Received: 13 June 2024 | Revised: 21 October 2024 | Accepted: 4 November 2024
DOI: 10.1111/csp2.13286

CONTRIBUTED PAPER

Conservation Science and Practice
A journal of the Society for Conservation Biology
Open Access
WILEY

Identifying focus zones for the conservation and promotion of priority birds in Swiss farmland

Noëlle Klein[1,2] | **Antoine Adde**[3] | **Adrienne Grêt-Regamey**[2] | **Antoine Guisan**[3,4] | **Felix Herzog**[1] | **Philippe Jeanneret**[1] | **Sonja Kay**[1]

[1]Agricultural Landscapes and Biodiversity, Department of Agroecology and Environment, Zurich, Switzerland

[2]Planning of Landscape and Urban Systems (PLUS), Institute for Spatial and Landscape Planning, Department of Civil Environmental and Geomatic Engineering, ETH Zürich, Zürich, Switzerland

[3]Institute of Earth Surface Dynamics, Faculty of Geosciences and Environment, University of Lausanne, Lausanne, Switzerland

[4]Department of Ecology and Evolution, University of Lausanne, Lausanne, Switzerland

Correspondence
Noëlle Klein, Agricultural Landscapes and Biodiversity, Department of Agroecology and Environment, Agroscope, Reckenholzstrasse 191, 8046 Zurich, Switzerland.
Email: noelle.klein@agroscope.admin.ch

Funding information
Swiss Federal Office for the Environment (FOEN) // Swiss Government under the project “ValPar.CH: Values of the ecological infrastructure in Swiss parks”, Grant/Award Number: Pilot Project A1.2; BiodivERsA-Belmont Forum Call on “Scenarios of Biodiversity and Ecosystem services”, Grant/Award Number: BiodivScen-157

Abstract

Modern agriculture faces conflicting objectives—increasing agricultural production while preserving and fostering biodiversity. As intensive agricultural management threatens biodiversity, legal obligations aim to halt biodiversity loss and safeguard threatened species. In Switzerland, agricultural priority species have been defined to set environmental goals for biodiversity, with limited success so far. This study spatially defines farmland focus zones with potential for the promotion of priority species for conservation in agricultural landscapes. We overlaid information about field-level impact of agricultural activities using the Swiss Agricultural Life Cycle Assessment (SALCA-BD) as “impact of agricultural activities” with the potential distribution of Swiss priority birds. The potential distribution was assessed by aggregating predictions from species distribution models of 27 bird priority species. We identified significantly high/low values for management impact and potential distribution using hotspot analyses. Multivariate clustering was used to identify zones that should be preserved (low management impact, high bird potential) and zones where conservation measures could be promoted (high management impact, high bird potential). Zones which were minimally impacted by management and had a high potential for birds included grassland with structures, covering ca. 18% of the studied farmland. Zones with high management impacts consisted mainly of arable land with little structures, covering ca. 31% of the studied farmland, occurring mainly in the Swiss lowlands. Our results help to assess and visualize the intertwined links between agricultural management and the species inhabiting these agricultural landscapes in a spatially explicit manner. This can help to identify zones and regions for ecological promotion and set priorities for action within future agricultural policies.

KEYWORDS
agricultural priority species, birds, hot/cold spots, multivariate clustering, species distribution models

1 | INTRODUCTION

The way that agricultural landscapes are managed is known to influence biodiversity (Benton et al., 2002; Donald et al., 2006; Emmerson et al., 2016). Documented negative impacts include homogenization on the landscape-level, as well as increased fertilization and use of pesticides on field-level (Emmerson et al., 2016; Kleijn et al., 2009). It is also known that diverse semi-natural landscape features (hedges, flower strips, fallows, etc.) are highly important for agricultural biodiversity (Jeanneret et al., 2021; Klein et al., 2023; Maurer et al., 2022). Accordingly, in many European countries, agri-environmental schemes have been introduced since the 90s, aiming to promote biodiversity and stop its decline (Herzog et al., 2005).

