparks, T. H. & Tryjanowski, P. (2013). New is not always better: low breeding success and different occupancy patterns in newly built nests of a long-lived species, the white stork *Ciconia ciconia*. *Bird Study* **60**, 399–403.

Tortosa, F. S. & Villafuerte, R. (1999). Effect of nest microclimate on effective endothermy in White stork *Ciconia ciconia* nestlings. *Bird Study* **46**, 336–341.

Tryjanowski, P. (1995). The composition and dynamics of a wintering bird community in an agricultural area of western Poland. *Acta Ornithologica* **30**, 153–160.

Tryjanowski, P. (2001). Proximity of raven (*Corvus corax*) nest modifies breeding bird community in an intensively used farmland. *Annales Zoologici Fennici* **38**, 131–138.

Tryjanowski, P., Hartel, T., Báldi, A., Szymański, P., Tobolka, M., Herzon, I., Goławski, A., Konvička, M., Hromada, M., Jerzak, L., Kujawa, K., Lenda, M., Orłowski, G., Panek, M., Skórka, P., et al. (2011). Conservation of farmland birds faces different challenges in Western and Central-Eastern Europe. *Acta Ornithologica* **46**, 1–12.

Tryjanowski, P., Kuźniak, S., Kujawa, K. & Jerzak, L. (2009). *Ekologia ptaków krajobrazu rolniczego*. Bogucki Wydawnictwo Naukowe, Poznań.

Tryjanowski, P. & Morelli, F. (2015). Presence of cuckoo reliably indicates high bird diversity: a case study in a farmland area. *Ecological Indicators* **55**, 52–58.

Tryjanowski, P., Sparks, T. H., Jerzak, L., Rosin, Z. M. & Skórka, P. (2014). A paradox for conservation: electricity pylons may benefit avian diversity in intensive farmland. *Conservation Letters* **7**, 34–40.

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I. & Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. *Ecology Letters* **8**, 857–874.

Tsiakiris, R., Stara, K., Pantis, J. & Sgardelis, S. (2009). Microhabitat selection by three common bird species of montane farmlands in northern Greece. *Environmental Management* **44**, 874–887.

Ungaro, F., Häfner, K., Zasada, I. & Piorr, A. (2016). Mapping cultural ecosystem services: connecting visual landscape quality to cost estimations for enhanced services provision. *Land Use Policy* **54**, 399–412.

Vanhinsbergh, D. & Evans, A. (2002). Habitat associations of the red-backed shrike (*Lanius collurio*) in Carinthia, Austria. *Journal für Ornithologie* **143**, 405–415.

van Leeuwen, C. H. A., van der Velde, G., van Lith, B. & Klaassen, M. (2012). Experimental quantification of long distance dispersal potential of aquatic snails in the gut of migratory birds. *PLoS One* **7**, e32292.

Walz, U. (2011). Landscape structure, landscape metrics and biodiversity. *Living Reviews in Landscape Research* **5**, 1–35.

Wang, S., Wang, S. & Smith, P. (2015). Ecological impacts of wind farms on birds: questions, hypotheses, and research needs. *Renewable and Sustainable Energy Reviews* **44**, 599–607.

Wilson, S., Mitchell, G. W., Pasher, J., Mcgovern, M., Hudson, M.-A. R. & Fahrig, L. (2017). Influence of crop type, heterogeneity and woody structure on avian biodiversity in agricultural landscapes. *Ecological Indicators* **83**, 218–226.

Winder, V. L., McNew, L. B., Gregory, A. J., Hunt, L. M., Wisely, S. M. & Sandercock, B. K. (2014). Effects of wind energy development on survival of female greater prairie-chickens. *Journal of Applied Ecology* **51**, 395–405.

Wretenberg, J., Lindström, Å., Svensson, S. & Pärt, T. (2007). Linking agricultural policies to population trends of Swedish farmland birds in different agricultural regions. *Journal of Applied Ecology* **44**, 933–941.

Wuczyński, A. (2005). Habitat use and hunting behaviour of common buzzards *Buteo buteo* wintering in South-Western Poland. *Acta Ornithologica* **40**, 147–154.

Żmihorski, M., Kotowska, D., Berg, Å. & Pärt, T. (2016). Evaluating conservation tools in polish grasslands: the occurrence of birds in relation to Agri-environment schemes and Natura 2000 areas. *Biological Conservation* **194**, 150–157.

Żmihorski, M., Krupiński, D., Kotowska, D., Knape, J., Pärt, T., Obłoza, P. & Berg, Å. (2018). Habitat characteristics associated with occupancy of declining waders in polish wet grasslands. *Agriculture, Ecosystems and Environment* **251**, 236–243.

Zwart, M. C., Dunn, J. C., McGowan, P. J. K. & Whittingham, M. J. (2016). Wind farm noise suppresses territorial defense behavior in a songbird. *Behavioral Ecology* **27**, 101–108.

VIII. Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. A list of questions included in the online survey, with possible answers.

Figs. S1–S20. Examples of singular point elements in agricultural landscapes (SPELs).

Fig. S21. Answers to question 7 from our online survey where respondents were asked to indicate all the elements on which they had observed a bird at least once.

Fig. S22. The answers to question 8 showing the opinion of respondents about the importance of particular types of point elements for birds.

Fig. S23. The answers to question 12 showing the opinion of respondents regarding the ability of singular point elements in the agricultural landscape to overcome several negative phenomena.

Table S2. List of species which, in the opinion of the respondents, most often use singular point elements in the agricultural landscape.

(*Received 20 March 2020; revised 23 February 2021; accepted 25 February 2021; published online 10 March 2021*)

Supporting Information

Table S1. A list of questions included in the online survey with possible answers. We pre-selected a set of 16 elements that were analysed during horizon scanning. The participants indicated (see question 14) the possible importance of other elements (e.g. piles of branches, piles of lime). We included these suggestions while preparing the final list of elements for literature review.

Question	Available answer
1. Number of years of birdwatching	number
2. How often (during the year, on average) do you go birdwatching?	once a week more than once a week once a month several times a year once a year
3. In what habitat do you usually observe birds? (maximum 3 answers)	urban area rural area forest water reservoirs industrial area agricultural area grassland area suburban area
4. In which voivodeship (Polish province) do you most often observe birds?	a list of Polish voivodeships
5. Do you have a biology-related education (e.g. biology, environmental protection, forestry, ecology)?	yes no
6. Is ornithology your profession?	yes no
7. Have you ever observed a bird in an agricultural landscape occurring on the following elements: (multiple choices allowed)	on single tree on single shrub on erratic boulder in a puddle on electricity pylon on a chapel/crucifix on a hunting platform on a road sign on a well on a wind turbine on a post on a pile of stones on a pile of manure on a haystack on a scarecrow on a pile of soil other
8. Evaluate what, in your opinion, is the importance of particular types of singular point elements in the agricultural landscape for birds erratic boulder chapel/crucifix puddle	

electricity pylon single tree single shrub post road sign pile of stones hunting platform wind turbine pile of manure haystack scarecrow pile of soil well	negative moderately negative null moderately positive positive I do not know
9. During what season do you think the importance of singular point elements for birds is the greatest?	spring migration breeding season autumn migration winter season
10. Evaluate, in your opinion, what functions do different singular point elements in the agricultural landscape perform for birds (multiple choices allowed) electricity pylon single tree puddle pile of manure single shrub chapel/crucifix erratic boulder hunting platform road sign wind turbine well pile of soil post pile of stones haystack scarecrow	nesting site foraging site roosting site singing post hunting site other
11. How often do you observe birds on particular types of singular point elements in the agricultural landscape? pile of stones puddle chapel/crucifix erratic boulder hunting platform well post single tree electricity pylon single shrub wind turbine pile of manure	very often quite often rarely never I am not sure

haystack scarecrow pile of soil road sign	
12. In your opinion, can singular point elements in the agricultural landscape mitigate the negative impact on birds of the following phenomena: homogenisation of crops land consolidation (increase in the arable area) excessive use of pesticides excessive use of fertilisers increase in the area of GMO crops invasion of alien plant species decline of semi-natural habitats (mid-field scrubs, meadows, fallow lands)	yes partly yes partly no no I do not know
13. List five species of birds that you think most often use singular point elements in the agricultural landscape	text
14. Do you have any observations or comments on singular point elements in the agricultural landscape that were not included in this survey that you would like to share? (optional answer)	text
15. If you want to receive the results of the survey in the form of a copy of the publication, you can enter the e-mail address to which the work will be sent below (optional answer, by providing an e-mail you consent to the storage and processing of your personal data by the Department of Biodiversity of the Institute of Nature Conservation PAS only for the purpose of sending information about the test results)	text

Supporting Information

Fig. S1. The use of singular trees as nesting sites for corvids. These nests may later be used by birds of prey or owls. A small group of young trees with a magpie *Pica pica* nest. 11 Januray 2014, Zaczarnie, Poland.

Fig. S2. Singular trees may also mediate predation. Corvids and many birds of prey foraging on rodents use trees as perching sites. A hooded crow *Corvus cornix* and magpie *Pica pica* are visible using this tree as a perch. Górno Wielkie, Southern Poland.

Supporting Information

Fig. S3. Singular tree in farmland near Tarnów (Poland) with red-backed shrike *Lanius collurio* in flight nearby. Singular trees may determine occurrence of farmland species such as grey shrike *Lanius excubitor* or common kestrel *Falco tinninculus*, and non-farmland species such as chaffinch *Fringilla coelebs*, great tit *Parus major* and blue tit *Cyanistes caeruleus*.

Fig. S4. Singular fruiting trees are important foraging sites for frugivorous species such as fieldfare *Turdus pilaris*, blackbird *Turdus merula*, corvids and tits. Brzozowka near Tarnów, southern Poland.

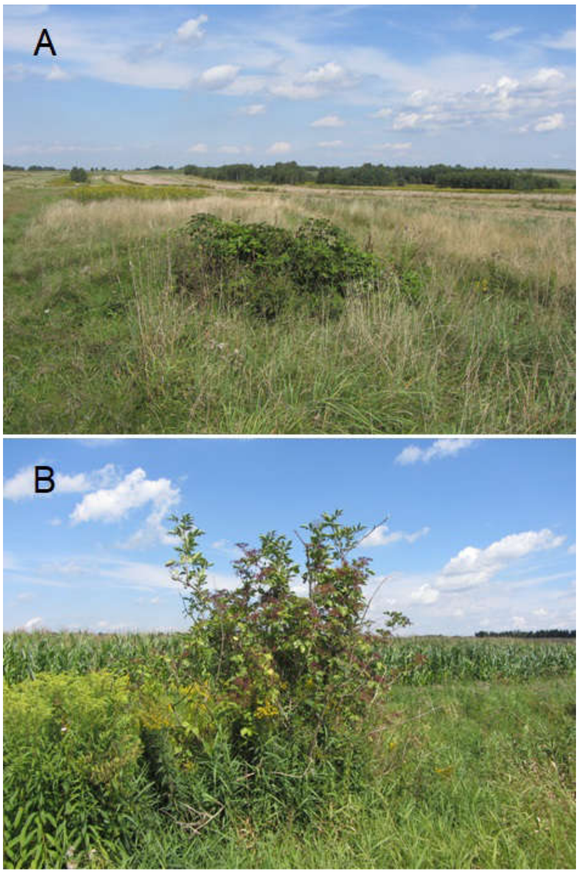


Fig. S5. Singular shrubs are perhaps the most important nesting site for many farmland birds such as common whitethroat *Sylvia communis*, red-backed shrike *Lanius collurio*, marsh warbler *Acrocephalus palustris*, whinchat *Saxicola rubetra*, African stonechat *Saxicola torquata*, yellowhammer *Emberiza citrinella* and several typically non-farmland species such as Eurasian blackcap *Sylvia atricapilla* or blackbird *Turdus merula*. If they are fruit-bearing shrubs such as elderberry *Sambucus nigra* (B), they may also contribute to the occurrence of fruit-eating birds that disperse seeds across the landscape. Wola Rzędzińska near Tarnów southern Poland (A), Lisia Góra near Tarnów, southern Poland (B).

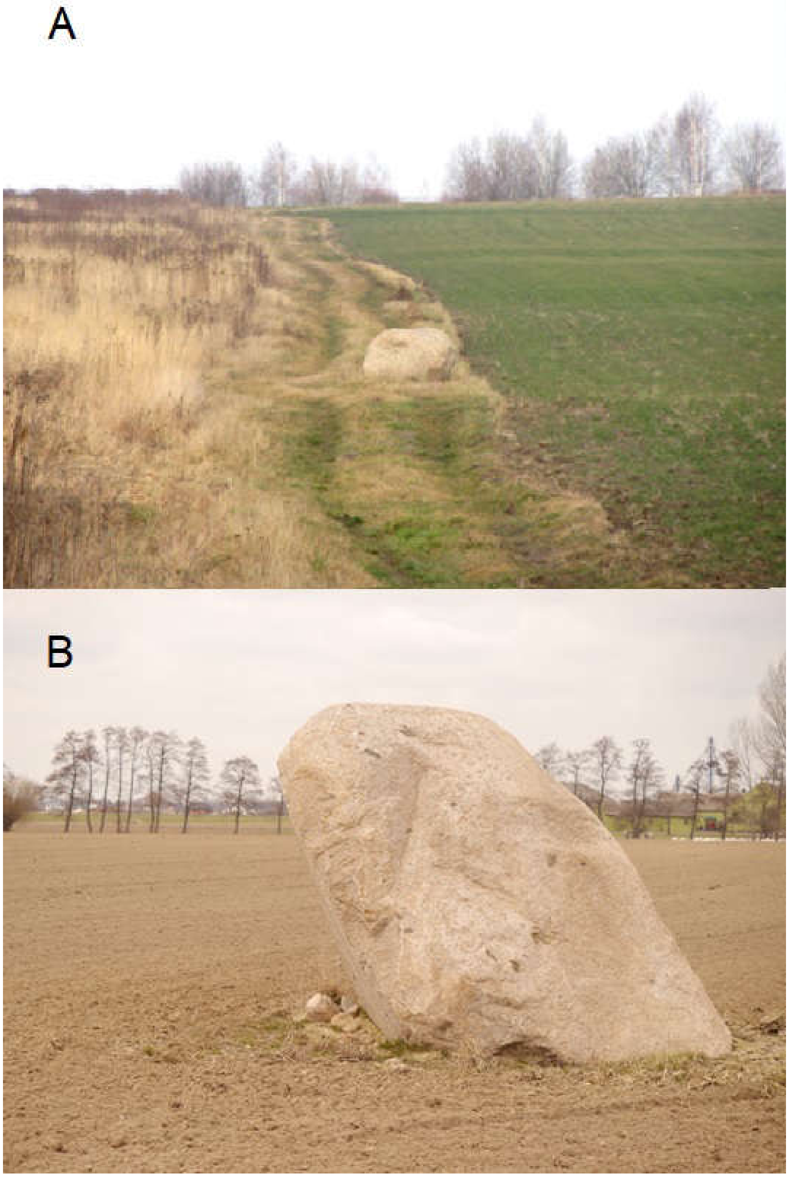


Fig. S6. Boulders and stones, especially in piles, may be an element preferred by some ground-nesting species. They are also used by some birds of prey as sites for consuming prey. Wola Rzędzińska near Tarnów, southern Poland (A) and Tanibórz near Poznań, western Poland (B).

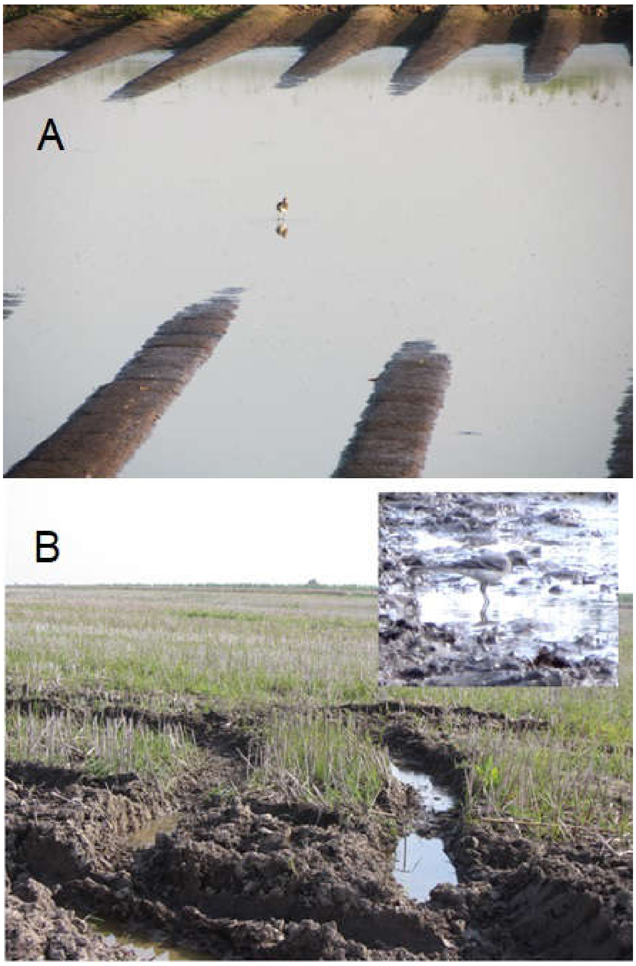


Fig. S7. Puddles constitute a temporary microhabitat that determines the occurrence of some farmland (e.g. white storks *Ciconia ciconia*) and non-farmland migratory species such as waders and shorebirds. Common greenshank *Tringa nebularia* (A) and white wagtail *Motacilla alba* (B) in puddles formed in arable fields in southern Poland in Kwikow and Zaczarnie, near Tarnów.

Fig. S8. Electricity pylons located inside extensive arable fields can introduce valuable microhabitats within the crops, in contrast to other measures such as field margins. Brzezie near Kraków, southern Poland.

Fig. S9. The microhabitat surrounding electricity pylons is important for the occurrence of many species (Tryjanowski *et al*., 2014). Kocmyrzów near Kraków, southern Poland.

Fig. S10. Electricity pylons can act as a hunting perch for sit-and-wait predators. A common kestrel *Falco tinnunculus* sitting on pylon in a field near Gowarzewo, western Poland.

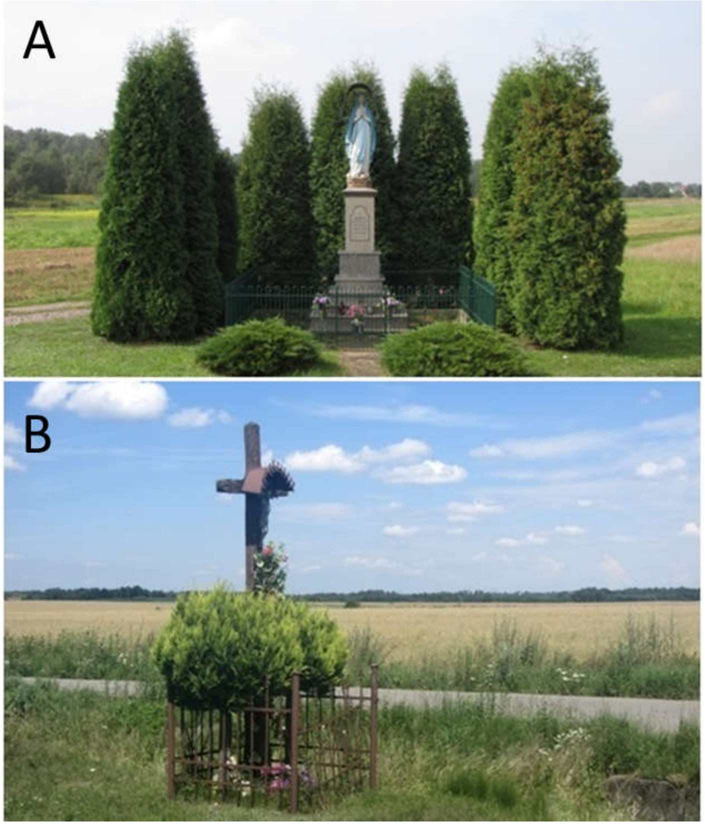


Fig. S11. Spiritual sites are a diverse group of singular point elements that offer nesting sites for species such as greenfinch *Chloris chloris*, common linnet *Linaria cannabina*, yellowhammer *Emberiza citrinella*, white wagtail *Motacilla alba* and European serin *Serinus serinus*. Wola Rzędzińska (A) and Stare Żukowice (B), both near Tarnów, southern Poland.

Supporting Information

Fig. S12. Hunting platforms may provide hunting sites for birds such as the red-backed shrike *Lanius collurio*. Wola Rzędzińska, southern Poland.

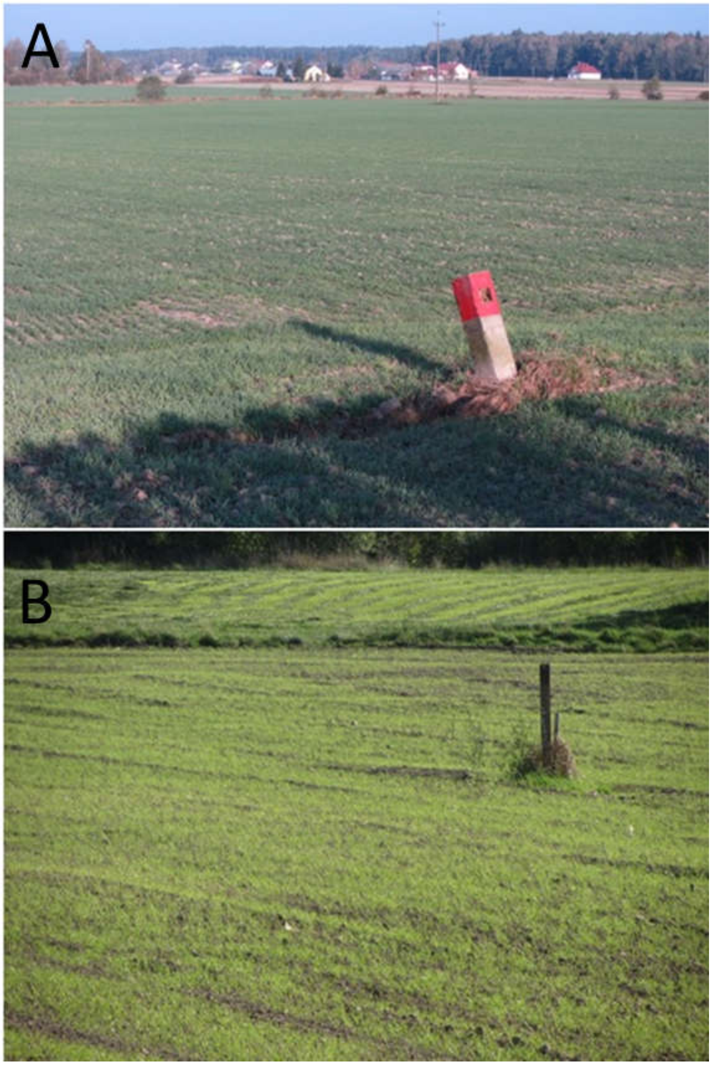


Fig. S13. Fence or border posts may be used by birds for perching, resting and singing. Stara Jastrząbka, southern Poland (A) and Morasko, Poznań, western Poland (B).

Fig. S14. Wells are often present within a fields, and may be used for singing, perching, resting or foraging (e.g. as thrush anvils). Plewiska near Poznań, western Poland.

Fig. S15. Road signs may provide a perching site, here for the whinchat *Saxicola rubetra*. Róża near Dębica, southern Poland.

Fig. S16. In more traditional landscapes, scarecrows are placed in crops in order to discourage some bird species from foraging. In reality, their effectiveness is doubtful as they often constitute perching or resting sites for granivorous species and birds of prey. Luszowice near Tarnów, southern Poland (A) and Karwin near Kraków, southern Poland (B).

Fig. S17. Piles of manure are a food resource for insectivorous birds, for example yellow wagtail *Motacilla flava*. Manure also may be an important roosting site for wintering birds. Dobieżyn near Buk, western Poland.

Fig. S18. A pile of stones and debris with a yellow wagtail *Motacilla flava* on the top. Dobieżyn near Buk, western Poland.

Fig. S19. A pile of lime with a yellow wagtail *Motacilla flava*. Lime piles may serve as a singing perch and a lookout point for birds. Drużyń near Grodzisk Wielkopolski, western Poland.

Fig. S20. Haystacks are very common elements of agricultural landscapes, appearing in large numbers periodically. Łukowa near Tarnów, southern Poland.

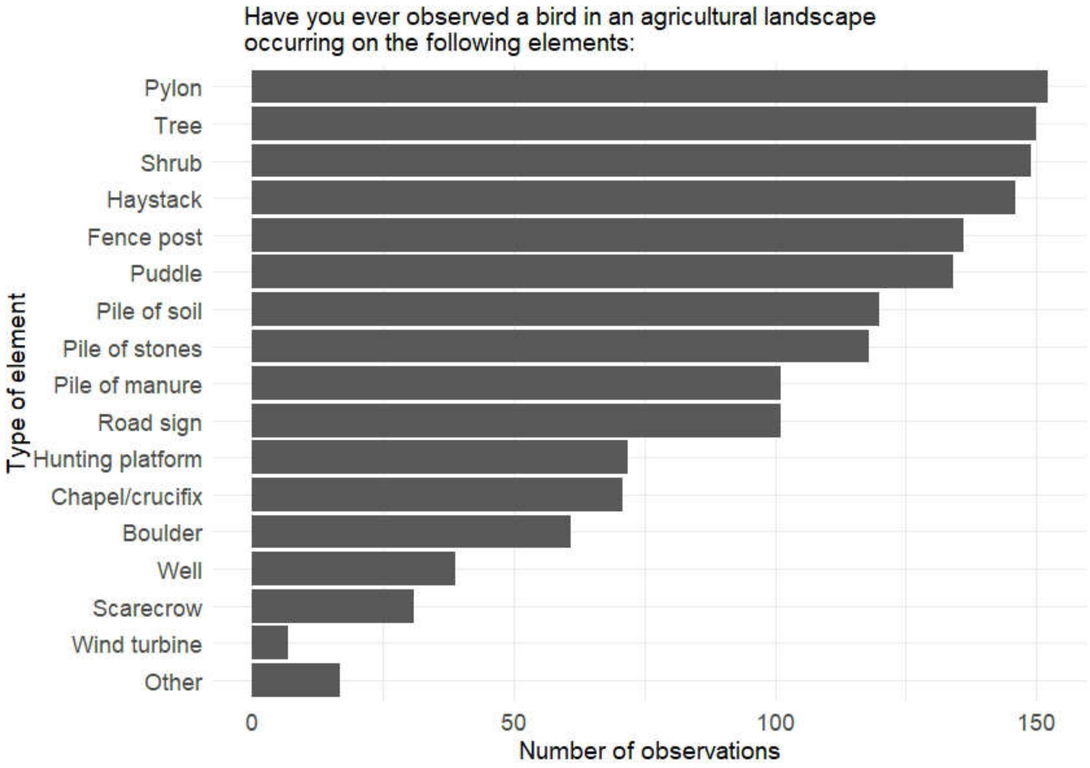


Fig. S21. The answers to question 7 from our online survey where respondents were to indicate all the elements on which they had observed a bird at least once.

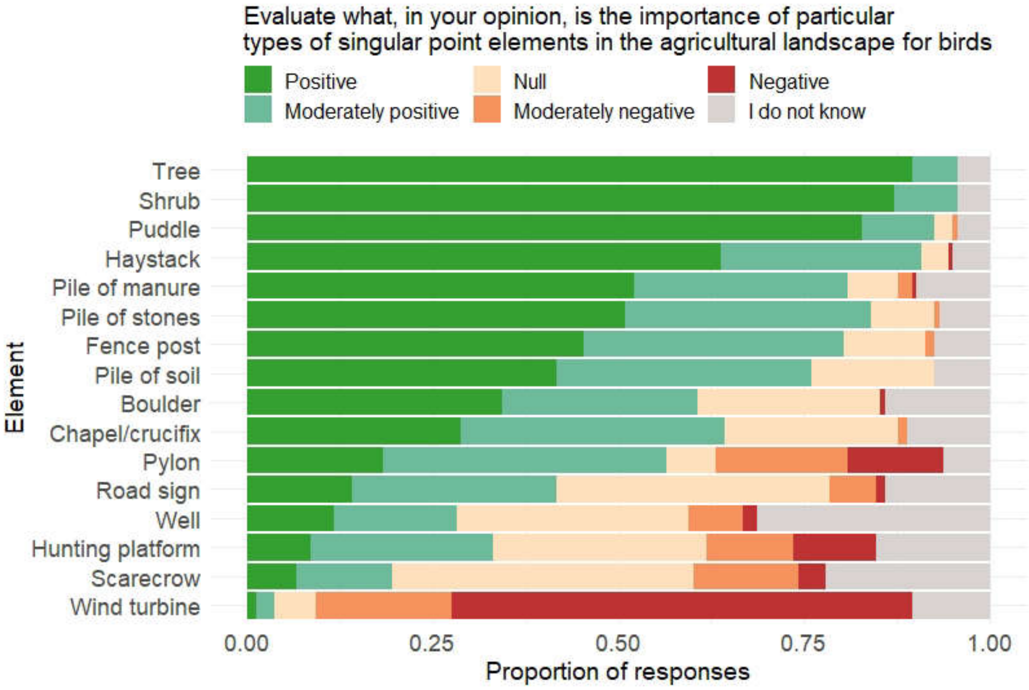


Fig. S22. The answers to question 8 showing the opinion of respondents about the importance of particular types of point elements for birds.

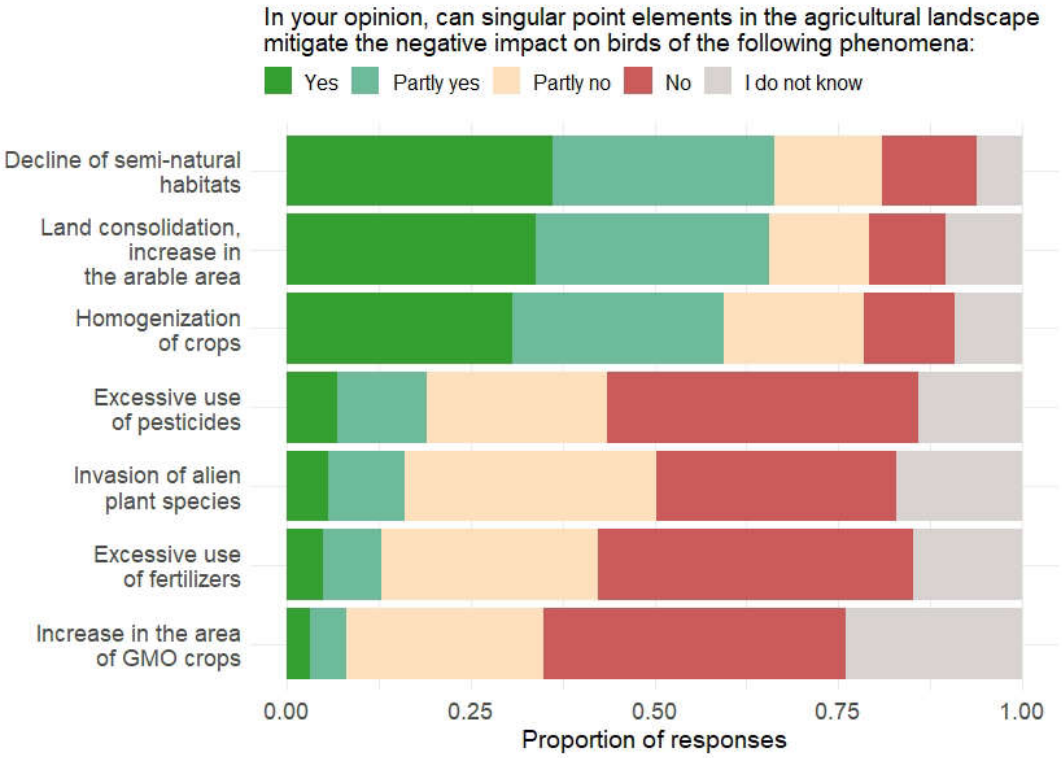


Fig. S23. The answers to question 12 showing the opinion of respondents regarding the ability of singular point elements in an agricultural landscape to overcome several negative phenomena.

Supporting Information

Table S2. A list of species which, in the opinion of the respondents, most often use singular point elements in agricultural landscape.

No.	Species	Frequency	No.	Species	Frequency
1	*Buteo buteo*	116	43	*Corydalla campestris*	2
2	*Lanius collurio*	79	44	*Haliaeetus albicilla*	1
3	*Emberiza citrinella*	76	45	*Circus aeruginosus*	1
4	*Falco tinnunculus*	56	46	*Circus cyaneus*	1
5	*Emberiza calandra*	55	47	*Spinus spinus*	1
6	*Lanius excubitor*	49	48	*Erythrina erythrinus*	1
7	*Motacilla flava*	30	49	*Chloris chloris*	1
8	*Sturnus vulgaris*	27	50	*Pyrrhula pyrrhula*	1
9	*Alauda arvensis*	24	51	*Curruca nisoria*	1
10	*Ciconia ciconia*	22	52	*Milvus milvus*	1
11	*Oenanthe oenanthe*	18	53	*Coracias garrulus*	1
12	*Corvus corax*	16	54	*Gallinago gallinago*	1
13	*Motacilla alba*	16	55	*Buteo rufinus*	1
14	*Saxicola rubetra*	16	56	*Lullula arborea*	1
15	*Pica pica*	14	57	*Muscicapa striata*	1
16	*Corvus cornix*	12	58	*Delichon urbicum*	1
17	*Saxicola rubicola*	11	59	*Curruca curruca*	1
18	*Passer domesticus*	11	60	*Athene noctua*	1
19	*Columba palumbus*	9	61	*Coturnix coturnix*	1
20	*Passer montanus*	9	62	*Strix aluco*	1
21	*Garrulus glandarius*	8	63	*Limosa limosa*	1
22	*Sylvia communis*	7	64	*Falco peregrinus*	1
23	*Phoenicurus ochruros*	6	65	*Troglodytes troglodytes*	1
24	*Galerida cristata*	5	66	*Carduelis carduelis*	1
25	*Linaria cannabina*	5	67	*Chroicocephalus ridibundus*	1
26	*Vanellus vanellus*	4	68	*Anthus trivialis*	1
27	*Upupa epops*	4	69	*Streptopelia turtur*	1
28	*Accipiter gentilis*	4	70	*Asio otus*	1
29	*Clanga pomarina*	4	71	*Merops apiaster*	1
30	*Streptopelia decaocto*	5		Unspecified	
31	*Phasianus colchicus*	3	72	Paridae	10
32	*Perdix perdix*	3	73	*Motacilla* sp.	8
33	*Turdus pilaris*	3	74	*Lanius* sp.	3
34	*Buteo lagopus*	3	75	*Columba* sp.	3
35	*Emberiza hortulana*	3	76	*Hirundo* sp.	3
36	*Parus major*	4	77	Strigiformes	2
37	*Hirundo rustica*	2	78	*Circus* sp.	1
38	*Corvus frugilegus*	2	79	*Anthus* sp.	2
39	*Turdus merula*	2	80	*Luscinia* sp.	1
40	*Accipiter nisus*	2	81	Larinae	1
41	*Schoeniclus schoeniclus*	2	82	Passeriformes	1
42	*Erithacus rubecula*	2	83	Raptors	1

Oświadczenie Kandydata o zakresie wkładu merytorycznego w publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej

Stopień naukowy, imię i nazwisko Kandydata
Mgr inż. Sylwia Pustkowiak

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z. M., Tryjanowski, P., & Skórka, P. (2021). Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews*, *96*(4), 1386-1403.

Mój udział był następujący:

Merytoryczny udział w publikacji:

Jestem głównym autorem i uczestniczyłam w powstawaniu jej założeń metodycznych. Realizowałam główną część badań literaturowych, a także przeprowadziłam wszystkie analizy, opracowanie statystyczne wyników oraz ich prezentację graficzną. Przygotowałam pierwszą wersję manuskryptu, a następnie naniosłam poprawki zasugerowane przez współautorów. Jako autor korespondencyjny uczestniczyłam we wszystkich etapach procesu redakcyjnego.

Procentowy udział w publikacji: **65%**

Sylwia Pustkowiak

27.06.2022

....

(data, podpis Kandydata)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr Zbigniew Kwieciński

Zakład Ekologii i Antropologii, Instytut Biologii, Uniwersytet Szczeciński, Wąska 13, 71-415, Szczecin, Polska

Zakład Biologii i Ekologii Ptaków, Instytut Biologii Środowiska, Wydział Biologii, Uniwersytet im. Adama Mickiewicza, Uniwersytetu Poznańskiego 6, 61-614 Poznań

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z. M., Tryjanowski, P., & Skórka, P. (2021). Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews*, *96*(4), 1386-1403.

Mój udział był następujący:

Merytoryczny udział w publikacji:

Udzielałem krytycznych uwag i sugestii podczas tworzenia koncepcji badań, a także w całym procesie powstawania pracy.

Procentowy udział w publikacji: **5%**

Zbigniew Kwieciński

15.06.2022

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr Magdalena Lenda

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z. M., Tryjanowski, P., & Skórka, P. (2021). Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews*, *96*(4), 1386-1403.

Mój udział był następujący:

Merytoryczny udział w publikacji:

Udzielałam krytycznych uwag i sugestii podczas tworzenia koncepcji badań, a także w całym procesie powstawania pracy.

Procentowy udział w publikacji: **5%**

24.06.22 Magdalena Lenda

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr hab. Michał Żmihorski prof. IBS PAN

Instytut Biologii Ssaków Polskiej Akademii Nauk, ul. Stoczek 1, 17-230 Białowieża, Polska

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z. M., Tryjanowski, P., & Skórka, P. (2021). Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews*, *96*(4), 1386-1403.

Mój udział był następujący:

Merytoryczny udział w publikacji:

Udzielałem krytycznych uwag i sugestii podczas tworzenia koncepcji badań, a także w całym procesie powstawania pracy.

Procentowy udział w publikacji: **5%**

15/06/2022

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr Zuzanna M. Rosin

Zakład Biologii i Ekologii Ptaków, Instytut Biologii Środowiska, Wydział Biologii, Uniwersytet im. Adama Mickiewicza, Uniwersytetu Poznańskiego 6, 61-614 Poznań

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z. M., Tryjanowski, P., & Skórka, P. (2021). Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews*, *96*(4), 1386-1403.

Mój udział był następujący:

Merytoryczny udział w publikacji:

Brałam udział w tworzeniu koncepcji badań oraz udzielałam krytycznych uwag i sugestii w całym procesie powstawania pracy.

Procentowy udział w publikacji: **5%**

15.06.2022 Zuzanna Rosin
....
(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

Prof. dr hab. Piotr Tryjanowski

Wydział Medycyny Weterynaryjnej, Katedra Zoologii, Uniwersytet Przyrodniczy w Poznaniu, Wojska Polskiego 71 C 60-625 Poznań

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z. M., Tryjanowski, P., & Skórka, P. (2021). Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews*, *96*(4), 1386-1403.

Mój udział był następujący:

Merytoryczny udział w publikacji:

Brałem udział w tworzeniu koncepcji badań oraz udzielałem krytycznych uwag i sugestii w całym procesie powstawania pracy.

Procentowy udział w publikacji: **5%**

KIEROWNIK
KATEDRY ZOOLOGII
15.06.2022
prof. dr hab. Piotr Tryjanowski

....

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr hab. Piotr Skórka prof. IOP PAN

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., Rosin, Z. M., Tryjanowski, P., & Skórka, P. (2021). Small things are important: the value of singular point elements for birds in agricultural landscapes. *Biological Reviews*, *96*(4), 1386-1403.

Mój udział był następujący:

Merytoryczny udział w publikacji:

Brałem udział w tworzeniu koncepcji badań oraz udzielałem krytycznych uwag i sugestii w całym procesie powstawania pracy.

Procentowy udział w publikacji: **10%**

27.06.2022

....

(data, podpis współautora)

The scale-dependent association between bird diversity and singular point elements in agricultural landscapes (SPEL) differing in management intensity

Sylwia Pustkowiak[1*], Zbigniew Kwieciński[2,3], Magdalena Lenda[1], Michał Żmihorski[4], Piotr Skórka[1]

[1]Institute of Nature Conservation, Polish Academy of Sciences, Mickiewicza 33, 31-120, Kraków, Poland

[2]Department of Ecology and Anthropology, Institute of Biology, University of Szczecin, Wąska 13, 71-415, Szczecin, Poland

[3]Department of Avian Biology and Ecology, Institute of Environmental Biology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland

[4]Mammal Research Institute, Polish Academy of Sciences, ul. Stoczek 1, 17-230 Białowieża, Poland

*corresponding author e-mail: sylwia.pustkowiak@gmail.com

telephone: +48 663 272 661

author's ORCID: 0000-0003-0175-4819

word count: 8727

Abstract

Farmland birds are indicators of biodiversity but their numbers are declining across Europe. Singular point elements in a landscape (SPEL; e.g., singular trees, shrubs, and chapels) provide basic resources for different species, thus may increase bird diversity. We assessed the associations between the number and types of SPEL and bird diversity and species composition at two spatial scales in agricultural landscapes differing in management intensity. The study was conducted in two regions: southern Poland (SouthPL, less intensive management) and western Poland (WestPL, more intensive management). We performed bird counts during the breeding season at two spatial scales: landscape (1 km^2 squares) and point scale (round plots 100 m in radius) with a selected SPEL. At the landscape scale, species richness was positively associated with the number of SPEL in SouthPL, but not in WestPL. Ordination analysis showed that pylons and trees in SouthPL and shrubs, pylons, and piles of manure in WestPL contributed the most to the species composition. At the point scale, more species with higher abundance were found next to the trees, pylons, shrubs, and chapels than at the reference points in both regions. Ordination analysis at this scale showed that trees and chapels in SouthPL and chapels in WestPL contributed the most to the species composition. This is the first empirical evidence of an association between SPEL numbers, types, and farmland bird populations. SPEL is positively associated with bird diversity at the local scale but is less obvious at the landscape scale. Maintaining or planting SPEL may be a low-cost measure to increase local bird diversity in European farmlands.

Keywords: agriculture; biodiversity; landscape ecology; landscape features; scattered shrubs; scattered trees

1. Introduction

Europe has experienced a drastic decline in farmland biodiversity and the disruption of many ecosystem services (Pe'er et al. 2014; Emmerson et al. 2016). Farmland birds, a group that performs numerous functions in agricultural ecosystems (Gregory et al. 2005) declined severely in Europe, and this effect was significantly greater in the western part of the continent (Krebs *et al.*, 1999; Donald, Green and Heath, 2001; Donald *et al.*, 2006; Tryjanowski et al. 2011). The main causes of this decline are an intensification of agriculture, changes in crop types, introduction of new methods of crop production, use of various chemicals which all simplify and homogenise the landscape, reduce structural diversity of bird habitats, and deplete of food resources (Krebs et al. 1999; Benton et al. 2003; Tscharntke et al. 2005; Skórka et al. 2013). Conservation strategies developed to reverse this negative trend are aimed at increasing the heterogeneity of the landscape and include less intensive farming, promotion of organic farming, and preservation of natural and semi-natural habitats (Redlich et al. 2018; Martin et al. 2020). This is linked to the idea that greater landscape heterogeneity offers a larger number of niches and resources, thus supporting a larger number of species with different potentially important functions (Benton et al. 2003; Morelli et al. 2013; Boesing et al. 2017). Moreover, the effect of heterogeneity on species richness may vary depending on the spatial scale considered (Pickett and Siriwardena 2011; Tscharntke et al. 2012). Bird diversity was positively related to habitat diversity at small and intermediate spatial scales, whereas variables related to climate were important at large (biogeographical) spatial scales (Būhning-Gaese 1997).