With the aim to preserve the environment and foster biodiversity, in 2008, the Swiss government defined national environmental targets for agriculture (FOEN and FOAG, 2008). Herein agriculture-related environmental objectives are defined, which are to be protected in agricultural landscapes (FOEN and FOAG, 2008). An evaluation conducted in 2016 showed that most of the biodiversity targets were not reached yet, with regional deficits of biodiversity-friendly areas, and a lack of habitat diversity and connectivity in farmland (BAFU and BLW, 2016), while the Swiss farmland biodiversity monitoring confirmed biodiversity deficits, particularly in the lowlands (Meier et al., 2021). Especially the pressure on agricultural land is increasing also through other factors such as urbanization (BAFU and BLW, 2016; Meier et al., 2022). Accordingly, many populations of farmland species are still declining, and a high proportion of these species is red-listed (Knaus et al., 2021, 2018). This is in line with the trends in many other countries (IPBES, 2019).

In the European Union, scientists have urged the European Common Agricultural Policy (CAP) to improve spatial planning and landscape-scale implementation in order to halt biodiversity loss (Pe'er et al., 2022). For Switzerland, to increase the effectiveness of agri-environmental measures, Walter et al. (2013) argue that a focus must be laid on regional prioritization based on the respective local potential, both for agricultural production and for biodiversity. To reach the national targets, increasing habitat quality at suitable locations and fostering protection schemes for priority species are essential (Walter et al., 2013). Therefore, it is important to optimize the placement of agri-environmental schemes to minimize negative effects to biodiversity. Different regions and habitats need to be considered for different species, and thus agri-environmental schemes must also be differently implemented in different regions. In 2017, this idea was incorporated into the Federal Constitution of the Swiss Confederation stating that "… [food production] is adapted to local conditions and (which) uses natural resources efficiently […]" (Art. 104a). This was concretized by the Swiss Agricultural Visions 2050 (Bundesrat, 2022), which emphasize, among other things, that agricultural production should be adapted to the carrying capacity of ecosystems while promoting biodiversity. To find long-term locally tailored solutions for both agriculture and biodiversity, it is crucial to develop tools that can delineate focus zones for the future conservation of species in farmland.

Birds are commonly used as indicator species for biodiversity monitoring in agricultural landscapes (Benton et al., 2002; Gregory et al., 2003; Zingg et al., 2019). They have been documented to be influenced by agricultural management, with generally negative impacts of intensification and positive impacts provided by landscape elements and heterogeneity (Klein et al., 2023; Zingg et al., 2018, 2019). Even though many bird species occurring in Swiss agricultural landscapes are listed as national priority species (FOEN and FOAG, 2008), most of their populations are still declining (Knaus et al., 2021). A specific set of species, 47 bird species among them, has been defined as so-called "agriculture-related environmental objectives (AEO species; Walter et al., 2012)," which are priority species for conservation in agricultural landscapes. In contrast to plants and invertebrates, birds are highly mobile, which enables them to move between habitat types and regions. As part of the national project Valpar.CH (Reynard et al., 2021), a large number of species—including most bird species—was modeled in Switzerland using a newly developed pipeline including the latest advances in species distribution modeling (SDMs; Adde, Rey, Brun, et al., 2023), which provide valuable data for biodiversity conservation planning (Guisan et al., 2013; Ramel et al., 2020).

The aim was to assess the current situation and identify focus zones for the conservation and promotion of agricultural priority bird species in Switzerland. Here, to foster long-term locally tailored solutions for both agriculture and biodiversity, we tested a new spatial approach to identify focus zones for farmland bird conservation. To this end, we spatially overlaid "impact of agricultural activities" assessed through field-level management, with "potential distribution" of the species studied. The impact of agricultural activities was derived from a Life Cycle Assessment (LCA) method that estimates the potential impact of agricultural management activities on 11 different indicator groups. The potential distribution was estimated with the national N-SDM outputs (see above) for our bird species.

2 | METHODS

To delineate focus zones for the conservation and promotion of AEO species, we linked the estimated agricultural management impact on birds with their predicted potential distribution. A life cycle assessment tool (described in section 2.1) was applied to yield a prediction of the impact of agricultural activities on birds (M1; Figure 1). SDMs were run to estimate the potential distribution of target bird species (see section 2.2 and Data S1–S4, Supporting Information for technical details on the SDM modeling). Then, hot spot analyses were conducted separately for management impact and potential distribution maps, to identify zones with significantly low and high values (see section 2.3, and M2, and S2 in Figure 1). The resulting hot/cold spot maps were then combined with a clustering approach to yield a cluster map that shows the combined values for both predicted management impact and potential distribution. This results in a "focus map" showing spatial clusters where either existing agricultural activities should be maintained, or new biodiversity focus zones should be promoted (see section 2.4 for more details). In a last step, the focus map was underlaid with information on agricultural land cover and landscape in order to strengthen the link between the focus map results and more applied agricultural management implications.