The incorporation of landscape heterogeneity in farmland management should include maintaining a high diversity of habitats or crops and smaller field sizes alongside some linear features, such as hedgerows, field margins, wildflower strips, and ditches (Fahrig *et al.*, 2011; Redlich et al. 2018) at an appropriate spatial scale (Hiron et al. 2013; Gonthier et al. 2014). The Common Agricultural Policy in the European Union (CAP EU) provides payments to farmers to protect the environment on their farmland by adopting environmentally friendly farming practices or maintaining habitats and species important for the EU. The total financial expenditure on agri-environmental payments in the EU from 2007–2013 was over 33 billion EUR (European Network for Rural Development 2014). However, meeting these goals is a very challenging task because of the many socio-economic factors involved in farmland management and obstacles in the incorporation of large-scale conservation actions (Renwick et al. 2014; Siebrecht 2020). Hence, efforts to stop biodiversity loss have largely been unsuccessful (Batáry et al. 2011; Kleijn et al. 2011; Pe'er et al. 2014; Zmihorski et al. 2016).

How then, can we overcome (at least some) obstacles linked with the introduction of costly agri-environmental schemes? Recent concepts of habitat quality highlight the importance of so-called "small natural features" which are sites with ecological importance that are disproportionate to their size, for example rocky outcrops, temporary wetlands, streams or caves (Hunter Jr. 2016; Hunter Jr. et al. 2016). Such small landscape features are also described in the literature as “keystone structures” (Tews et al. 2004), which constitute a biodiversity hotspot; however, because of their small size, these cannot be captured by most of the available land-use statistics. This idea was further specified and developed by introducing the concept of Singular Point Elements in Agricultural Landscape (SPEL) to supplement farmland suitability for birds (Pustkowiak et al. 2021). SPEL are various singular point elements, which are often very small, natural, or man-made structures common to farmland. They may act as infield islands and provide birds with vital resources in crop-dominated matrices, thus supporting the functioning of farmlands. As defined by Pustkowiak et al. (2021), a SPEL must meet the following criteria: (1) its structure is clearly different (usually vertical) from the surrounding flat farmland habitat, that is, in a satellite image it appears as a single point distinguishable from a surrounding landscape matrix; (2) it is very small in size, often below the resolution of most publicly available land cover layers, so that its area is not measured or included in most of the official statistics concerning land use; (3) its size is below the home range of all farmland bird species and, thus, does not provide all the resources needed by an individual. In a previous study (Pustkowiak et al. 2021) we listed 17 types of SPEL (for example, singular trees, shrubs, pylons, chapels, piles of manure, and haystacks; see Fig. S1) of different origins, histories, and temporal dynamics, some of which also have a high cultural value (Hartel et al. 2017; Rolo et al. 2020).

A review of the literature (Pustkowiak et al. 2021) revealed that, despite some SPEL often being mentioned in ecological studies (e.g., trees, shrubs, pylons), other types such as spiritual sites, stones, piles of lime, piles of branches, puddles, hunting platforms, haystack wells, road signs, and fence posts are ignored. There are only few publications in which SPEL have been included in statistical models (Szymkowiak et al. 2014; Elts et al. 2015; Mõisja et al. 2016). The role of trees and shrubs in bird populations is most often described (review in Pustkowiak et al., 2021) and the authors underline numerous functions that trees and shrubs perform to birds, such as provisioning food or nesting sites and supporting hunting and movement through the landscape. Some SPEL (e.g., wind turbines) are associated with negative impacts on bird populations (Graff et al. 2016; Rosin et al. 2016). The role of some SPEL is ambiguous, for example, that of electricity pylons, which can positively affect the species richness of breeding birds (Tryjanowski et al. 2014) while also causing threats associated with collisions and electrocutions (Dwyer et al. 2016; Bernardino et al. 2018). Overall, the role of SPEL in birds is poorly understood and has never been explicitly tested in a comprehensive study in relation to land-use intensity and heterogeneity.

The lack of sufficient empirical data on the role of SPEL in bird populations makes them an undiscovered area of study; consequently, they are mainly omitted in the modelling of habitat suitability. SPEL may be a cheap, easy-to-implement tool for increasing and possibly halting bird diversity loss in farmlands. Various singular point elements commonly appear worldwide at different timescales (Pustkowiak et al. 2021). This diversity may mean that they can perform various functions in birds, but so far, no one has empirically investigated the effect of different types of SPEL in a comprehensive study. Agricultural landscapes may vary in amount and configuration of particular features, elements, and microhabitats as well as management practices and intensification across the world; it was also stated, mainly in Europe, that the success of conservation approaches is landscape-dependent (Tryjanowski et al. 2011). For example, agri-environmental management is more effective in enhancing biodiversity in simple landscapes than in complex landscapes (Batáry et al. 2011). Thus, it is possible that the effect of SPEL may also be landscape-dependent, as isolated trees were found to support more species (including those of conservation concern) in modified landscapes than in reserves (Le Roux et al. 2018). Consequently, there may be a difference between numbers and types of SPEL in landscapes differing in management intensity, and the positive effect of SPEL on bird populations may be higher in a more intensively managed landscape than in a less intensively managed one.

This study is the first to assess how differences in the number and types of SPEL are associated with species richness, abundance, and community composition of birds during the breeding season in more intensively and less intensively managed agricultural landscapes at two spatial scales. We tested the following hypotheses:

1) Presence of SPEL is positively associated with the occurrence and species richness of birds in the farmland both at the landscape and local scale.

2) Different types of SPEL support different species and thus add to total species richness and variation in bird community composition.

3) The positive association between SPEL and farmland birds is stronger (more positive) in an intensively managed landscape than in a less intensively managed one.

All hypotheses were tested on two spatial scales, landscape scale and point count (field) scale, and controlled for the effects of other potentially important variables, such as habitat heterogeneity, field size, and road density. We expected a similar effect of SPEL on birds in less intensively managed and more intensively managed landscapes on a small scale, because of space limitations for species. However, the difference in the effect of SPEL on birds between landscapes differing in management intensity should be pronounced at the landscape scale (1 km^2 quadrat).

2. Materials and methods

2.1.Study site and design

The study was conducted in the two distinct agricultural sites: in the low intensively managed landscape of southern Poland (Lesser Poland Voivodeship, centroid position: 50° 11' 11.763"N 20° 26' 25.714"E, hereafter called SouthPL) and in the more intensively managed landscape of western Poland (Greater Poland Voivodeship, study sites in two clusters in environs of Poznań, centroid 1 position: 52° 14' 55.194"N 16° 33' 32.793"E, centroid 2 position: 52° 16' 9.561"N 17° 17' 12.021"E, hereafter WestPL). The two regions, SouthPL and WestPL, were more than 300 km apart (Fig. S2).

Within the two regions, we conducted two separate bird surveys: at the landscape scale in 2016 and at the point scale in 2018 and 2020 (e.g. Skórka et al., 2013). For the landscape-scale survey, we designated 50 study plots, 1 × 1 km each, differing in the number and types of singular point elements (26 plots in SouthPL, 24 in WestPL). The average distance between the two closest plots was 6.37 km (min 2.25 km, max 25.92 km). For the point-scale approach we have selected 128 SPEL of 4 types: 32 trees (12 SouthPL, 20 WestPL), 34 shrubs (14 SouthPL, 20 WestPL), 31 pylons (11 SouthPL, 20 WestPL) and 31 chapels (11 SouthPL, 20 WestPL) to conduct point-counts of birds within the closest vicinity of an element. As a control site, we determined 32 points within the fields with no SPEL (13 in the SouthPL, 19 in WestPL). Because many elements are located along roads, which may have a negative impact on birds (Benítez-López et al. 2010) we selected 33 additional points along roads with no SPEL (12 in SouthPL and 21 in WestPL) to account for the effect of road presence. The average distance between the two closest points was 1.4 km (min 0.27 km, max 10.6 km). The following criteria were followed when selecting the study areas: the number of SPEL was possibly weakly or not correlated with the habitat heterogeneity (crops and land cover types) at the landscape scale; there were possibly no other point elements than this one surveyed in the 100-m radius at the point-scale; and there was low share of forested area (preferably no larger than 1%) and settlements (preferably no larger than 5%) in both scales.

2.2.Field procedure at a landscape-scale

We performed two bird censuses in each plot during the breeding season in 2016: the first between 15 April and 15 May and the second between 16 May and 15 June. Field surveys were carried out in fine weather from dawn to 11 a.m., and each plot was surveyed for one hour during which the observer walked through a plot evenly using available roads, paths and balks. We counted all birds except those flying directly at a high altitude (probably migratory and not associated with the plot). We recorded whether a given individual was seen on a singular element (e.g., sitting or foraging) or apart. During the second census, we counted all the singular point elements within each plot. Because particular elements were often spaced apart at different distances, it is sometimes difficult to distinguish singular elements from rows or groups of elements. Therefore, we considered a singular point element as separated from the other elements by a distance equal to or greater than its height (Fig. S3). The land-use structure of each plot was measured as a percentage cover for each land-use type.

2.3.Field procedure at a point-scale

We performed two 10-min long bird counts at each study point during the spring of 2018 (WestPL) and 2020 (SouthPL), the first between 15 April and 15 May and the second between 16 May and 15 June. The birds were counted within a 100-m radius from the observation point set 50 m apart from the element (we did not get to the element itself, so as not to scare off the birds sitting on it). Other conditions were similar to those from the landscape-scale approach (fine weather, survey hours, and exclusion of high-flying migrants). As in highly developed areas, it was sometimes difficult to designate the point elements (especially spiritual sites) that are not surrounded by other elements; therefore, we counted all the SPEL within a 200-m radius from the observational point (excluding the surveyed one) to include their number as a covariate. We noted the percentage cover of land use types within a 100-m radius.

2.4.Statistical analysis

For each 1-km^2 plot and 3.1-ha circular plot (count point) we calculated: (1) mean field size using a layer with a cadastral division from the geoportal website (Main Office of Geodesy and Cartography 2017), (2) the total length of roads, and (3) the landscape heterogeneity expressed as a Simpson's Diversity Index based on share of different land use types using "vegan" package (Oksanen et al. 2020) in R (R Core Team 2021).

We fitted eight generalised additive models (GAMs) using "mgcv" package (Wood 2017) with negative binomial distribution and smoothing parameter selected using restricted maximum likelihood method ("REML") explaining bird species richness (two visits pooled) and bird abundance (the maximum numbers of each species from the two visits). We performed separate models for the two regions, as they differ markedly in agricultural management, chemical use, and landscape composition (GUS Statistics Poland 2020). In GAMs at a landscape scale, our major explanatory variable was a smooth function of the total number of SPEL. In GAMs for point scale, our main explanatory variables were point type (a categorical explanatory variable with six levels: four element types and two control sites, point without SPEL at road and a point without SPEL located in the field with the latter set as a reference level). We used the following explanatory variables for both spatial scales: habitat heterogeneity, mean field size, and the total length of roads. In GAMs for the landscape scale, we also included a number of distinct SPEL types within each plot as a linear predictor. On a point-scale, we included an additional smooth function—the number of all remaining SPEL (excluding surveyed elements) within a 200-m radius. Within each model, we controlled the effect of possible spatial autocorrelation, including the coordinates of plots/points as an interaction of splines.

Furthermore, to understand how SPEL adds to the variation in species composition, we performed canonical correspondence analysis implemented in Canoco 5 (Šmilauer and Lepš 2014) using the log-transformed (log[10y+1]) maximum number of individuals of the two bird counts for each species as the response (rare species downweighted). Separate CCA models for the two regions and the two scales were performed. In a landscape-scale first CCA, the number of SPEL of different types within a plot is associated with species composition, considering the other explanatory variables (habitat heterogeneity, road length, and mean field size) and plot coordinates as supplementary variables (to rule out their effect). We reduced the number of SPEL types to the most common ones (total number equalling at least 10 in each region) with a category "other" for rare SPEL, to make constrained analysis possible. The second CCA analysed the relative contribution of the total number of SPEL, habitat heterogeneity, mean field size, and road length to the bird community composition in a landscape plot (keeping their coordinates as a supplementary variable). In a point-scale first CCA explained species composition by the type of surveyed point (six levels: four SPEL types, field control, and road control), with other explanatory variables (habitat heterogeneity, field size, road length, coordinates of a point, and total number of remaining SPEL in a 200-m radius) kept as a supplementary variable. The second CCA model analysed the relative role of all point count types, number of remaining SPEL in a 200-m radius, habitat heterogeneity, field size, and road length to explain variation in species composition. The coordinates of a count point were included as supplementary variables.

In all the above-mentioned CCA models, we looked at the overall significance test of the axes and summarised the effects of the explanatory variables.

3. Results

3.1.Landscape-scale

During both bird counts, we noted a total of 106 species within our study plots (Table S1), 79 in SouthPL and 92 in WestPL (mean 16.8/20.9 per plot in SouthPL/WestPL). In SouthPL, the most abundant species were the common wood pigeon *Columba palumbus*, European starling *Sturnus vulgaris*, Eurasian skylark *Alauda arvensis*, black-headed gull *Larus ridibundusi,* and yellow wagtail *Motacilla flava*. In West PL, the most abundant species were Eurasian skylark, European starling, yellow wagtail, barn swallow *Hirundo rustica*, and corn bunting *Emberiza calandra*. Both regions differed in the amount, frequency, and diversity of SPEL (Table S2). In Małopolska (SouthPL) we recorded on average 34 ± 28 (SD) SPEL per plot (min = 0, max = 98) and 27.8 ± 16 (SD) SPEL per plot in Wielkopolska (WestPL, min = 7, max = 71). In SouthPL, we recorded an average of 3.9 ± 2 (SD) different SPEL types per plot, while in WestPL, 6.5 ± 2 (SD) types per plot were recorded.

The GAM model for SouthPL revealed that there was a significant positive association between the number of SPEL and bird species richness, while the number of SPEL types was negatively associated with species richness (Table1, Fig. 1a–b). An analogous model for bird abundance did not show any significant associations between the explanatory variables and response (Table 1). The GAM conducted for WestPL did not show any significant association between explanatory variables or bird species richness or abundance (Table 1).

Tests on ordination axes revealed that there was a significant association between different types of SPEL and species composition in both regions when other explanatory variables were kept as supplementary variables (SouthPL: first axis pseudo-F = 2.5, p = 0.002; pseudo-F = 1.3, p = 0.024; WestPL: first axis pseudo-F = 1.8, p = 0.006; all axes pseudo-F = 1.1, p = 0.062; Fig. 2a–b). Different SPEL types in SouthPL explained 33% of the variation in bird community composition, and the SPEL that significantly contributed to the ordination were pylons (8% of explained variation, pseudo-F = 2.1, p = 0.002), trees (7.6% of explained variation, pseudo-F = 2.0, p = 0.002), and other (rare) SPEL (7.6% of explained variation, pseudo-F = 2.0, p = 0.004). In WestPL, different types of SPEL explained 46.4% of the total variation in bird abundance, and SPEL significantly associated with species composition were shrubs (6.4% of explained variation, pseudo-F = 1.5, p = 0.02), pylons (6% of explained variation, pseudo-F = 1.4, p = 0.05), and piles of manure (5.9% of explained variation, pseudo-F = 1.4, p = 0.048). When all explanatory variables were included in the CCA, their effect on bird species composition in the SouthPL was significant (first axis pseudo–F = 2.4, p = 0.002; all axes pseudo-F = 1.3, p = 0.016; Fig. 2c) and accounted for 20% of the explained variation. Variables that contributed significantly to ordination were the total number of SPEL (9.6% of explained variation, pseudo-F = 2.5, p = 0.002) and marginally the length of roads (5.9% of explained variation, pseudo-F = 1.5, p = 0.05). Analogous CCA for the association between all explanatory variables and bird species composition in WestPL gave only marginally significant results in the test for all ordination axes (first axis pseudo–F = 1.5, p = 0.132; all axes pseudo-F = 1.2, p = 0.058; Fig. 2d), with explanatory variables explaining 19.6% of the variation in bird species composition. The variables that contributed significantly to the ordination were field size (6.2% of the explained variation, pseudo-F = 1.4, p = 0.03) and crop heterogeneity (5.9% of the explained variation, pseudo-F = 1.4, p = 0.044).

3.2.Point-scale

During both bird counts, we noted a total of 65 species at our study points in SouthPL and 74 in WestPL (mean 3.8/4.9 species per point in SouthPL/WestPL). In SouthPL, the most abundant species were European starling, rook *Corvus frugilegus*, yellow wagtail, common wood pigeon, and yellowhammer *Emberiza citrinella*. In WestPL, the most abundant species were European starling, Eurasian skylark, barn swallow, common wood pigeon, and the house sparrow *Passer domesticus*. In both regions, there were significantly higher species richness and abundance of birds at sites with pylons as compared to the control points (Table 2, Fig. 3a–d). Sites with trees were associated with higher species richness and abundance in SouthPL but only with species richness in WestPL (Table 2, Fig. 3a–c). Sites with chapels hosted more bird species in West PL (Fig. 3b). Around singular shrubs, there were significantly more bird species in WestPL and a higher abundance in SouthPL than in the open fields (Fig. 3b–c). The road was the site with significantly fewer bird species than fields in the SouthPL (Fig. 3a). Of the other terms included in GAM, a positive association with the species richness and abundance in SouthPL showed both the total number of remaining SPEL in a 200-m radius and habitat heterogeneity (Table 2, Fig. 4a–d).

The CCA revealed a significant association between the type of point surveyed (with other explanatory variables set as supplementary) and the bird community composition in both regions (SouthPL: first axis pseudo-F = 2.9, p = 0.002; all axes pseudo-F = 1.7, p = 0.002; WestPL: first axis pseudo-F = 3.0, p = 0.002; all axes pseudo-F = 1.5, p = 0.002; Fig. 5a–b). In SouthPL, different types of count points explained 11% of the total variation in bird community composition, and the point types with a significant contribution to the species ordination were sites in fields (3.2% of explained variation, pseudo-F = 2.4, p = 0.002), trees (3.1% of explained variation, pseudo-F = 2.2, p = 0.002), and chapels (2.5% of explained variation, pseudo-F = 1.8, p = 0.01). In WestPL, different types of bird count points accounted for 6% of the total variation in species composition, and the point types having a significant effect on ordination were chapels (1.7% of explained variation, pseudo-F = 2.1, p = 0.004) and fields (1.6% of explained variation, pseudo-F = 1.9, p = 0.006). Adding all other explanatory variables (habitat heterogeneity, field size, and road length) also resulted in significant species ordination (SouthPL: first axis pseudo-F = 2.9, p = 0.002; all axes pseudo-F = 1.4, p = 0.002; WestPL: first axis pseudo-F = 3.6, p = 0.002; pseudo-F = 1.3, p = 0.006; Fig. 5c–d). All these explanatory variables (point types and other explanatory variables) accounted for 16.7% and 9.3% of the explained variation in bird species composition in SouthPL and WestPL, respectively. Variables with significant effects on species composition in SouthPL were of the point types: fields (3.2% of explained variation, pseudo-F = 2.4, p = 0.002), trees (3.1% of explained variation, pseudo-F = 2.2, p = 0.002), and chapels (2.5% of explained variation, pseudo-F = 1.8, p = 0.01). In WestPL, apart from chapels and fields, bird community composition was also associated with the overall number of surrounding SPEL (2.3% of explained variation, pseudo-F = 2.8, p = 0.002).

4. Discussion

We recorded a positive association between the presence of SPEL and the number of bird species on a landscape scale in less intensively managed farmland in southern Poland, and also on a point-scale in both studied regions of Poland, where we counted substantially more species with higher abundance around some SPEL than in open fields. Thus, we partially confirm the first hypothesis. Despite the negative association between the number of SPEL types and the number of species in SouthPL being in opposition to our second hypothesis, CCA analyses showed that in both regions and at two spatial scales, different SPEL types contributed to variation in species composition, indicating that certain species are associated with specific SPEL types (e.g., *Upupa epops* with piles of branches, *Vanellus vanellus* with water holes, *Anthus pratensis* with border posts). Also, certain species were negatively associated with SPEL in both regions (e.g., *Alauda arvensis, Perdix perdix).* This may partially explain the negative association between the number of SPEL types and species richness in SouthPL. At the landscape scale, there are different bird associations related to the presence of pylons in both regions—trees in the SouthPL, and piles of manure and shrubs in WestPL. At a point scale, we found distinct species assemblages close to the chapels (e.g. *Serinus serinus*, *Parus major*, *Phoenicurus ochruros*) and within the open fields (e.g. *Vanellus vanellus, Grus grus*) in both regions and around trees in SouthPL (e.g. *Muscicapa striata, Sylvia borin* or *Oriolus oriolus*). The significant contribution of the total number of SPEL to the CCA ordination in SouthPL is also a confirmation of our hypotheses and is in line with earlier findings. For instance, Tews et al. (2004) proposed that species diversity may be linked to the presence of specific "keystone structures", which may be a structural feature or arrangement of vegetation. Thus, the concept of SPEL may be an extension of this definition, as we also found an association between SPEL and bird diversity.

Birds responded differently to the presence of SPEL in western countries than in southern Poland. First, on a landscape scale, there was only a positive association between the number of SPEL and species richness in SouthPL. One possible explanation is that, in intensive agriculture, the occurrence of SPEL is often associated with field management and infrastructure development, which may have detrimental effects on birds (Donald et al., 2006). This view is supported by the quantitative distribution of SPEL types in both regions (Table S2), as the diversity of SPEL types and the frequency of man-made structures are higher in intensively managed WestPL, so it is difficult to isolate the effect of an element from the impact of agricultural management. Second, the GAM models revealed significant effects on a point scale in both regions. There was substantially higher species richness or abundance around trees, singular shrubs, pylons, and chapels than in open fields in West PL. Similar results (except for chapels) were obtained for SouthPL. In addition, the impact of the overall number of other SPEL (restricted to trees, shrubs, pylons, and chapels) in the 200-m radius from the point count was a significant predictor of species richness and abundance in SouthPL, but the ordination analysis showed that only in WestPL did this this variable contribute significantly to the species composition as compared to other environmental variables. These results make the verification of the third hypothesis ambiguous, but we may infer that, in an intensive landscape, the positive effect of SPEL is confined to its close vicinity. It should also be noted that the proportion of trees, shrubs, and pylons in the overall number of SPEL in SouthPL is almost 90%, while in WestPL, this group accounts for about 60% of all SPEL (Table S2). As the contribution of these elements to bird diversity and abundance was confirmed by point counts and CCA, the effect of other mentioned elements is probably not so strong, which may also explain why the impact of the total number of SPEL on bird diversity is non-significant in WestPL. Because the category “other” comprised very rare SPEL that had a significant effect on ordination in SouthPL at the landscape scale, further studies targeting the less abundant SPEL types may help to evaluate their contribution to bird diversity at larger spatial scales.

In addition to trees and shrubs, whose positive association with birds may be intuitive (and also widely described, see Pustkowiak et al., 2021), the elements that stand out are pylons, chapels, and piles of manure. The first was perceived as a threat to birds due to collision and electrocution risk (Bernardino et al. 2018), but is also used as a perch for singing and hunting or even nesting, and their role was assessed as positive (Tryjanowski et al. 2014). The value of piles of manure has also been reported in the literature (Šálek and Żmihorski 2018); these are a food base for both insectivorous (Orłowski and Karg 2011) and granivorous birds (Orłowski et al. 2014). Chapels, which turned out to be important for the population of birds regardless of the region, have not been described in the literature so far, despite being common in an agricultural landscape in many European countries. As local people mostly care for chapels, that is, they plant conifers and flowers and care for these plants by providing water birds may benefit from additional breeding and foraging sites, which are hardly available in otherwise open landscapes. This is a very good example of the importance of cultural and religious landscape components in biodiversity (Skórka et al. 2018).

Other variables included in the analysis also showed high importance, although some associations were ambiguous in their interpretation. In WestPL GAM models, there was a non-significant negative association between habitat heterogeneity of 1-km^2 plots and species richness and abundance, however, there was a significant contribution of this parameter to species ordination. This suggests that there is a group of species associated with more diverse habitats (e.g., *Acrocephalus scirpaceus* and *Acrocephalus arundinaceus*). In addition, the effect of this predictor on species richness at the landscape scale in SouthPL was also negative, but non-significant, while on the point-scale, the effect was significantly positive both in the case of species richness and abundance. Generally, landscape heterogeneity is expected to favour biodiversity (Benton et al. 2003), but not all species benefit equally. The area-heterogeneity trade-off concept states that the relationship between habitat heterogeneity and species richness is rather unimodal than positive (Allouche et al. 2012). Species occurrence patterns may vary depending on niche width, with a unimodal response of species diversity to the environmental heterogeneity true for generalists. With a narrower niche width, the response was negative as the amount of appropriate habitat decreased and the rate of stochastic extinction increased. In a multi-scale analysis, Pickett and Siriwardena (2011) showed that migrants and farmland specialists, especially ground nesters, are less abundant in a heterogeneous landscape on a 1 km^2 scale. For generalist raptors, this association between occupancy and landscape heterogeneity tends to be quadratic, with the most abundant occupied areas being those with the highest and lowest habitat diversity (Navarro-López and Fargallo 2015). Moreover, the results of landscape heterogeneity studies vary depending on the measure applied, and while considering only the two-dimensional measure of heterogeneity as the percentage cover of certain habitats, we might miss the structure of the landscape that is important for biodiversity. In addition to compositional heterogeneity, configurational heterogeneity may affect biodiversity (Fahrig et al. 2011), which in the agricultural landscape is related to the fragmentation of fields (Šálek, Martin et al. 2021). In this study, the only significant correlation was found between the mean field size and species composition of 1-km^2 plots in WestPL, where a few rare species (e.g. *Tringa ochropus* and *Riparia riparia*) showed a strong preference for larger fields. The association between the length of roads and birds partially followed our prediction. In SouthPL, there was a significant association with bird community composition at the landscape scale. However, at the point-count scale, there were significantly fewer species next to roads than in open fields. The expected negative effect of roads on the landscape scale may be mitigated by the presence of numerous tree rows and hedges along the roads, especially in WestPL (Kujawa 1995), while for point-counts, we selected roads with no such features. Moreover, recent studies have shown that many common bird species may be positively associated with roads (Cooke et al. 2020).

Despite some differences between the scales and regions considered, many observed associations were consistent across analyses. Certain effects were independent of the spatial scale (trees in the SouthPL) and regions (pylons and chapels). Trees are, in turn, the SPEL most often mentioned in the literature, classified as "keystone structures", and are valued for their multifunctionality (Manning et al. 2006). Examples of empirical approaches concerning the effects of trees at different landscape scales (Martin et al. 2009; Fischer et al. 2010; de-Carvalho et al. 2021) show convergent results. The important finding of our study regarding the third hypothesis is that the effect of SPEL on more intensively managed WestPL is more visible on a smaller scale. It is possible that, in an intensively managed landscape, similar bird species are grouped around SPEL; thus, species richness does not increase with the number of SPEL. In contrast, in SouthPL, the impact on species was transferred on a landscape scale, indicating that there were different species at different SPEL. This requires confirmation with further analyses.

Our findings show only general relationships, and further detailed studies linking particular species or groups with particular SPEL are needed. The key to designing conservation actions targeting a specific species is to know exactly which factors species respond to. For instance, pylons and fence posts are often used by birds of prey for hunting, but not for raptors that hunt by surprise and need camouflage, such as northern goshawk (Mirski and Väli 2021). Some open landscape specialists avoid high density of SPEL (Oien et al. 1996; Morgado et al. 2010; Lautenbach et al. 2017; Żmihorski et al. 2018), which is also confirmed by ordination diagrams in this study (e.g., *Coturnix coturnix*, *Perdix perdix*). As certain SPEL are quite rare and it is difficult to verify their exact role in birds, a research experiment involving the manipulation of the abundance of specific elements in the field would be helpful. Further studies using telemetry may evaluate the role of SPEL in species movement and foraging behaviour, as it was assessed for small woody features (tree lines and small wood) and birds of prey (Mirski & Väli, 2021). As SPEL provides different resources for different species (such as food, shelter, and nesting opportunity), it is worth assessing their value in the annual cycle.

5. Conclusions

We found a positive association between the presence of SPEL and the bird species richness on a landscape scale in less intensively managed farmland, and also on a point-scale in less intensively and more intensively managed regions of Poland. Pylons and trees in less intensively managed landscape and shrubs, pylons, and piles of manure in more intensively managed landscape contributed the most to the species composition. At the point scale we found more species with higher abundance next to the trees, pylons, shrubs, and chapels than at the reference points in fields in both regions. The association of SPEL with farmland birds differ between the studied regions, in more intensively managed WestPL their effect is more visible on a smaller scale. Overall, the utility of SPEL is promising for supporting biodiversity with minimal cost and conflict.

Author's contributions

SP, PS, and ML conceived the idea. SP, ZK, MŻ, and PS designed the methodology; SP, ZK, ML, and PS collected the data; SP and PS analysed the data and led the writing of the manuscript. All the authors contributed critically to the drafts and approved the final manuscript for publication.

Acknowledgements

This work was partially financed by a Sonata Bis 4 grant (2014/14/E/NZ8/00165) from the National Science Centre, Poland and through grant funding for PhD students and young scientists received from the Institute of Botany, Polish Academy of Sciences (Kraków, Poland).

References

Allouche O, Kalyuzhny M, Moreno-Rueda G, et al (2012) Area-heterogeneity tradeoff and the diversity of ecological communities. Proc Natl Acad Sci U S A 109:17495–17500. https://doi.org/10.1073/pnas.1208652109

Batáry P, Báldi A, Kleijn D, Tscharntke T (2011) Landscape-moderated biodiversity effects of agri-environmental management: a meta-analysis. Proc R Soc B Biol Sci 278:1894–1902. https://doi.org/10.1098/rspb.2010.1923

Benítez-López A, Alkemade R, Verweij PA (2010) The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. Biol Conserv 143:1307–1316. https://doi.org/10.1016/j.biocon.2010.02.009

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol Evol 18:182–188. https://doi.org/10.1016/S0169-5347(03)00011-9

Bernardino J, Bevanger K, Barrientos R, et al (2018) Bird collisions with power lines: State of the art and priority areas for research. Biol Conserv 222:1–13. https://doi.org/10.1016/j.biocon.2018.02.029

Boesing AL, Nichols E, Metzger JP (2017) Effects of landscape structure on avian-mediated insect pest control services: a review. Landsc Ecol 32:931–944. https://doi.org/10.1007/s10980-017-0503-1

Būhning-Gaese K (1997) Determinants of avian species richness at different spatial scales. J Biogeogr 24:49–60. https://doi.org/10.1111/j.1365-2699.1997.tb00049.x

Cooke SC, Balmford A, Donald PF, et al (2020) Roads as a contributor to landscape-scale variation in bird communities. Nat Commun 11:1–10. https://doi.org/10.1038/s41467-020-16899-x

de-Carvalho M, Prevedello JA, Pardini R, et al (2021) Isolated trees support lower bird taxonomic richness than trees within habitat patches but similar functional diversity. Biotropica 53:213–220. https://doi.org/10.1111/btp.12862

Donald PF, Green RE, Heath MF (2001) Agricultural intensification and the collapse of Europe’s farmland bird populations. Proc R Soc London Ser B Biol Sci 268:25–29. https://doi.org/10.1098/rspb.2000.1325

Donald PF, Sanderson FJ, Burfield IJ, van Bommel FPJ (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. Agric Ecosyst Environ 116:189–196. https://doi.org/10.1016/j.agee.2006.02.007

Dwyer JF, Harness RE, Gerber BD, et al (2016) Power pole density informs spatial prioritization for mitigating avian electrocution. J Wildl Manage 80:634–642. https://doi.org/10.1002/jwmg.1048

Elts J, Tätte K, Marja R (2015) What are the important landscape components for habitat selection of the ortolan bunting Emberiza hortulana in northern limit of range? Eur J Ecol 1:13–25. https://doi.org/10.1515/eje-2015-0003

Emmerson M, Morales MB, Oñate JJ, et al (2016) How agricultural intensification affects biodiversity and ecosystem services. In: Advances in ecological research. Academic Press, pp 43–97

European Network for Rural Development (2014) Rural Development Policy in Figures. Financial and physical indicators. http://enrd.ec.europa.eu/enrd-static/policy-in-action/rural-development-policy-in-figures/rdp-monitoring-indicator-tables/financial-and-physical-indicators/en/financial-and-physical-indicators_en.html. Accessed 1 Mar 2021

Fahrig L, Baudry J, Brotons L, et al (2011) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101–112. https://doi.org/10.1111/j.1461-0248.2010.01559.x

Fischer J, Stott J, Law BS (2010) The disproportionate value of scattered trees. Biol Conserv 143:1564–1567. https://doi.org/10.1016/j.biocon.2010.03.030

Gonthier DJ, Ennis KK, Farinas S, et al (2014) Biodiversity conservation in agriculture requires a multi-scale approach. Proc R Soc B Biol Sci 281:20141358. https://doi.org/10.1098/rspb.2014.1358

Graff BJ, Jenks JA, Stafford JD, et al (2016) Assessing spring direct mortality to avifauna from wind energy facilities in the Dakotas. J Wildl Manage 80:736–745. https://doi.org/10.1002/jwmg.1051

Gregory RD, Van Strien A, Vorisek P, et al (2005) Developing indicators for European birds. Philos Trans R Soc B Biol Sci 360:269–288. https://doi.org/10.1098/rstb.2004.1602

GUS Statistics Poland (2020) Means of production in agriculture in the 2018/19 farming year. Warsaw

Hartel T, Réti K-O, Craioveanu C (2017) Valuing scattered trees from wood-pastures by farmers in a traditional rural region of Eastern Europe. Agric Ecosyst Environ 236:304–311. https://doi.org/10.1016/j.agee.2016.11.019

Hiron M, Berg Å, Eggers S, et al (2013) Bird diversity relates to agri-environment schemes at local and landscape level in intensive farmland. Agric Ecosyst Environ 176:9–16. https://doi.org/10.1016/j.agee.2013.05.013

Hunter Jr. ML (2016) Conserving small natural features with large ecological roles: An introduction and definition. Biol Conserv 211:1–2. https://doi.org/10.1016/j.biocon.2016.12.019

Hunter Jr. ML, Acuña V, Bauer DM, et al (2016) Conserving small natural features with large ecological roles: A synthetic overview. Biol Conserv 211:88–95.

https://doi.org/10.1016/j.biocon.2016.12.020

Kleijn D, Rundlöf M, Scheper J, et al (2011) Does conservation on farmland contribute to halting the biodiversity decline? Trends Ecol Evol 26:474–481. https://doi.org/10.1016/J.TREE.2011.05.009

Krebs JR, Wilson JD, Bradbury RB, Siriwardena GM (1999) The second silent spring? Nature 400:611–612. https://doi.org/10.1038/23127

Kujawa K (1995) Composition and dynamics of wintering bird communities in mid-field woods and woodbelts in Turew (western Poland). Acta Ornithol 29:145–154

Lautenbach JM, Plumb RT, Robinson SG, et al (2017) Lesser prairie-chicken avoidance of trees in a grassland landscape. Rangel Ecol Manag 70:78–86. https://doi.org/10.1016/j.rama.2016.07.008

Le Roux DS, Ikin K, Lindenmayer DB, et al (2018) The value of scattered trees for wildlife: Contrasting effects of landscape context and tree size. Divers Distrib 24:69–81. https://doi.org/10.1111/ddi.12658

Main Office of Geodesy and Cartography (2017) National Integration of Land Registry. In: geoportal.gov.pl. https://integracja.gugik.gov.pl/cgi-bin/KrajowaIntegracjaEwidencjiGruntow

Manning AD, Fischer J, Lindenmayer DB (2006) Scattered trees are keystone structures– implications for conservation. Biol Conserv 132:311–321. https://doi.org/10.1016/j.biocon.2006.04.023

Martin AE, Collins SJ, Crowe S, et al (2020) Effects of farmland heterogeneity on biodiversity are similar to—or even larger than—the effects of farming practices. Agric Ecosyst Environ 288:106698. https://doi.org/10.1016/j.agee.2019.106698

Martin EA, Ratsimisetra L, Laloë F, Carrière SM (2009) Conservation value for birds of traditionally managed isolated trees in an agricultural landscape of Madagascar. Biodivers Conserv 18:2719–2742. https://doi.org/10.1007/s10531-009-9671-x

Mirski P, Väli Ü (2021) Movements of birds of prey reveal the importance of tree lines, small woods and forest edges in agricultural landscapes. Landsc Ecol 36:1409–1421. https://doi.org/10.1007/s10980-021-01223-9

Mõisja K, Uuemaa E, Oja T (2016) Integrating small-scale landscape elements into land use/cover: The impact on landscape metrics' values. Ecol Indic 67:714–722. https://doi.org/10.1016/j.ecolind.2016.03.033

Morelli F, Pruscini F, Santolini R, et al (2013) Landscape heterogeneity metrics as indicators of bird diversity: Determining the optimal spatial scales in different landscapes. Ecol Indic 34:372–379. https://doi.org/10.1016/j.ecolind.2013.05.021

Morgado R, Beja P, Reino L, et al (2010) Calandra lark habitat selection: strong fragmentation effects in a grassland specialist. Acta Oecologica 36:63–73. https://doi.org/10.1016/j.actao.2009.10.002

Navarro-López J, Fargallo JA (2015) Trophic niche in a raptor species: The relationship between diet diversity, habitat diversity and territory quality. PLoS One 10:1–14.

https://doi.org/10.1371/journal.pone.0128855

Oien IJ, Honza M, Moksnes A, Roskaft E (1996) The risk of parasitism in relation to the distance from reed warbler nests to cuckoo perches. J Anim Ecol 65:147–153. https://doi.org/10.2307/5717

Oksanen J, Blanchet, F. Guillaume Friendly M, Kindt R, et al (2020) vegan: Community Ecology Package

Orłowski G, Czarnecka J, Goławski A (2014) Winter diet of Yellowhammers Emberiza citrinella on contemporary farmland: the different contribution of forbs, wild grasses and cereals in semi-natural and agricultural habitats. Bird Study 61:484–495. https://doi.org/10.1080/00063657.2014.954984

Orłowski G, Karg J (2011) Diet of nestling Barn Swallows Hirundo rustica in rural areas of Poland. Open Life Sci 6:1023–1035. https://doi.org/10.2478/s11535-011-0070-4

Pe'er G, Dicks L V., Visconti P, et al (2014) EU agricultural reform fails on biodiversity. Science (80-) 344:1090–1092. https://doi.org/10.1126/science.1253425

Pickett SRA, Siriwardena GM (2011) The relationship between multi-scale habitat heterogeneity and farmland bird abundance. Ecography (Cop) 34:955–969. https://doi.org/10.1111/j.1600-0587.2011.06608.x

Pustkowiak S, Kwieciński Z, Lenda M, et al (2021) Small things are important: the value of singular point elements for birds in agricultural landscapes. Biol Rev 96:1386–1403. https://doi.org/10.1111/brv.12707

R Core Team (2021) R: A language and environment for statistical computing.

Redlich S, Martin EA, Wende B, Steffan-dewenter I (2018) Landscape heterogeneity rather than crop diversity mediates bird diversity in agricultural landscapes. PLoS One 13:e0200438. https://doi.org/10.1371/journal.pone.0200438

Renwick AR, Vickery JA, Potts SG, et al (2014) Achieving production and conservation simultaneously in tropical agricultural landscapes. Agric Ecosyst Environ 192:130–134. https://doi.org/10.1016/j.agee.2014.04.011

Rolo V, Hartel T, Aviron S, et al (2020) Challenges and innovations for improving the sustainability of European agroforestry systems of high nature and cultural value: stakeholder perspectives. Sustain Sci 15:1301–1315. https://doi.org/10.1007/s11625-020-00826-6

Rosin ZM, Skórka P, Szymański P, et al (2016) Constant and seasonal drivers of bird communities in a wind farm: Implications for conservation. PeerJ 4:e2105. https://doi.org/10.7717/peerj.2105

Šálek, Martin, Kalinova K, Daňková R, et al (2021) Reduced diversity of farmland birds in homogenized agricultural landscape: A cross-border comparison over the former Iron Curtain. Agric Ecosyst Environ 321:107628. https://doi.org/10.1016/j.agee.2021.107628

Šálek M, Żmihorski M (2018) Manure heaps attract farmland birds during winter. Bird Study 65:426–430. https://doi.org/10.1080/00063657.2018.1513989

Siebrecht N (2020) Sustainable agriculture and its implementation gap—Overcoming obstacles to implementation. Sustain 12:3853. https://doi.org/10.3390/su12093853

Skórka P, Lenda M, Moroń D, Tryjanowski P (2013) New methods of crop production and farmland birds: Effects of plastic mulches on species richness and abundance. J Appl Ecol 50:1387–1396. https://doi.org/10.1111/1365-2664.12148

Skórka P, Żmihorski M, Grzędzicka E, et al (2018) The role of churches in maintaining bird diversity: A case study from southern Poland. Biol Conserv 226:280–287. https://doi.org/10.1016/j.biocon.2018.08.013

Šmilauer P, Lepš J (2014) Multivariate Analysis of Ecological Data using CANOCO 5, 2nd ed. Cambridge university press, Cambridge

Szymkowiak J, Skierczyński M, Kuczyński L (2014) Are buntings good indicators of agricultural intensity? Agric Ecosyst Environ 188:192–197. https://doi.org/10.1016/j.agee.2014.02.037

Tews J, Brose U, Grimm V, et al (2004) Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. J Biogeogr 31:79–92. https://doi.org/10.5700/rege502

Tryjanowski P, Hartel T, Báldi A, et al (2011) Conservation of farmland birds faces different challenges in Western and Central-Eastern Europe. Acta Ornithol 46:1–12. https://doi.org/10.3161/000164511x589857

Tryjanowski P, Sparks TH, Jerzak L, et al (2014) A paradox for conservation: electricity pylons may benefit avian diversity in intensive farmland. Conserv Lett 7:34–40. https://doi.org/10.1111/conl.12022

Tscharntke T, Klein AM, Kruess A, et al (2005) Landscape perspectives on agricultural intensification and biodiversity - Ecosystem service management. Ecol Lett 8:857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x

Tscharntke T, Tylianakis JM, Rand TA, et al (2012) Landscape moderation of biodiversity patterns and processes - eight hypotheses. Biol Rev 87:661–685. https://doi.org/10.1111/j.1469-185X.2011.00216.x

Wood SN (2017) Generalized Additive Models: An Introduction with R, 2nd Edition. Chapman and Hall/CRC, Boca Raton

Zmihorski M, Kotowska D, Berg Å, Pärt T (2016) Evaluating conservation tools in Polish grasslands: The occurrence of birds in relation to agri-environment schemes and Natura 2000 areas. Biol Conserv 194:150–157. https://doi.org/10.1016/j.biocon.2015.12.007

Żmihorski M, Krupiński D, Kotowska D, et al (2018) Habitat characteristics associated with occupancy of declining waders in Polish wet grasslands. Agric Ecosyst Environ 251:236–243. https://doi.org/10.1016/j.agee.2017.09.033

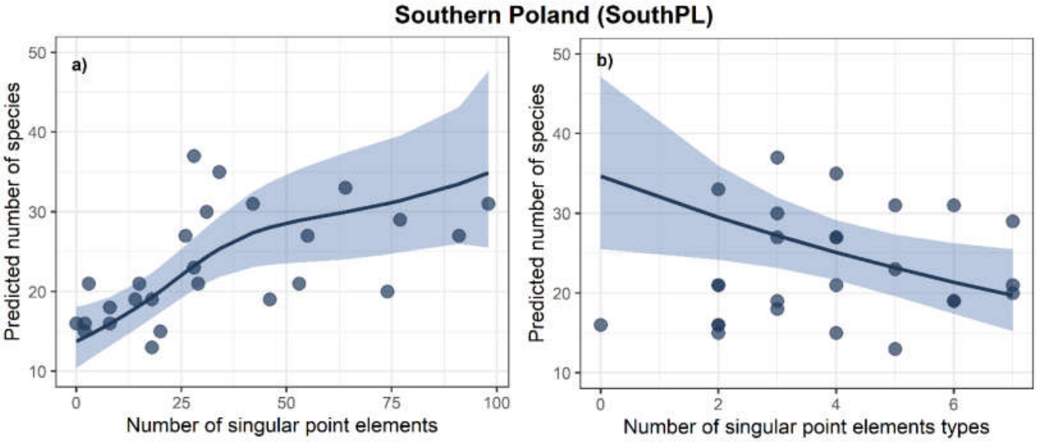


Fig. 1. Results of GAM models showing statistically significant predictions of the number of bird species by explanatory variables in SouthPL. The predicted relationship is represented by lines, confidence intervals are represented by the shaded region, while points represent original data.

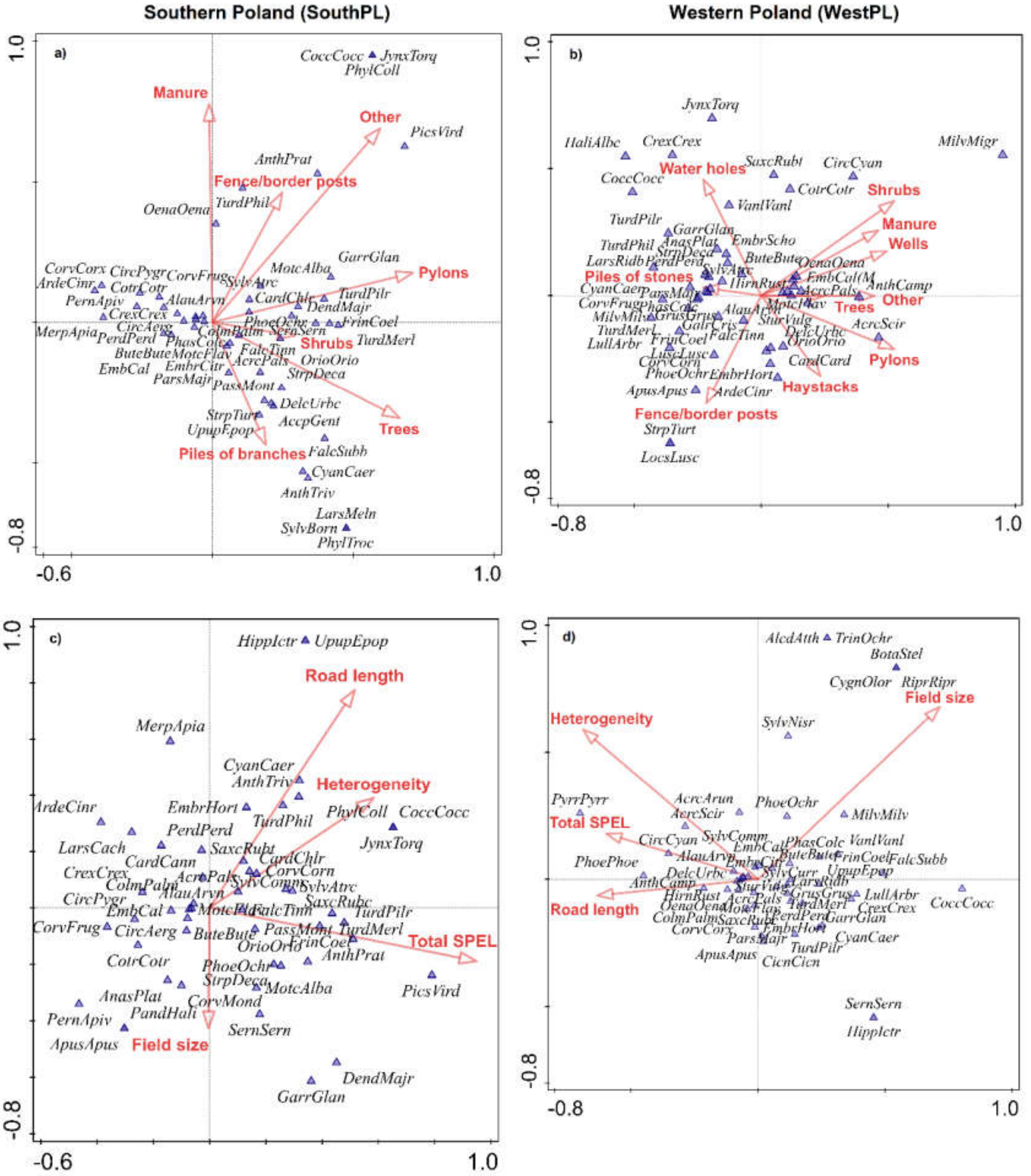


Fig. 2. The species ordination with the most common SPEL (a, b), and landscape characteristics (c, d) as explanatory variables in 50 landscape plots (1 km^2) of southern (SouthPL) and western Poland (WestPL). Trees, pylons, and other type have a significant effect on ordination in SouthPL while in WestPL there was a significant contribution of shrubs, pylons, and piles of manure. For general landscape characteristics there is significant effect of total number of SPEL and road length in SouthPL and field size and heterogeneity in WestPL. Species are represented by abbreviation of scientific name and triangles while explanatory variables are in red and arrows.

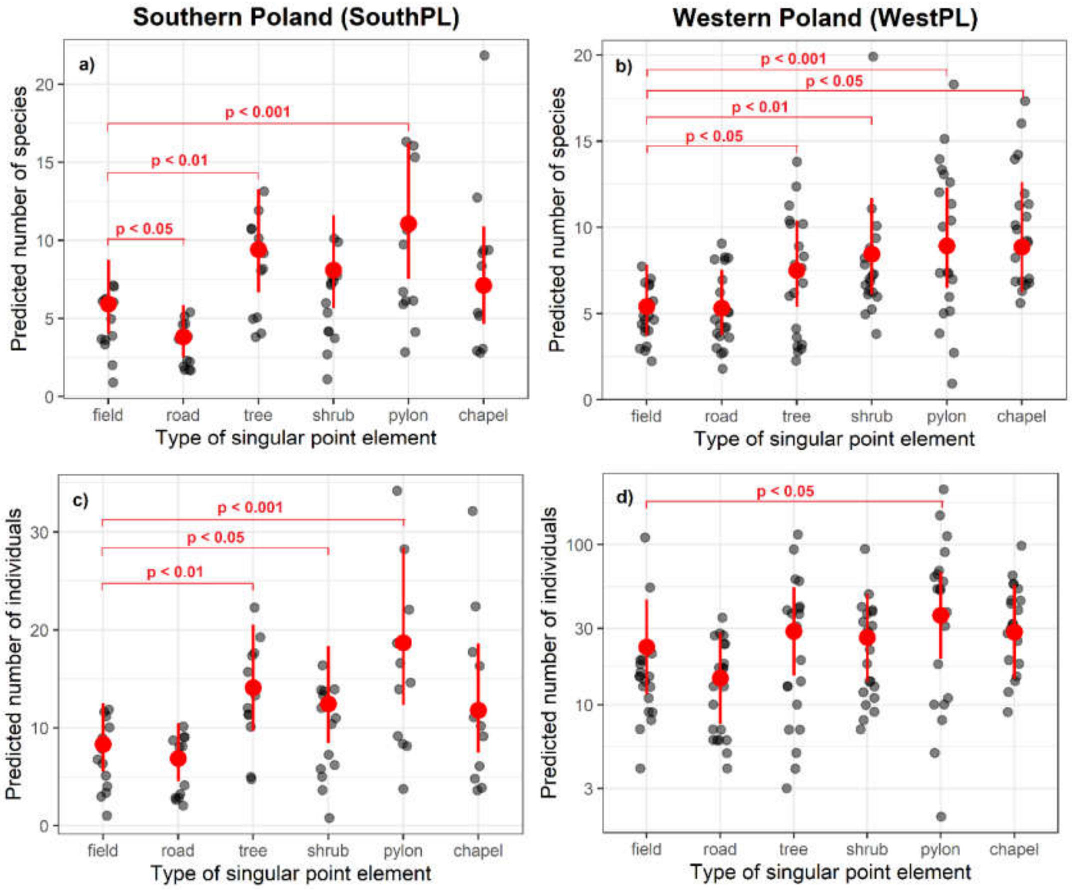


Fig. 3. Predicted number of species (a, b) and individuals (c, d) at the field and road control sites and at particular singular elements for Southern Poland (SouthPL) and Western Poland (WestPL). The red whiskers represent confidence intervals of estimated mean (red point) and grey points represent original data.

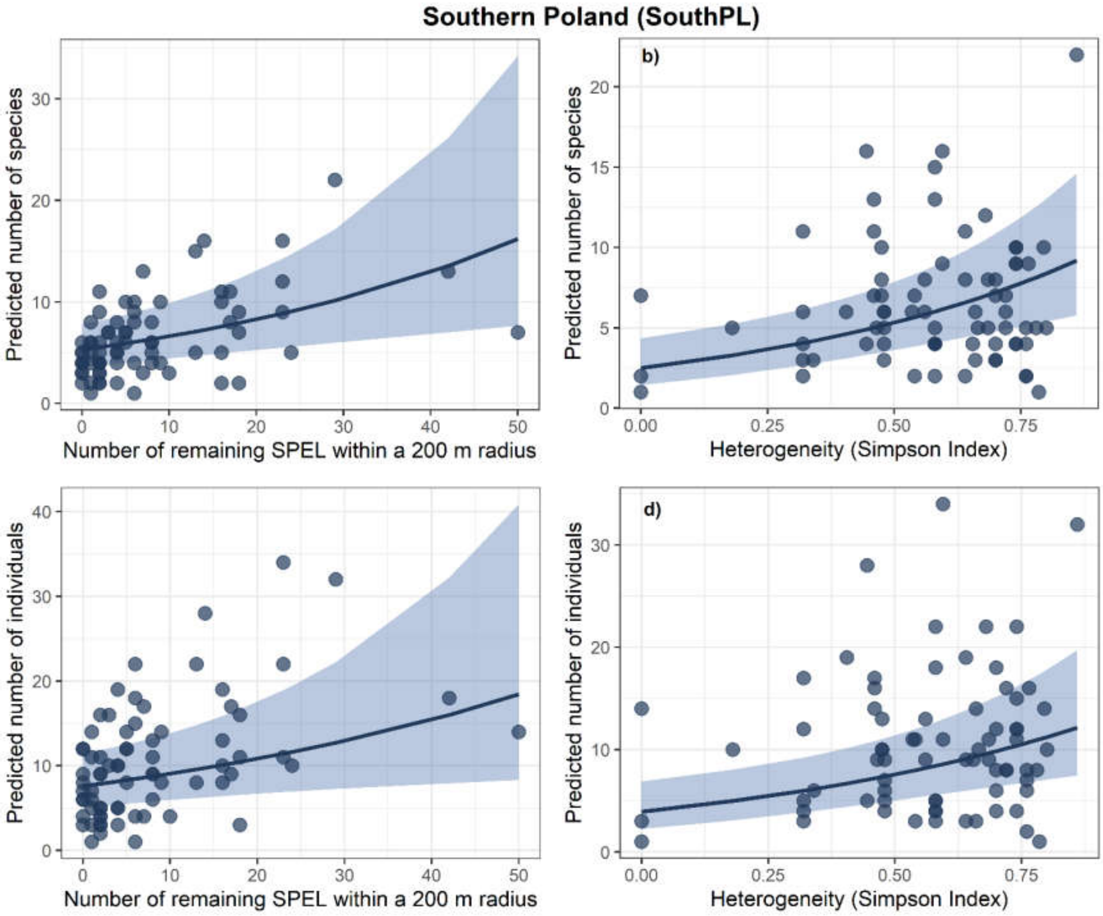


Fig. 4. Results of GAM models showing significant predictions of the number of bird species (subplots a, b) and number of individuals (subplots c, d) at count points by variables in SouthPL. Predicted relationships are represented by lines with confidence intervals (shaded area), while points represent original data.

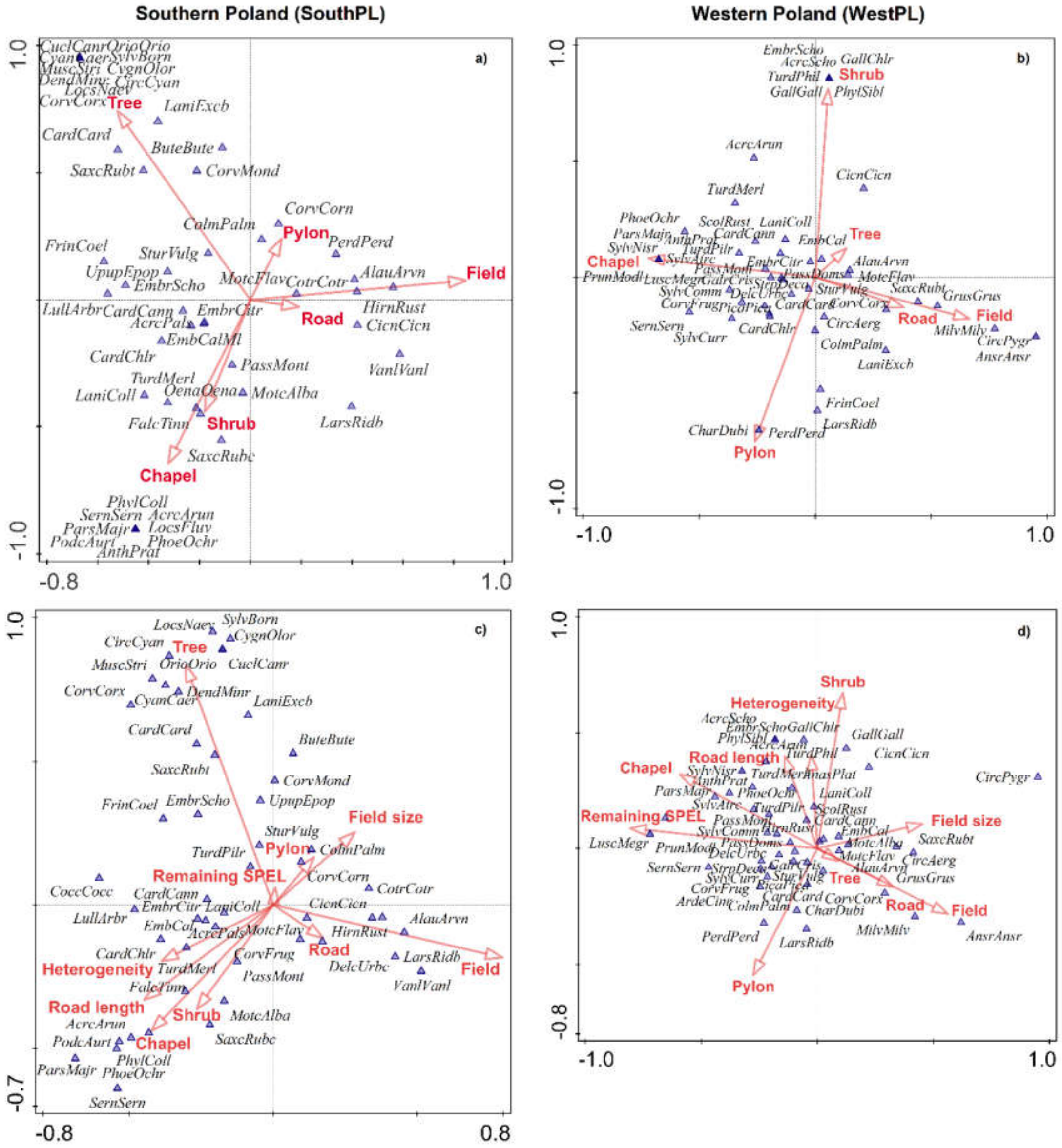


Fig. 5. The ordination of bird's species and the type of point-count (SPEL and control points, [a,b]), and the point type with other explanatory variables added (c,d) in southern and western Poland. Fields, trees, and chapels have a significant contribution to ordination in SouthPL (a) while in WestPL there is a significant effect of chapels and fields (b). When additional explanatory variables were included, point-count with fields, trees, and chapels were the sites with significant contribution to ordination in SouthPL (c) while point-counts with chapels, fields, and the total number of surrounding SPEL had significant contribution in WestPL (d).

Table 1. Effects of the total number of SPEL, number of distinct SPEL types, and other landscape characteristics of the study plots on the overall number of bird species and total number of individuals by landscape-scale approach. Statistically significant effects are emboldened and marked with asterisks: *** - P<0.001, ** - P<0.01, *P<0.05.

Explanatory variables	Response variables			
	Number of bird species in SPL	Number of bird individuals in SPL	Number of bird species in WPL	Number of bird individuals in WPL
GAM estimates of slopes with standard errors (in brackets) for explanatory variables with assumed linear response				
Intercept	**3.655 (0.306)***	**5.426 (0.632)***	**3.695 (0.403)***	**5.204 (0.442)***
SPEL types	**-0.081 (0.035)***	-0.108 (0.068)	0.001 (0.046)	-0.003 (0.049)
Mean field size	-0.023 (0.060)	-0.076 (0.110)	0.007 (0.015)	<-0.001 (0.017)
Heterogeneity	-0.425 (0.394)	0.038 (0.820)	-0.741 (0.409)	-0.624 (0.454)
Road length	0.028 (0.045)	-0.091 (0.090)	0.047 (0.066)	0.064 (0.070)
Approximate significance of smooth terms:				
Total number of SPEL	**Df = 2.458***	Df = 1.000	Df = 1.691	Df = 2.186
XY Coordinates	Df = 2.264	**Df = 2.000**	**Df = 2.000***	**Df = 2.000**

Table 2. Effects of the type of point count (type of element surveyed/control site), total number of SPEL in a 200-m radius, and other landscape characteristics of the study site on the overall number of bird species and total number of individuals by the point-scale approach. A field control site is a reference level for other terms estimates. Statistically significant effects are emboldened and marked with asterisks: *** - P<0.001, ** - P<0.01, *P<0.05.

Explanatory variables	Response variables			
	Number of bird species in SPL	Number of bird individuals in SPL	Number of bird species in WPL	Number of bird individuals in WPL
GAM estimates of slopes with standard errors (in brackets) for explanatory variables with assumed linear response				
Control: field (Intercept)	**0.621 (0.263)***	**1.132 (0.259)*****	**1.535 (0.144)*****	**2.994 (0.204)*****
Control: road	**-0.436 (0.217)***	-0.190 (0.202)	-0.017 (0.177)	-0.447 (0.253)
Element: tree	**0.464 (0.178)****	**0.529 (0.181)****	**0.328 (0.153)***	0.227 (0.218)
Element: shrub	0.314 (0.192)	**0.405 (0.192)***	**0.447 (0.154)****	0.137 (0.225)
Element: pylon	**0.625 (0.185)*****	**0.812 (0.186)*****	**0.502 (0.150)*****	**0.455 (0.224)***
Element: chapel	0.185 (0.234)	0.350 (0.239)	**0.494 (0.204)***	0.216 (0.307)
Mean field size	0.015 (0.014)	0.002 (0.015)	0.002 (0.002)	<-0.001 (0.003)
Heterogeneity	**1.512 (0.385)*****	**1.312 (0.386)*****	0.180 (0.159)	0.049 (0.245)
Road length	0.292 (0.331)	0.135 (0.353)	0.195 (0.467)	0.419 (0.741)
Approximate significance of smooth terms:				
Number of remaining SPEL	**Df = 1.000****	**Df = 1.000***	Df = 1.000	Df = 1.902
XY Coordinates	**Df = 10.010****	**Df = 11.680*****	**Df = 9.886*****	**Df = 15.008*****

SUPPORTING INFORMATION

Hunting platforms Wind turbines Electricity pylons Spiritual sites Fence/border posts Road signs

Singular shrubs Singular trees Wells Boulders Haystacks Puddles

Piles of branches Piles of stones/debris Piles of manure Piles of lime Scarecrows

Fig. S1. Examples of common singular point elements in a landscape (SPEL) studied in a landscape-scale

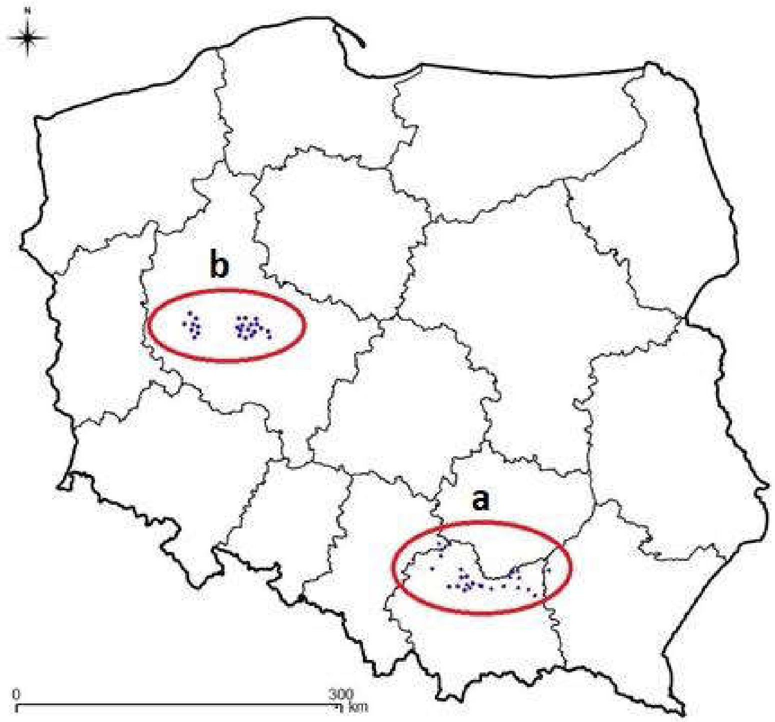


Fig. S2. The localization of study sites in a) southern (SouthPL) and b) western Poland (WestPL). Dots indicate landscape plots 1 km^2.

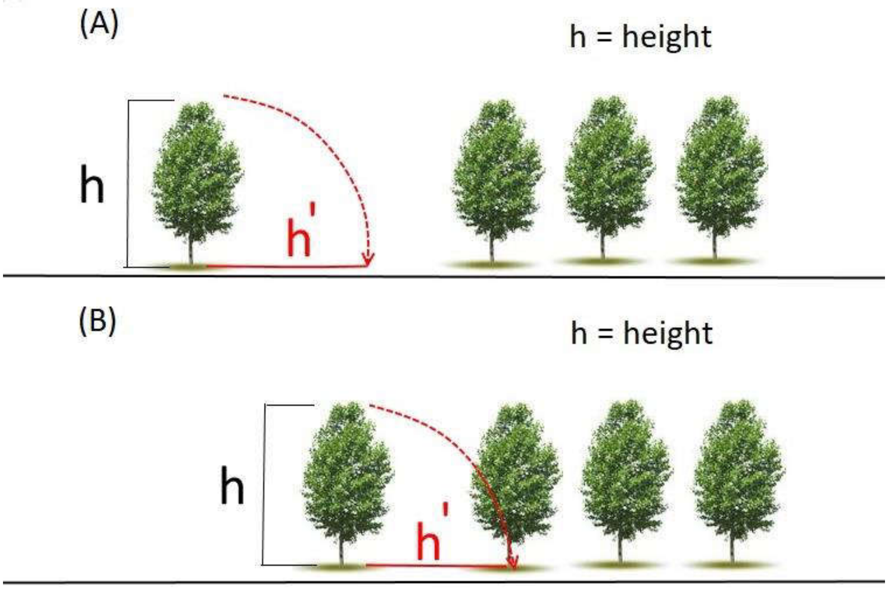


Fig. S3. The methodology for determining singular point elements in a landscape. (A) If the projection of the height of a given element (shrub, tree, etc.) does not overlap other elements, we consider it as a single element. (B) If the projection of the height of a given element (shrub, tree, etc.) overlaps with other elements, this is not considered a single element but a group of elements.

Table S1. The summary statistics of bird counts within all of the study plots (landscape-scale) and for both regions separately.

	Bird count 1		Bird count 2		Species (mean)	Individuals (mean)	Species total
	Species	Individuals	Species	Individuals			
Birds both regions							
Total	90	4288	91	4202	90.5	4245	106
Mean/plot	16.4	85.8	21.0	84.0	18.7	84.9	
Min/plot	9	26	10	28			
Max/plot	33	318	45	195			
Birds SouthPL							
Total	69	2459	64	1393	66.5	1926	79
Mean/plot	15.7	94.6	17.8	53.6	16.8	74.1	
Min/plot	9	26	10	28			
Max/plot	24	318	30	111			
Birds WestPL							
Total	66	1829	86	2809	76	2319	92
Mean/plot	17.3	76.2	24.5	117.0	20.9	96.6	
Min/plot	9	34	12	52			
Max/plot	33	265	45	195			

Table S2. The frequency of particular Singular Point Elements (SPEL) within the study area in 1 km^2 landscape-plots. The summary statistics are provided for both regions together, as well as for western Poland (WestPL) and southern Poland (SouthPL) separately. “Other SPEL” are objects that were uncommon within the study area. The mean number of different SPEL types (“SPEL types”) in each study plot for both regions are also provided.

	tree	shrub	pylon	chapel	hunting platform	boulder	pile of stones/debris	pile of manure	pile of branches	pile of lime	pile of soil	haystack	well	fence/border post	scarecrow	water hole/puddle	road sign	other SPEL	SPEL types	TOTAL SPEL
Singular elements both regions																				
Total SPEL	351	471	375	2	9	4	34	75	13	6	7	34	19	109	3	22	5	11	-	1550
Mean/plot	7.0	9.4	7.5	0.0	0.2	0.1	0.7	1.5	0.3	0.1	0.1	0.7	0.4	2.2	0.1	0.4	0.1	0.2	5.1	31.0
Min/plot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max/plot	37	56	72	1	4	2	5	7	3	2	5	4	7	50	2	3	5	3	10	98
Singular elements SouthPL																				
Total SPEL	226	346	219	1	7	1	5	25	10	0	5	3	3	16	0	8	5	4	-	884
Mean/plot	8.7	13.3	8.4	0.0	0.3	0.0	0.2	1.0	0.4	0.0	0.2	0.1	0.1	0.6	0.0	0.3	0.2	0.2	3.9	34.0
Min/plot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Max/plot	37	56	72	1	4	1	2	4	3	0	5	2	3	6	0	3	5	2	7	98
Singular elements WestPL																				
Total SPEL	125	125	156	1	2	3	29	50	3	6	2	31	16	93	3	14	0	7	-	666
Mean/plot	5.2	5.2	6.5	0.0	0.1	0.1	1.2	2.1	0.1	0.3	0.1	1.3	0.7	3.9	0.1	0.6	0.0	0.3	6.5	27.8
Min/plot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	7
Max/plot	10	17	37	1	2	2	5	7	2	2	1	4	7	50	2	3	0	3	10	71

Table S3. Summary statistics of bird counts at all of the point-counts (point–scale) and for both regions separately.

	bird count 1		bird count 2		species (mean)	individuals (mean)	species total
	species	individuals	species	individuals			
Birds both regions							
Total	73	2356	73	3299	73	2827.5	90.0
Mean/point	4.3	12.2	4.7	17.1	4.5	14.7	
Min/point	0	0	0	0			
Max/point	15	93	13	210			
Birds SouthPL							
Total	42	427	59	438	50.5	432.5	65
Mean/point	3.3	5.9	4.3	6.0	3.8	5.9	
Min/point	0	0	0	0			
Max/point	11	19	13	18			
Birds WestPL							
Total	63	1929	57	2861	60	2395	74
Mean/point	4.9	16.1	5.0	23.8	4.9	20.0	
Min/point	0	0	0	0			
Max/point	15	93	13	210			

Oświadczenie Kandydata o zakresie wkładu merytorycznego w publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej

Stopień naukowy, imię i nazwisko Kandydata
Mgr inż. Sylwia Pustkowiak

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., & Skórka, P. The scale-dependent association between bird diversity and singular point elements in agricultural landscapes (SPEL) differing in management intensity. Agriculture, Ecosystems and Environment [w trakcie procesu redakcyjnego]

Mój udział był następujący:

Merytoryczny udział w publikacji:

Jestem głównym autorem i uczestniczyłam w powstawaniu jej założeń metodycznych. Realizowałam główną część badań terenowych, a także przeprowadziłam wszystkie analizy, opracowanie statystyczne wyników oraz ich prezentację graficzną. Przygotowałam pierwszą wersję manuskryptu, a następnie naniosłam poprawki zasugerowane przez współautorów. Jako autor korespondencyjny uczestniczyłam we wszystkich etapach procesu redakcyjnego.

Procentowy udział w publikacji: **60%**

Sylwia Pustkowiak

27.06.2022

....

(data, podpis Kandydata)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr Zbigniew Kwieciński

Zakład Ekologii i Antropologii, Instytut Biologii, Uniwersytet Szczeciński, Wąska 13, 71-415, Szczecin, Polska

Zakład Biologii i Ekologii Ptaków, Instytut Biologii Środowiska, Wydział Biologii, Uniwersytet im. Adama Mickiewicza, Uniwersytetu Poznańskiego 6, 61-614 Poznań

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., & Skórka, P. The scale-dependent association between bird diversity and singular point elements in agricultural landscapes (SPEL) differing in management intensity. Agriculture, Ecosystems and Environment [w trakcie procesu redakcyjnego]

Mój udział był następujący:

Merytoryczny udział w publikacji:

Udzielałem krytycznych uwag i sugestii podczas tworzenia koncepcji badań, a także w całym procesie powstawania pracy. Brałem udział w pracach terenowych i zbieraniu danych do badań.

Procentowy udział w publikacji: **15%**

Zbigniew Kwieciński

15.06.2022

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr Magdalena Lenda

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., & Skórka, P. The scale-dependent association between bird diversity and singular point elements in agricultural landscapes (SPEL) differing in management intensity. Agriculture, Ecosystems and Environment [w trakcie procesu redakcyjnego]

Mój udział był następujący:

Merytoryczny udział w publikacji:

Udzielałam krytycznych uwag i sugestii podczas tworzenia koncepcji badań, a także w całym procesie powstawania pracy. Brałam udział w pracach terenowych i zbieraniu danych do badań.

Procentowy udział w publikacji: **5%**

24.06.22 Magdalena Lenda
(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr hab. Michał Żmihorski prof. IBS PAN

Instytut Biologii Ssaków Polskiej Akademii Nauk, ul. Stoczek 1, 17-230 Białowieża, Polska

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., & Skórka, P. The scale-dependent association between bird diversity and singular point elements in agricultural landscapes (SPEL) differing in management intensity. Agriculture, Ecosystems and Environment [w trakcie procesu redakcyjnego]

Mój udział był następujący:

Merytoryczny udział w publikacji:

Brałem udział w tworzeniu koncepcji i metodyki badań oraz udzielałem krytycznych uwag w całym procesie powstawania pracy.

Procentowy udział w publikacji: **5%**

Żmihorski

15/06/2022

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr hab. Piotr Skórka prof. IOP PAN

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Lenda, M., Żmihorski, M., & Skórka, P. The scale-dependent association between bird diversity and singular point elements in agricultural landscapes (SPEL) differing in management intensity. Agriculture, Ecosystems and Environment [w trakcie procesu redakcyjnego]

Mój udział był następujący:

Merytoryczny udział w publikacji:

Brałem udział w tworzeniu koncepcji badań, pracach terenowych, analizie statystycznej zebranego materiału, a także w całym procesie powstawania pracy.

Procentowy udział w publikacji: **15%**

27.06.2022

....

(data, podpis współautora)

Does social information change the number, distribution and size of animal territories when habitat heterogeneity varies?

Sylwia Pustkowiak[1*], Zbigniew Kwieciński[2,3], Michał Bełcik[1], Piotr Skórka[1]

[1]Institute of Nature Conservation, Polish Academy of Sciences, Mickiewicza 33, 31-120, Kraków, Poland

[2]Department of Ecology and Anthropology, Institute of Biology, University of Szczecin, Wąska 13, 71-415, Szczecin, Poland

[3]Department of Avian Biology and Ecology, Institute of Environmental Biology, Faculty of Biology, Adam Mickiewicz University, Uniwersytetu Poznańskiego 6, 61-614 Poznań, Poland

*corresponding author e-mail: sylwia.pustkowiak@gmail.com

telephone: +48 663 272 661

author's ORCID: 0000-0003-0175-4819

wordcount:

Abstract

Habitat heterogeneity is one of the most important characteristics of the environment affecting the distribution of animals. Despite heterogeneity may be positively correlated with resources it may also indicate unpredictability of habitat suitability in space. Physical characteristics of the habitat are not the only one deciding on its quality, though. Many animal species select habitat based on social information, e.g. conspecific presence, known as conspecific attraction. It is possible that social information becomes more important for species occurrence in landscapes with higher habitat heterogeneity. Thus, we tested whether the social information may modify effects of habitat heterogeneity on the number, clustering and size of territories of yellow wagtail *Motacilla flava,* a common farmland bird. We expected that social information will increase number and clustering of territories and this effect will be larger in landscapes with higher habitat heterogeneity. We broadcasted either conspecific signals (male song), procedural control (ambient sounds) or performed no broadcasting (control) in 24 landscapes differing in habitat heterogeneity. The experiment showed that social information had no effect on distribution and clustering of wagtail territories. Territory size decreased due to experiment in landscapes with less heterogeneous habitats but increased in landscapes with more heterogenous ones. However, the procedural control had similar effect as the social information indicating that experimental manipulation, surprisingly, had an effect on results. Thus, it seems that social information has little impact on the number and distribution of wagtail territories. The observed changes in territory size suggest that broadcasted wagtail songs are rather social deterrent and that social context should be considered when ecological effects of habitat heterogeneity are studied.

Keywords: conspecific attraction, habitat selection, heterogeneity, population density, public social information, social cues

Introduction

Models of animal distribution rely mainly on analyses of habitat suitability, where certain physical attributes of the environment predict the occurrence and abundance of animals and thus species richness (Pearce and Ferrier 2000; Guisan and Thuiller 2005). One of the most important features of the environment is habitat heterogeneity, i.e. the spatial and temporal variation in structural and compositional complexity (Tews et al. 2004; Fahrig et al. 2011a). Habitat heterogeneity is often an important predictor of the occurrence and abundance of species (Benton et al. 2003) and thus strongly affects community composition, biodiversity and available resources (Lundholm 2009; Gastauer et al. 2021). Habitat heterogeneity is also a central concept of conservation biology because of the positive correlation with species richness (Stein et al. 2014). Most land management schemes incorporated at a national or even continental scale (for example, agri-environmental schemes in the European Union) are based on the concept that spatial habitat heterogeneity increases ecosystem functioning and services (Benton et al. 2003; Bode et al. 2011). For example, it is argued that keeping high habitat heterogeneity (e.g. higher diversity of crops and non-managed habitats) may stop decline of farmland birds, one of the most endangered vertebrate group in Europe (Donald et al. 2001; Gregory et al. 2005). However, from the perspective of a single species the high habitat heterogeneity may not be a favourable feature of the environment. High habitat heterogeneity decreases spatial autocorrelation and thus predictability of habitat quality (Jager et al. 2005; Mcnew et al. 2013). Reduced predictability of habitat conditions may thus diminish its suitability and lead to lower population density and clustered distribution. Also, higher number of other species in heterogenous habitats may be associated with increased inter-specific competition and/or predation (Giorini et al. 2011; Chen et al. 2020).

Owing to the high heterogeneity of habitats (Tews et al. 2004), individuals may need to gather information on the environment to correctly assess local habitat quality (Doligez et al. 2002; Szymkowiak 2013). However, information gathered by one individual regarding the structural features of the habitats may be misleading for making vital decisions (Dall et al. 2005; Schmidt et al. 2010). Thus, animals may use social public information during their assessment of the local habitat quality and selection of their subsequent breeding site (Doligez et al. 2003; Schmidt et al. 2010). The term, social public information (hereafter in this study just “social information”), may refer to the presence of other individuals, their behaviour, the sounds they make, or other traces of their presence or activity (Fletcher 2007; Hromada et al. 2008; Suzuki 2015). Social information may be carried by other heterospecific or conspecific individuals, and may reduce of uncertainty in habitat selection and thus increase individual fitness (Ward et al. 2010; Szymkowiak et al. 2017). Calls and songs of conspecifics constitute positive social information indicating high quality habitat and increase the social attraction of the area (Fletcher, Jr. 2007; Suzuki and Kutsukake 2017). This may lead to clustering distribution as individuals may be attracted by availability of mates, and both males and females may benefit from the extra pair mating (Stamps 1988). The predation risk is also lower when living in aggregations (Perry et al. 2008).

As habitat heterogeneity increases it is possible that animals must use multiple cues to asses habitat quality. Hence, it is possible that social information may play major role in shaping animal population density and distribution mostly in highly heterogeneous habitats but not necessary in more homogeneous and thus more predictable ones. This hypothesis has not been tested despite habitat heterogeneity and social information seem to be major drivers of ecological processes.

In this large-scale experimental study, we tested how conspecific social information changes the number, spatial clustering and size of territories of the common farmland passerine bird – the yellow wagtail *Motacilla flava* L - occurring in landscapes varying in habitat heterogeneity. We predicted that adding a social information may increase number and clustering of territories and reduce their territory size. Moreover, we also expected that these effects will be stronger in landscapes with higher heterogeneity of habitats than in landscapes with lower habitat heterogeneity.

Methods

Study area and design

The study was conducted in the western Poland (Greater Poland Voivodeship, study sites in two clusters in environs of Poznań, centroid 1 position: 52° 15' 19.247"N 17° 17' 35.019"E, centroid 2 position: 52° 16' 6.482"N 16° 30' 59.056"E) where we selected 24 square plots, with an area of 9 km^2 each. While selecting the plots we used the data from the National Agricultural Census 2010 (GUS Statistics Poland 2013), to look for the territorial administrative units (communes) with the high share of the root crops, vegetables and rape, preferred by the yellow wagtail (Kuczyński and Chylarecki 2012). While delineating plots we also kept the following criteria: a low share of woodland (preferably no higher than 1 %) and a cover of human settlements no higher than 5%.). The mean distance between the boundaries of the two closest plots was 2.05 ± 0.36 km (min = 1.61 km, max = 3.59 km).

Study species

The western yellow wagtail is a small passerine in the wagtail family *Motacillidae*. This species breeds in much of temperate Europe and Asia. It is resident in the milder parts of its range, such as western Europe, but populations form Eastern and Northern Europe migrate to Africa. It is a 15–16 cm long bird, with the characteristic long, constantly wagging tail. The breeding adult male is basically olive above and yellow below. The heads of breeding males come in a variety of colours and patterns depending on subspecies. This insectivorous bird inhabits open areas near water, such as wet meadows. It nests in tussocks, laying 4–8 speckled eggs. In Poland, the yellow wagtail prefers open agricultural landscape with high share of roots and vegetables (Kuczyński and Chylarecki 2012).

Field surveys

We visited each plot six times during each breeding season between 15 April and 15 July in years 2016-2017. We walked through the area using different routes and mapped yellow wagtail occurrences. Field surveys were carried out in fine weather from dawn till the noon. In 2017 year, the mapping of yellow wagtails started after the experimental broadcast had finished. After all the surveys the data on land-use structure of each plot as a percentage cover of crops and other land-use types were collected. All data were digitalized in QGIS v. 3.22.7 (QGIS Association 2022).

Field experiment

We randomly assigned all of the 24 plots to three experimental groups (with eight plots each): social information, procedural control and no manipulation. The social information comprised the territorial songs of yellow wagtail male. Procedural control was the ambient sounds (i.e. sound of moving vegetation, wind and other sounds coming from the surrounding landscape) and was included to assess the potential effect of the field procedure (i.e. regular visits of field workers, the presence of field equipment). Each plot was divided into four smaller squared subplots (quarters) measuring 2.25 km^2 and two diagonally adjacent quarters were selected for experimental manipulation (Fig. 1A). We broadcasted either songs of yellow wagtail males or procedural control in five randomly chosen sites in each subplot (10 playback point per plot)

Playback of the yellow wagtail songs consisted of 5-minute fragments of vocalization between which there were 10-minute fragments of silence (Fig. 1B). Songs and calls of males were obtained from the XenoCanto website – a platform for sharing bird's recordings (www.xeno-canto.org). We used only recordings with the highest quality available for this portal ("A" mark, see Supplementary Material) originated from a similar agricultural landscape in Poland and eastern Germany. Procedural control playback was arranged in the same manner as social information playback and the sounds were recorded in the nearby agricultural area early in the season (before most of the songbirds arrival). Playbacks were broadcasted from the loudspeakers (JAM HX-P710 speaker set for loudness corresponding to the loudness of the wagtail song) connected via bluetooth with Mp3 player (Philips GoGear Azure SA5AZU08KF). The equipment was secured from water with mesh material and hang on the tree/shrub or pole at the height of 0.5-1 m (Fig. S2). The experiment took place in year 2017 during the period when the wagtails arrive and establish territories, and lasted two weeks (17-30 April). We started setting up the speakers each day at 7 am. Playback lasted 5 hours, so we started removing speakers at 12 p.m. The order in which the loudspeakers were turned on was shuffled.

Spatial analysis

The habitat heterogeneity was expressed as a Simpson's Diversity Index based on share of different crops and land use types, calculated using "vegan" package (Oksanen et al. 2020) in R (R Core Team 2021). Using QGIS v. 3.22.7 (QGIS Association 2022) also two other landscape metrics were obtained: mean field size, calculated using a layer with a cadastral division from the geoportal.pl website (Main Office of Geodesy and Cartography 2017) and the total length of roads in each plot calculated using Open Street Map data (OpenStreetMap Contributors 2022). While calculating heterogeneity we excluded forests, roads, human settlements and other man-mad infrastructure which are not suitable habitat for yellow wagtail.

Based on the yellow wagtail occurrence records in each year we delineated wagtail territories using methodology by Kotowska et al. (2019). Territories were clusters of occurrences calculated in CrimeStat software (Levine 2015) using the Nearest Neighbour Hierarchical Clustering Algorithm (NNH) with 100 simulation runs and the minimum of three points required for a cluster ("territory") as it is assumed in the combined territory mapping technique (Tomiałojć 1980a, b; Bibby et al. 2000). We set the search threshold distance to 0.05 of random nearest neighbour distance (fewer than 5% of the pairs could be expected to be as close or closer by chance). The number of clusters approximated the number of territories (Kotowska et al. 2019) with additional information about the number of points (occurrences) in each cluster. The ellipsoids of the clusters were exported to QGIS where we designated their centroids and calculated the Nearest Neighbour Index (the measure of clustering of the territories) for each plot.

Statistical analysis

All models were fitted using R environment (R Core Team 2021). We analysed the response of the three main dependent variables: the number of territories per plot in each year, the Nearest Neighbour Index per plot in each year (NN_Index), and the area of each territory. Number of territories was fitted using general linear model (GLM) model with negative binomial error distribution using glm.nb function from "MASS" package (Venables and Ripley 2002). For the NN_Index we fitted linear model (LM) with lm function. The linear mixed model (LMM) was used for territory area using "lme4" package (Bates et al. 2015), with plot ID set as a random factor because there were several territories delineated in each plot. Separate models were prepared for 2016 and 2017 year. We used following explanatory variables: experimental manipulation type, habitat heterogeneity in a given year (Simpson's Diversity Index), mean field size in the plot, total road length in a plot and the interaction between manipulation type and habitat heterogeneity. Experimental manipulation in 2016 was, of course, a dummy variable, as the experiment was performed in 2017. For modelling territory area, we used additional variable – the number of occurrences in each territory – as a covariate to account for the fact that larger territories were slightly correlated the with number of wagtail records. Both territory area and the number of occurrences were left-skewed and were $\log_{10}$-transformed.

Results

The mean share of roots and other vegetables per plot in the initial 2016 year was 22.69 ± 11.43% (min = 7.96%, max = 50.14%). The heterogeneity of crops and other land uses did not differ significantly between years ($t = -1.148$, $p = 0.263$) and was on average 0.84±0.02 (min = 0.79, max = 0.88) in 2016 and 0.83±0.03 (min = 0.77, max = 0.88) in 2017. The number of territories and NN_index also did not differ between years (N territories: $t = 1.232$, $p = 0.23$; NN_index: $t = -0.758$, $p = 0.452$). There were on average 16.6±5.0 territories per plot in 2016 (min = 7, max = 24) and on average 18.1±5.7 territories per plot (min = 10, max = 37) in 2017 (Table S1). The average NN_index was 1.14±0.18 (min = 0.84, max = 1.50) in 2016 and 1.10±0.20 (min = 0.84, max = 1.76) in 2017 year. The calculated territories of yellow wagtails were significantly larger in 2017 year ($t = 3.56$, $p < 0.001$), with an average value of 2.14±1.48 ha (min = 0.06, max = 7.91) in 2016 and 2.47±1.39 ha (min = 0.06, max = 6.87) in 2017 year. The mean field size, the length of the roads and a heterogeneity in a given year were not correlated with each other (Table S2).

There was no effect of any explanatory variable on the number of yellow wagtails' territories and the clustering of territories (NN_index) in both 2016 (pre-manipulation) and 2017 (manipulation) year (Table 1). The territory area was negatively correlated with the size of the fields in 2016 (Table 1, Fig. 2A). The assumed correlation between the number of occurrences and the territory area was also highly significant in this year (Table 1, Fig. 2B).

Analysis for 2017 data showed that the territory area varied among plots with different manipulation types (Table 1) and associated negatively with habitat heterogeneity (Table 1, Fig. 3) However, the significant interaction between these variables showed that the effect of manipulation varied depending on the habitat heterogeneity. In the plots with less heterogeneous habitats the broadcasted social information and procedural control resulted in smaller territories of yellow wagtails comparing to the plots with no manipulation (Table 1). In plots with more heterogeneous habitats both the social information and procedural control were associated with increased territory area as compared to the plots with no manipulation (Table 1, Fig. 4 A-C). Moreover, the length of the roads and number of occurrences were positively associated with the territory area (Table 1, Fig. S3)

Discussion

Conspecific social information attracts individuals of the same species which usually results in the increased abundance, but there are also cases of lack of this effect (Ahlering et al. 2010). Our study showed no association between the number of the yellow wagtail territories and manipulation type and non-significant effect of interaction between the manipulation type and heterogeneity. These results do not support conspecific attraction hypothesis in this species. The second presumed association – the clustering of wagtail territories due to social information was also non-significant. The mean value of the clustering index in both years was above one which means that the distances between two closest territories are smaller than expected by random distribution. This shows that the territories were already clustered and may explain the lack of effect of the social information on the distances between the territories.

Many studies show a strong relationship between habitat heterogeneity and biodiversity (Benton et al. 2003; Stein et al. 2014) but this relationship is not always straightforward in the case of particular species and was described as area-heterogeneity tradeoff concept (Allouche et al. 2012). Species with narrower niche width may respond negatively to the habitat heterogeneity, as with the more diverse landscapes the amount of appropriate habitat decreases and this phenomenon was found in ground nesting birds, including the yellow wagtail (Pickett and Siriwardena 2011). Moreover, species richness increasing with heterogeneity often results in a lower abundance of each particular species. Our study showed that the habitat heterogeneity does not influence the abundance (number of territories) nor the distribution (clustering pattern) but negatively affect the territory size. Increased bird species richness in response to increasing heterogeneity may cause the increased competition for resources and limit available space and thus constrain the population growth of yellow wagtail (Kadmon and Allouche 2007). However, confirmation of this hypothesis would require counting all species in the studied plots.

The significant interaction between the manipulation type and habitat heterogeneity revealed that social information may alter the negative association between the heterogeneity and yellow wagtail's territory size. In the areas with the lower heterogeneity wagtails receiving social information had smaller territories comparing to those from plots with no manipulation. This may suggest that wagtails compare information on intra-species competition with the presumed quality of the habitat and remain in smaller territories. When the habitat heterogeneity is high their territories remain at similar size (comparing to plots with lower heterogeneity) while the territory size in plots with no manipulation decreases. This seems to partially supports our second hypothesis that social cues play more important role in heterogeneous habitats than in homogeneous ones.

The procedural control was aimed at estimating the effect of the manipulation procedure (i.e. the regular visits of field staff, the presence of new unknown object, e.g., a loudspeaker). Unfortunately, the territory size of yellow wagtails increased with increasing heterogeneity under the procedural control conditions, contrary to the plots with no manipulation, and in a similar manner as it was found in plots with broadcasted social information. The significant effect of procedural control was fairly unexpected because in a pilot study we did not observe behavioural response of wagtails to loudspeakers emitting ambient sounds but they strongly responded to loudspeakers emitting male songs. In the latter case males and females approached the loudspeaker and vocalised intensively but this was not observed at loudspeakers aimed to be procedural control. This indicates that procedural control is required in studies on social information, as the observer effect may indeed influence results and thus our understanding of the role of social information in shaping bird’s distribution. However, several studies suggest to not use procedural control playbacks because birds can be influenced by heterospecific and anthropogenic sounds (e.g. Brumm and Slabbekoorn 2005; Seppänen et al. 2007; Szymkowiak et al. 2017). We do not agree with point. Our playback in procedural control was just sound of wind with little other anthropogenic sounds. Thus, it is unlikely that birds responded to sounds alone or observers because people (e.g. farmers) were constantly present in farmland. Why thus did we find the effect of the procedural control? This might be explained by the effect of fear caused by the presence of a novel object in the environment. For example, other research found differences between the rural and urban populations of birds in reaction to a novel item placed in the habitat, with the rural birds being less likely to exploit unknown resources than urban birds (Tryjanowski et al. 2016; Golawski and Sytykiewicz 2021). If loudspeakers emitting ambient sounds had similar deterring effect on wagtails this could explain why we did not observe behavioural response to them. This however contradicts strong response of wagtails to loudspeakers with male songs but we may assume that the broadcast of male songs may mitigate the fear of the novel object.

The evidences of an interaction between environmental and social cues are scarce. The studies of Black-throated Blue Warbler *Dendroica caerulescens* occupancy patterns showed no effect of prebreeding social cues nor the interaction between habitat cues and social cues (Cornell and Donovan 2010). It should be noted that in our study the broadcast of social information took place during the wagtails’ arrival, while the bird mapping took place after the broadcast had ended. It is likely that wagtails in a more heterogeneous plots, were interested in monitoring the area of a spurious neighbour when it seemed to leave. At the same time, when the heterogeneity was low, they stayed with smaller territories after the broadcast had finished than males from plots without manipulation. This suggests that for individual birds social and environmental cues are complimentary.

Other environmental variables also showed the association with territory size. The field area and the length of the roads were constant variables across studied years – the first one is derived from the cadastral division of the fields. Even if the amount of habitat is similar among plots, their spatial arrangement and mean habitat patch size may vary depending on the configurational heterogeneity (Fahrig et al. 2011b). The results from 2016 year suggests that spatial arrangement with smaller fields promotes bigger territories. It is in line with the hypothesis that bigger fields and monocultures are generally unfavourable for certain species (Fahrig et al. 2015). This effect was no longer significant in 2017 probably due to the broadcast effect which caused changes in territory size. Another effect that emerged in a manipulation year (2017) was a positive association of a length of the roads and the territory area. The presence of roads is mainly associated with the amount of marginal habitat along them (shrubby or grassy road verges). Wagtails may explore roadsides because they may forage on roadkilled insects (Skórka 2016). Also, spatial configuration of roads may cause birds change movement and singings sites (Kociolek et al. 2011; Husby 2017) that may change the territory size. Moreover, a common element of a Polish farmland are piles of manure which are stored by the roads and field paths. Yellow wagtails often forage on the piles of manure, Fig. S4).

Social information was proposed to be management tool for improving colonisation of suitable areas but decision to settle in the area is a complex process and there is a need to recognise the potential obstacles (Ahlering and Faaborg 2006). Here, we found that social information did not induce the increase in the number of wagtails' territories nor their distribution. However social information affected the territory size but this effect was altered by the heterogeneity. Social cues are useful especially when searching for dynamically changing habitats, like for example temporal wetlands (Ward et al. 2010). In our research, the distribution of the yellow wagtail's preferred habitat - root crops - is to some extent predictable. Although potatoes can grow on poorer-quality soils, sugar beet requires better-quality soils (Baryga et al. 2020; Koco et al. 2020). There are also farms specializing in vegetable crops. The experienced males may thus make a settling decision based on the previous year area assessment and do not need to invest much time in habitat assessment at the beginning of a new breeding season. An evolutionary sense of social attraction is improving the fitness of an individual (Ahlering et al. 2010). It is unclear whether the modification of territory area under varying heterogeneity condition in response to social information has adaptive properties because we did not estimate the breeding success of yellow wagtails in the study plots One possible explanation is that keeping larger territory area when heterogeneity increases reduce individuals' isolation and increases the chances of social contacts.

Conclusion

The decision where to establish a territory involves different sources of information and depends on the ecological niche occupied. Yellow wagtails do not increase the number of territories nor change social context by territory clustering in response to both social information and heterogeneity of habitat. However social information is diminishing the negative association between the habitat heterogeneity and the yellow wagtail's territory area. This is the first experimental evidence that social information may modify the effect of habitat heterogeneity on the territory area of a farmland bird. However, this effect was confounded by similar effect of a procedural control. This indicates that studies without procedural control may produce spurious results difficult to interpret.

Acknowledgements

We want to thank Maciej Bronikowski, Zuzanna Jagiełło, Mariusz Janowski, Patryk Kokociński, Halszka Łożyńska, Sebastian Mertowski, Agata Ożarowska, Michał Oźmiński, Michał Przystański and Viktoria Takacs who helped to carry out the field experiment and data collection.

Funding

This work was financed by a Sonata Bis 4 grant – 2014/14/E/NZ8/00165 from the National Science Centre, Poland

References

Ahlering MA, Arlt D, Betts MG, et al (2010) Research Needs and Recommendations for the use of Conspecific-Attraction Methods in the Conservation of Migratory Songbirds. Condor 112:252–264. https://doi.org/10.1525/cond.2010.090239

Ahlering MA, Faaborg J (2006) Avian habitat management meets conspecific attraction: If you build it, will they come? Auk 123:301–312. https://doi.org/10.1093/auk/123.2.301

Allouche O, Kalyuzhny M, Moreno-Rueda G, et al (2012) Area-heterogeneity tradeoff and the diversity of ecological communities. Proc Natl Acad Sci U S A 109:17495–17500. https://doi.org/10.1073/pnas.1208652109

Baryga A, Połeć B, Klasa A (2020) Quality of sugar beets under the effects of digestate application to the soil. Processes 8:1–12. https://doi.org/10.3390/pr8111402

Bates D, Maechler M, Bolker B, Walker S (2015) Fitting Linear Mixed-Effects Models Using lme4. J Stat Softw 67:1–48. https://doi.org/10.18637/jss.v067.i01

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol Evol 18:182–188. https://doi.org/10.1016/S0169-5347(03)00011-9

Bibby CJ, Burgess ND, Hill DA, Mustoe S (2000) Bird census techniques. Academic Press, London, United Kingdom

Bode M, Probert W, Turner WR, et al (2011) Conservation planning with multiple organizations and objectives. Conserv Biol 25:295–304. https://doi.org/10.1111/j.1523-1739.2010.01610.x

Brumm H, Slabbekoorn H (2005) Acoustic communication in noise. Adv Study Behav 35:151–209. https://doi.org/10.1016/S0065-3454(05)35004-2

Chen D, Liao J, Bearup D, Li Z (2020) Habitat heterogeneity mediates effects of individual variation on spatial species coexistence. Proc R Soc B: Biol Sci 287:20192436.

https://doi.org/10.1098/rspb.2019.2436

Cornell KL, Donovan TM (2010) Scale-Dependent Mechanisms of Habitat Selection for a Migratory Passerine: An Experimental Approach. Auk 127:899–908. https://doi.org/10.1525/auk.2010.09171

Dall SRX, Giraldeau LA, Olsson O, et al (2005) Information and its use by animals in evolutionary ecology. Trends Ecol Evol 20:187–193. https://doi.org/10.1016/j.tree.2005.01.010

Doligez B, Cadet C, Danchin E, Boulinier T (2003) When to use public information for breeding habitat selection? The role of environmental predictability and density dependence. Anim Behav 66:973–988. https://doi.org/10.1006/anbe.2002.2270

Doligez B, Doligez B, Danchin E, Clobert J (2002) Public Information and Breeding Habitat Selection in a Wild Bird Population. Science (80-) 297:1168–1170. https://doi.org/10.1126/science.1072838

Donald PF, Green RE, Heath MF (2001) Agricultural intensification and the collapse of Europe’s farmland bird populations. Proc R Soc B: Biol Sci 268:25–29. https://doi.org/10.1098/rspb.2000.1325

Fahrig L, Baudry J, Brotons L, et al (2011a) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101–112. https://doi.org/10.1111/j.1461-0248.2010.01559.x

Fahrig L, Baudry J, Brotons L, et al (2011b) Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101–112. https://doi.org/10.1111/j.1461-0248.2010.01559.x

Fahrig L, Girard J, Duro D, et al (2015) Farmlands with smaller crop fields have higher within-field biodiversity. Agric Ecosyst Environ 200:. https://doi.org/10.1016/j.agee.2014.11.018

Fletcher, Jr. RJ (2007) Species interactions and population density mediate the use of social cues for habitat selection. J Anim Ecol 76:598–606. https://doi.org/10.1111/j.1365-2656.2007.01230.x

Fletcher RJ (2007) Species interactions and population density mediate the use. J Anim Ecol 76:598–606. https://doi.org/10.1111/j.1365-2656.2007.01230.x

Gastauer M, Sarmento PS de M, Caldeira CF, et al (2021) Shannon tree diversity is a surrogate for mineland rehabilitation status. Ecol Indic 130:. https://doi.org/10.1016/j.ecolind.2021.108100

Gorini L, Linnell JDC, May R, Panzacchi M, Boitani L, Odden M, Nilsen Erlend B (2011) Habitat heterogeneity and mammalian predator-prey interactions. Mamm Rev 42:55–77. https://doi.org/10.1111/j.1365-2907.2011.00189.x

Golawski A, Sytykiewicz H (2021) How urban and rural birds respond to the colour of bird feeders? J Ornithol 162:1193–1198. https://doi.org/10.1007/s10336-021-01907-8

Gregory RD, Van Strien A, Vorisek P, Gmelig Meyling AW, Noble DG, Foppen RP, Gibbons DW (2005) Developing indicators for European birds. Philos. Trans. R. Soc. B: Biol. Sci. 360:

Guisan A, Thuiller W (2005) Predicting species distribution: Offering more than simple habitat models. Ecol Lett 8:993–1009. https://doi.org/10.1111/j.1461-0248.2005.00792.x

GUS Statistics Poland (2013) National Agricultural Census 2010

Hromada M, Antczak M, Valone TJ, Tryjanowski P (2008) Settling Decisions and Heterospecific Social Information Use in Shrikes. PLoS One 3:26–30. https://doi.org/10.1371/journal.pone.0003930

Husby M (2017) Traffic influence on roadside bird abundance and behaviour. Acta Ornithol 52:93–103. https://doi.org/10.3161/00016454AO2017.52.1.009

Jager HI, King AW, Schumaker NH, et al (2005) Spatial uncertainty analysis of population models. Ecol Modell 185:13–27. https://doi.org/10.1016/j.ecolmodel.2004.10.016

Kadmon R, Allouche O (2007) Integrating the effects of area, isolation, and habitat heterogeneity on species diversity: A unification of island biogeography and niche theory. Am Nat 170:443–454. https://doi.org/10.1086/519853

Kociolek A V., Clevenger AP, St. Clair CC, Proppe DS (2011) Effects of road networks on bird populations. Conserv Biol 25:241–249. https://doi.org/10.1111/j.1523-1739.2010.01635.x

Koco Š, Vilček J, Torma S, et al (2020) Optimising potato (Solanum tuberosum L.) cultivation by selection of proper soils. Agric 10:1–10. https://doi.org/10.3390/agriculture10050155

Kotowska D, Skórka P, Walasz K (2019) Delineating the number of animal territories using digital mapping and spatial hierarchical clustering in GIS technology. Ecol Indic 107:105670. https://doi.org/10.1016/j.ecolind.2019.105670

Kuczyński L, Chylarecki P (2012) Atlas pospolitych ptaków lęgowych Polski. Rozmieszczenie, wybiórczość siedliskowa, trendy. GIOŚ, Warszawa

Levine N (2015) CrimeStat: A Spatial Statistics Program for the Analysis of Crime Incident Locations

Lundholm JT (2009) Plant species diversity and environmental heterogeneity: spatial scale and competing hypotheses. J Veg Sci 20:377–391. https://doi.org/10.1111/j.1654-1103.2009.05577.x

Main Office of Geodesy and Cartography (2017) National Integration of Land Registry. In: geoportal.gov.pl. https://integracja.gugik.gov.pl/cgi-bin/KrajowaIntegracjaEwidencjiGruntow

Mcnew LB, Gregory AJ, Sandercock BK (2013) Spatial heterogeneity in habitat selection: Nest site selection by greater prairie-chickens. J Wildl Manage 77:791–801. https://doi.org/10.1002/jwmg.493

Oksanen J, Blanchet, F. Guillaume Friendly M, Kindt R, et al (2020) vegan: Community Ecology Package

OpenStreetMap Contributors (2022) Openstreetmap

Pearce J, Ferrier S (2000) Evaluating the predictive performance of habitat models developed using logistic regression. Ecol Modell 133:225–245. https://doi.org/10.1016/S0304-3800(00)00322-7

Perry EF, Manolis JC, Andersen DE (2008) Reduced predation at interior nests in clustered all-purpose territories of least flycatchers (Empidonax minimus). Auk 125:643–650. https://doi.org/10.1525/auk.2008.07001

Pickett SRA, Siriwardena GM (2011) The relationship between multi-scale habitat heterogeneity and farmland bird abundance. Ecography (Cop) 34:955–969. https://doi.org/10.1111/j.1600-0587.2011.06608.x

QGIS Association (2022) QGIS Geographic Information System

R Core Team (2021) R: A language and environment for statistical computing.

Schmidt KA, Dall SRX, van Gils JA (2010) The ecology of information: an overview on the ecological significance of making informed decisions. Oikos 119:304–316. https://doi.org/10.1111/j.1600-0706.2009.17573.x

Seppänen JT, Forsman JT, Mönkkönen M, Thomson RL (2007) Social information use is a process across time, space, and ecology, reaching heterospecifics. Ecology 88:1622–1633. https://doi.org/10.1890/06-1757.1

Skórka P (2016) The detectability and persistence of road-killed butterflies: An experimental study. Biol Conserv 200:36–43. https://doi.org/10.1016/j.biocon.2016.05.026

Stamps JA (1988) Conspecific attraction and aggregation in territorial species. Am Nat 131:329–347. https://doi.org/10.1086/284793

Stein A, Gerstner K, Kreft H (2014) Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. Ecol Lett 17:866–880. https://doi.org/10.1111/ele.12277

Suzuki TN (2015) Assessment of predation risk through referential communication in incubating birds. Sci Rep 5:10239. https://doi.org/10.1038/srep10239

Suzuki TN, Kutsukake N (2017) Foraging intention affects whether willow tits call to attract members of mixed-species flocks. R Soc Open Sci 4:170222. https://doi.org/10.1098/rsos.170222

Szymkowiak J (2013) Facing uncertainty: how small songbirds acquire and use social information in habitat selection process? Springer Sci Rev 1:115–131. https://doi.org/10.1007/s40362-013-0012-9

Szymkowiak J, Thomson RL, Kuczynski L (2017) Interspecific social information use in habitat selection decisions among migrant songbirds. Behav Ecol 28:767–775. https://doi.org/10.1093/beheco/arx029

Tews J, Brose U, Grimm V, et al (2004) Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. J Biogeogr 31:79–92. https://doi.org/10.5700/rege502

Tomiałojć L (1980a) The combined version of the mapping method. In: Oelke H (ed) Bird Census Work and Nature Conservation. Proc.VI Intern. Conf. Bird Census and Atlas Work, Göttingen, pp 92–106

Tomiałojć L (1980b) Combined version of the mapping method. Notatki Ornitol 21:33–54

Tryjanowski P, Møller AP, Morelli F, et al (2016) Urbanization affects neophilia and risk-taking at bird-feeders. Sci Rep 6:1–7. https://doi.org/10.1038/srep28575

Venables WN, Ripley BD (2002) Modern Applied Statistics with S, Fourth Edi. Springer, New York

Ward MP, Benson TJ, Semel B, Herkert JR (2010) The use of social cues in habitat selection by Wetland birds. Condor 112:245–251. https://doi.org/10.1525/cond.2010.090238

www.xeno-canto.org www.xeno-canto.org

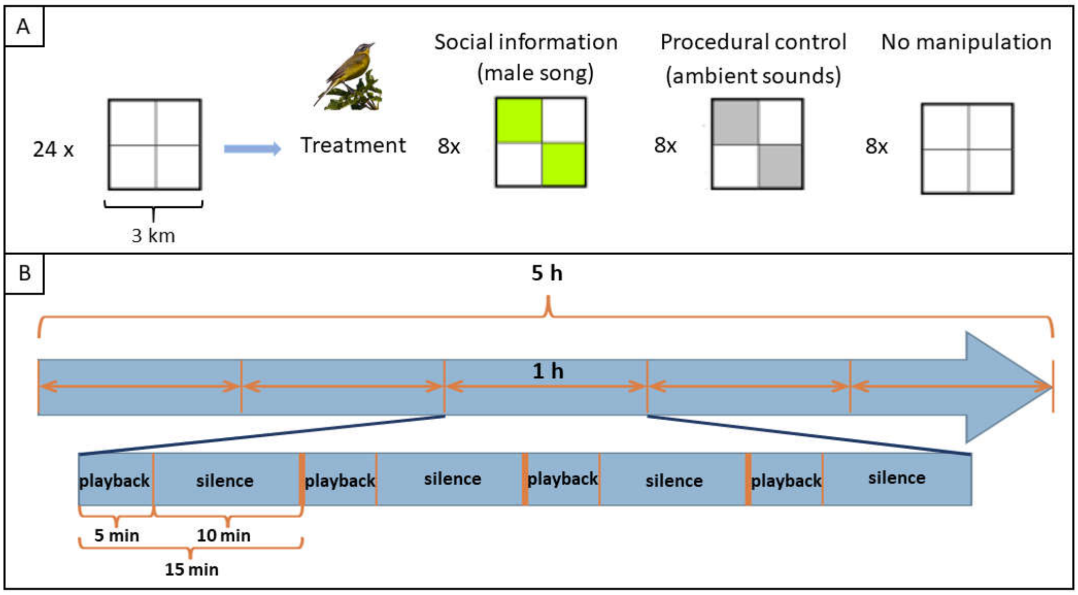


Figure 1. The experimental design used in the study. A - division of the plots into individual manipulations and arrangement of playbacks inside the plots. B - Arrangement of the playback path with social information and procedural control.

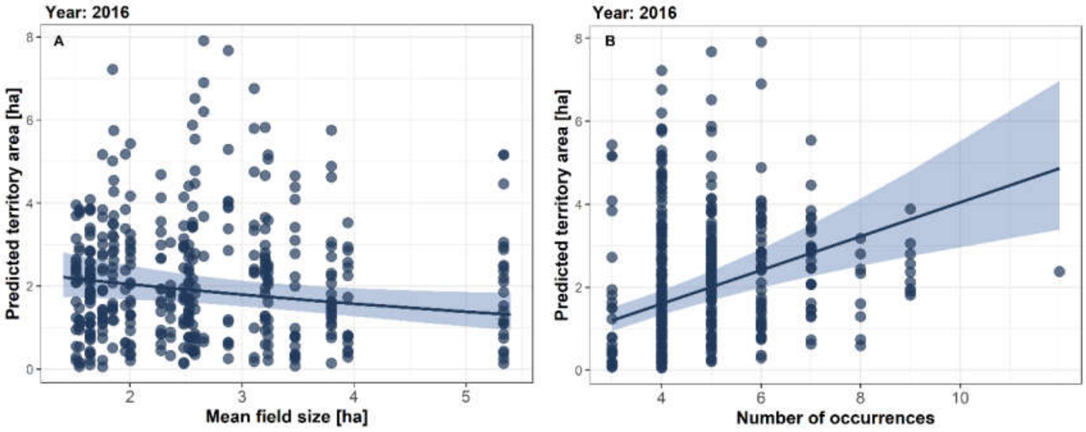


Figure 2. Results of linear mixed model showing statistically significant predictors of the territory area of the yellow wagtail. (A) - the mean field size, and the number of occurrences in each delineated territory (B) in year 2016 (pre-manipulation year). The predicted associations are represented by lines, confidence intervals are represented by the shaded region, while semi-transparent points represent original data.

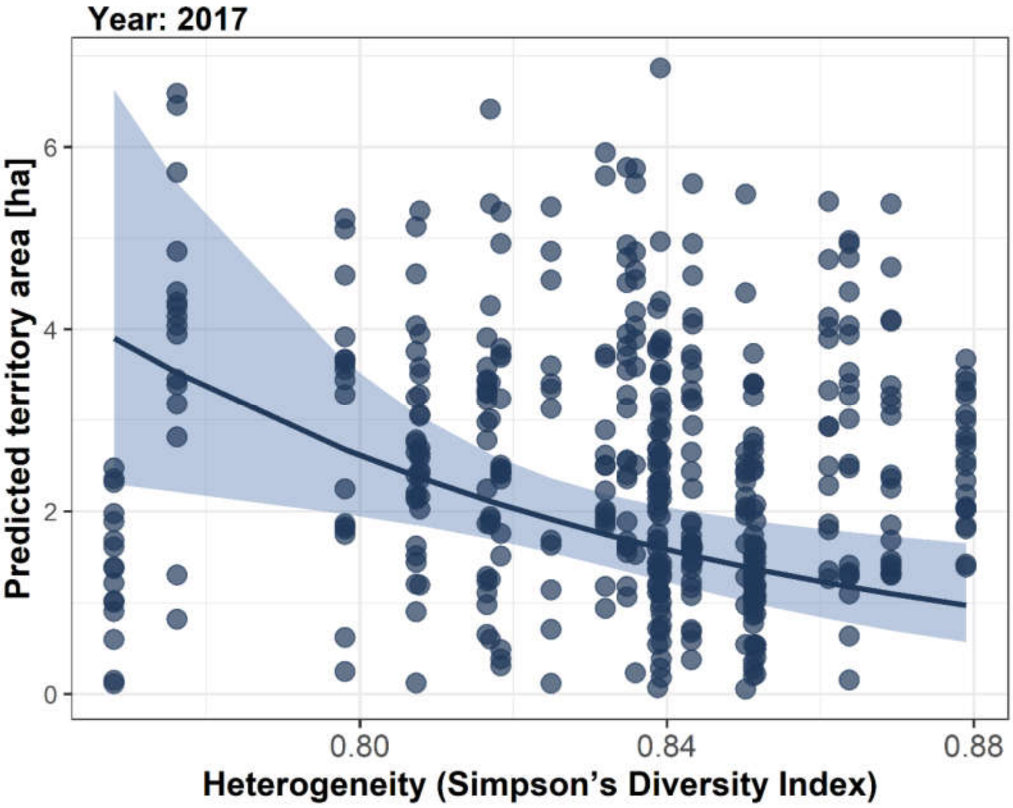


Figure 3. Results of linear mixed model showing a statistically significant prediction of the territory area of the yellow wagtail by the habitat heterogeneity in plots (expressed as Simpson's Diversity Index) in year 2017 (manipulation year). The predicted relationship is represented by a line, confidence intervals are represented by the shaded region, while semi-transparent points represent original data.

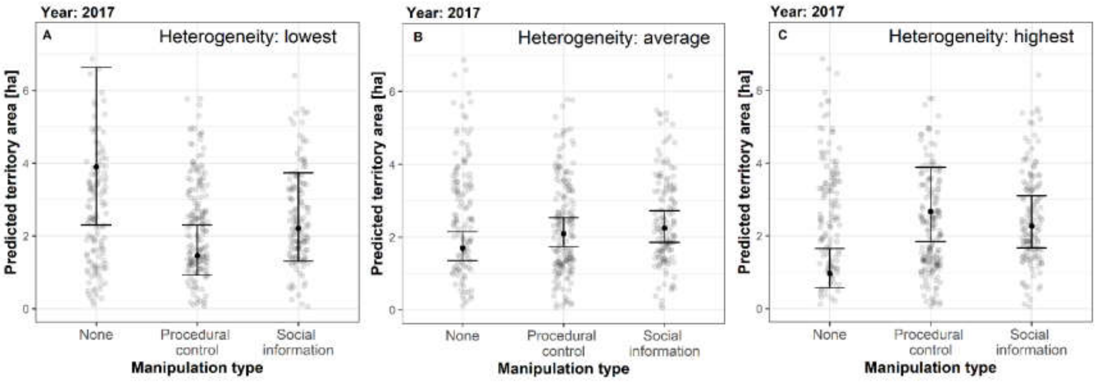


Figure 4. Predicted territory area of the yellow wagtail at different values of habitat heterogeneity in plots calculated from the original data: the minimum (A), average (B) and maximum (C). The plot identity was set as a random factor. The whiskers represent confidence intervals of estimated mean (black point) and grey points represent original data (territory sizes).

Table 1. Effects of the explanatory variables on the overall number of yellow wagtails' territories (GLM), NN_index (the index of territory clustering, LM) and the territory area (LMM) in year 2016 (pre-manipulation year) and 2017 (manipulation year). Plot identity was set as a random factor. Plots with no manipulation are a reference level for other terms estimates. Statistically significant effects are emboldened and marked with asterisks: *** - p<0.001, ** - p<0.01, *p<0.05.

	Year 2016	Year 2017
Response variable: Number of territories	*GLM estimates of slopes with standard errors (in brackets) for explanatory variables with assumed negative binomial response*	
(Intercept)	-1.015 (4.523)	2.311 (3.445)
Manipulation: procedural control	4.194 (5.771)	-3.439 (4.346)
Manipulation: social information	-2.397 (7.018)	-1.339 (4.427)
Heterogeneity	4.060 (5.290)	1.162 (4.189)
Mean field size	0.062 (0.075)	-0.047 (0.060)
Length of the roads	0.007 (0.013)	-0.021 (0.011)
(Manipulation: procedural control)*heterogeneity	-4.709 (6.893)	4.311 (5.256)
(Manipulation: social information)*heterogeneity	3.045 (8.352)	1.589 (5.326)
Response variable: NN_Index	*LM estimates of slopes with standard errors (in brackets) for explanatory variables with assumed normal response*	
(Intercept)	-1.542 (3.189)	-1.733 (2.934)
Manipulation: procedural control	5.433 (4.244)	1.751 (3.750)
Manipulation: social information	3.991 (5.289)	5.447 (3.764)
Heterogeneity	3.270 (3.734)	3.236 (3.588)
Mean field size	-0.003 (0.056)	0.024 (0.052)
Length of the roads	-0.001 (0.010)	0.005 (0.010)
(Manipulation: procedural control)*heterogeneity	-6.546 (5.071)	-2.137 (4.546)
(Manipulation: social information)*heterogeneity	-4.811 (6.300)	-6.457 (4.532)
Response variable: log10(Territory area)	*LMM estimates of slopes with standard errors (in brackets) for explanatory variables with assumed normal response*	
(Intercept)	1.333 (1.550)	**3.886 (1.592)***
Manipulation: procedural control	-1.972 (1.993)	**-6.416 (2.022)****
Manipulation: social information	-4.617 (2.465)	**-4.509 (2.031)***
Heterogeneity	-1.941 (1.805)	**-5.441 (1.941)***
Mean field size	**-0.057 (0.025)***	0.037 (0.027)
Length of the roads	0.003 (0.004)	**0.014 (0.005)***
(Manipulation: procedural control)*heterogeneity	2.237 (2.377)	**7.799 (2.449)****
(Manipulation: social information)*heterogeneity	5.319 (2.927)	**5.551 (2.445)***
log10(N occurrences in territory)	**1.010 (0.173)*****	**0.841 (0.126)*****

SUPPORTING INFORMATION

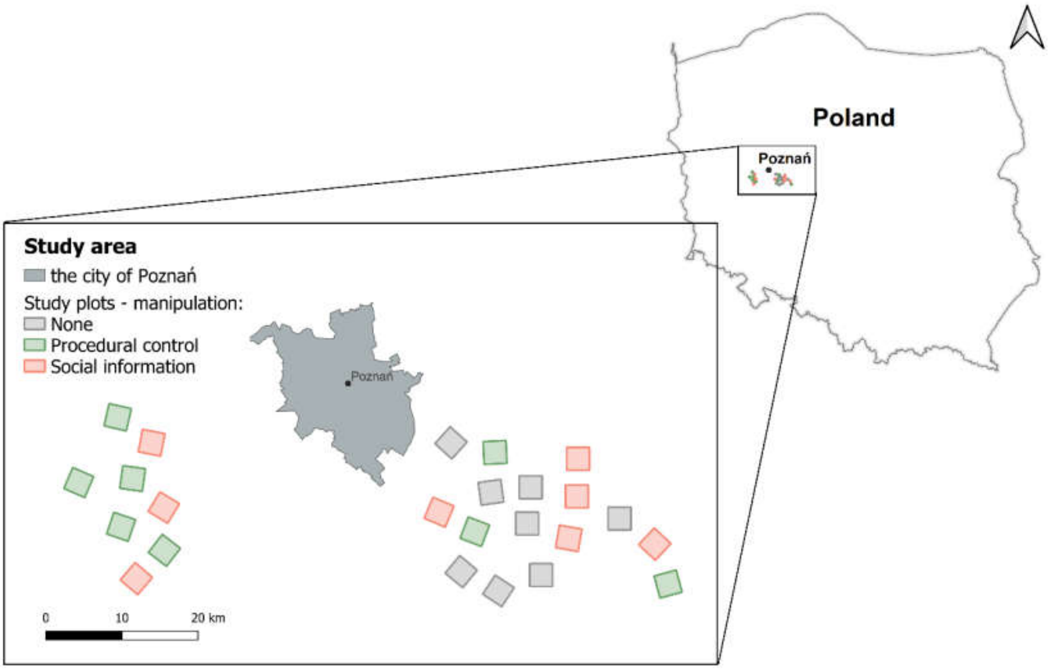


Figure S1. The localization of study plots in Poland. Colour of the plots corresponds with the experimental manipulations.

Figure S2. Loudspeaker hanging on a shrub during an experiment with broadcasting social information in 2017 (fot. S. Pustkowiak).

SUPPORTING INFORMATION

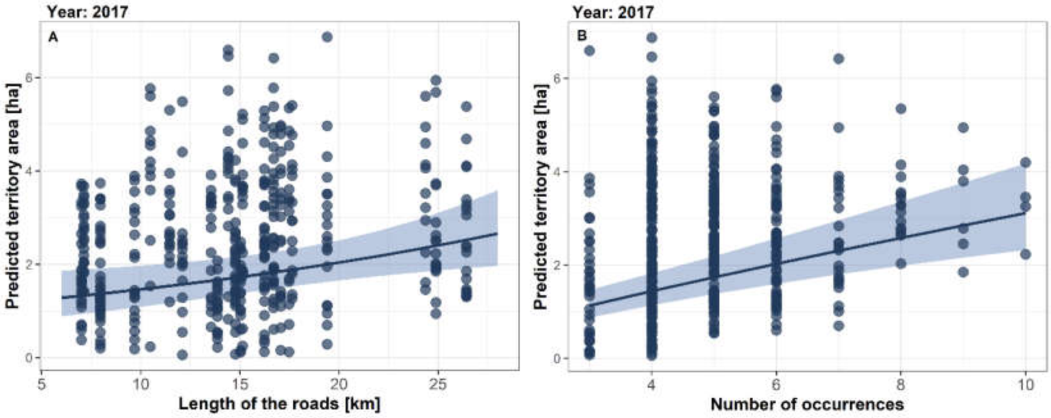


Figure S3. Results of LMM model showing statistically significant predictions of the territory area of the yellow wagtail by the length of the roads (A) and the number of occurrence records in each delineated territory (B) in year 2017 (manipulation year). The predicted associations are represented by lines, confidence intervals are represented by the shaded region, while semi-transparent points represent original data.

Figure S4. Yellow wagtail is often found near piles of manure where they catch insects (fot. S. Pustkowiak).

SUPPORTING INFORMATION

Table S1. Basic statistics of the distribution of the analyzed dependent variables in both research years

	Year 2016			Year 2017		
	Number of territories	NN index	Territory area [ha]	Number of territories	NN index	Territory area [ha]
Mean	16.6	1.14	2.14	18.1	1.10	2.47
SD	5.0	0.18	1.48	5.7	0.20	1.39
Min	7	0.84	0.06	10	0.84	0.06
Max	24	1.50	7.91	37	1.76	6.87

Table S2. The matrix of correlations between explanatory variables used in the models predicting number, clustering and the size of the yellow wagtail's territories. Presented value is the Pearson's correlation coefficient between the two variables, the result of the correlation test is marked with asterisks: ** - $p<0.01$,

	Heterogeneity 2016	Heterogeneity 2017	Mean field size	Length of the roads
Heterogeneity 2016		0.600**	-0.180	-0.088
Heterogeneity 2017	0.600**		-0.006	0.008
Mean field size	-0.180	-0.006		-0.080
Length of the roads	-0.088	0.008	-0.080	

Sound References:

Piotr Szczypiński 2013. *Motacilla flava*, XC134257. www.xeno-canto.org

Piotr Szczypiński 2013. *Motacilla flava*, XC151528. www.xeno-canto.org

Piotr Szczypiński 2014. *Motacilla flava*, XC187550. www.xeno-canto.org

Piotr Szczypiński 2015. *Motacilla flava*, XC252756. www.xeno-canto.org

Piotr Szczypiński 2015. *Motacilla flava*, XC252757. www.xeno-canto.org

Bodo Sonnenburg 2016. *Motacilla flava*, XC314267. www.xeno-canto.org

Bodo Sonnenburg 2015. *Motacilla flava*, XC264281. www.xeno-canto.org

Oświadczenie Kandydata o zakresie wkładu merytorycznego w publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej

Stopień naukowy, imię i nazwisko Kandydata
Mgr inż. Sylwia Pustkowiak

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Bełcik, M., & Skórka, P. Does social information change the number, distribution and size of animal territories when habitat heterogeneity varies?

Mój udział był następujący:

Merytoryczny udział w publikacji:

Jestem głównym autorem i uczestniczyłam w powstawaniu jej założeń metodycznych. Realizowałam główną część badań terenowych, koordynowałam pracę zespołu, a także przeprowadziłam wszystkie analizy, opracowanie statystyczne wyników oraz ich prezentację graficzną. Przygotowałam pierwszą wersję manuskryptu, a następnie naniosłam poprawki zasugerowane przez współautorów.

Procentowy udział w publikacji: **70%**

Sylwia Pustkowiak

28.06.2022

....

(data, podpis Kandydata)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr Zbigniew Kwieciński

Zakład Ekologii i Antropologii, Instytut Biologii, Uniwersytet Szczeciński, Wąska 13, 71-415, Szczecin, Polska

Zakład Biologii i Ekologii Ptaków, Instytut Biologii Środowiska, Wydział Biologii, Uniwersytet im. Adama Mickiewicza, Uniwersytetu Poznańskiego 6, 61-614 Poznań

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Bełcik, M., & Skórka, P. Does social information change the number, distribution and size of animal territories when habitat heterogeneity varies?

Mój udział był następujący:

Merytoryczny udział w publikacji:

Udzielałem krytycznych uwag i sugestii w całym procesie powstawania pracy. Brałem udział w pracach terenowych i zbieraniu danych do badań.

Procentowy udział w publikacji: **15%**

Zbigniew Kwieciński

27.06.2022r.

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

Mgr inż. Michał Bełcik

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Bełcik, M., & Skórka, P. Does social information change the number, distribution and size of animal territories when habitat heterogeneity varies?

Mój udział był następujący:

Merytoryczny udział w publikacji:

Udzielałem krytycznych uwag i sugestii w całym procesie powstawania pracy. Brałem udział w pracach terenowych i zbieraniu danych do badań.

Procentowy udział w publikacji: **5%**

24.06.2022 Bełcik

(data, podpis współautora)

Oświadczenie współautorów o zakresie udziału merytorycznego we wspólnych publikacjach, z których fragment stanowi samodzielną i wyodrębnioną część rozprawy doktorskiej mgr inż. Sylwii Pustkowiak

Stopień naukowy, imię i nazwisko współautora

dr hab. Piotr Skórka prof. IOP PAN

Instytut Ochrony Przyrody Polskiej Akademii Nauk, al. Adama Mickiewicza 33, 31-120 Kraków

Oświadczam, że w pracy:

Pustkowiak, S., Kwieciński, Z., Bełcik, M., & Skórka, P. Does social information change the number, distribution and size of animal territories when habitat heterogeneity varies?

Mój udział był następujący:

Merytoryczny udział w publikacji:

Brałem udział w tworzeniu koncepcji badań, analizie statystycznej zebranego materiału, a także udzielałem krytycznych uwag i sugestii w całym procesie powstawania pracy.

Procentowy udział w publikacji: **10%**

27.06.2022

....

(data, podpis współautora)