2.1 | Impact of agricultural activities on birds (SALCA-BD)

The impact of land use on the environment can be assessed by tools such as Life Cycle Assessment (LCA) (e.g., Milà i Canals et al., 2007), which are commonly used for impact assessment in the industry sector (Crenna et al., 2020). The Swiss Agricultural Life Cycle Assessment for Biodiversity (SALCA-BD) (Jeanneret et al., 2014) is an expert-based and evidence-based tool that aims at estimating the relative impact of agricultural activities on biodiversity.

From an inventory of detailed agricultural practices (e.g., fertilization, pesticide application, mowing regime), the SALCA-BD tool scores the potential impact of those practices on 11 indicator species groups including birds, butterflies, and plants (Jeanneret et al., 2014). SALCA-BD can be a useful tool to describe the potential impact of a given combination of crop type and detailed agricultural activity options on indicator species and compare the impact to alternative combinations. Combining habitat and management coefficients with ratings of individual management options, the scores range between 0 and 50, with 50 indicating very favorable activities for the species. SALCA-BD has been named one of the best LCA approaches to assess impact of agriculture on biodiversity (Curran et al., 2016), and the scores were shown to highly correlate with field-scale species richness (Klein et al., 2023; Lüscher et al., 2017).

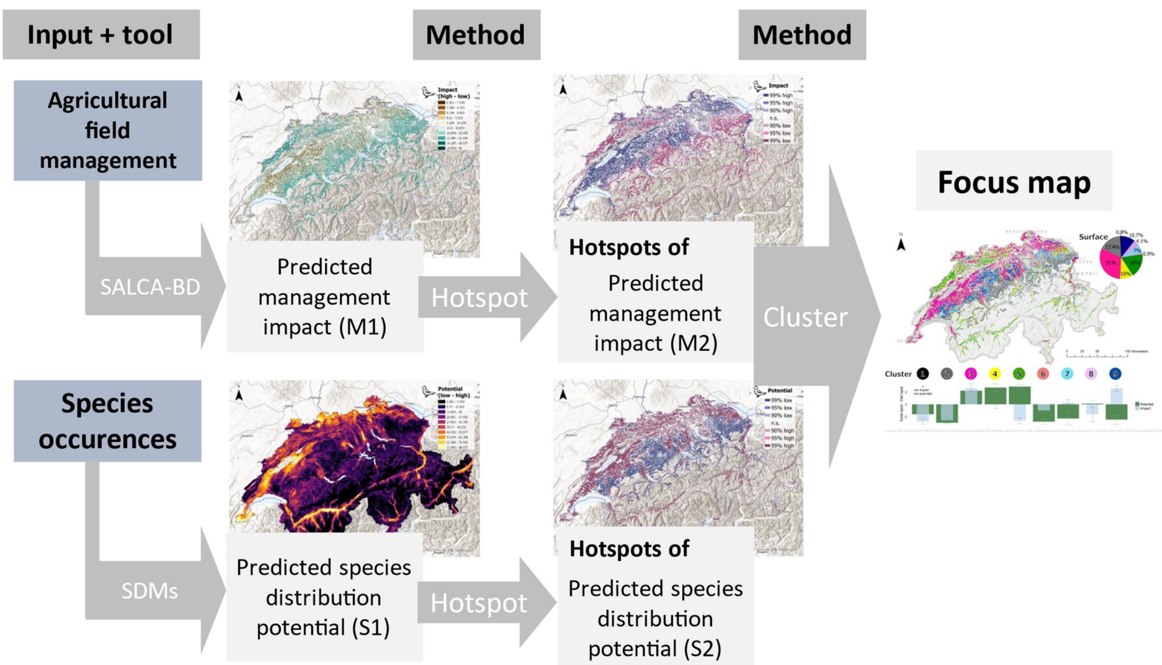

FIGURE 1 Workflow to identify focus zones for farmland bird (AEO species) conservation and promotion.

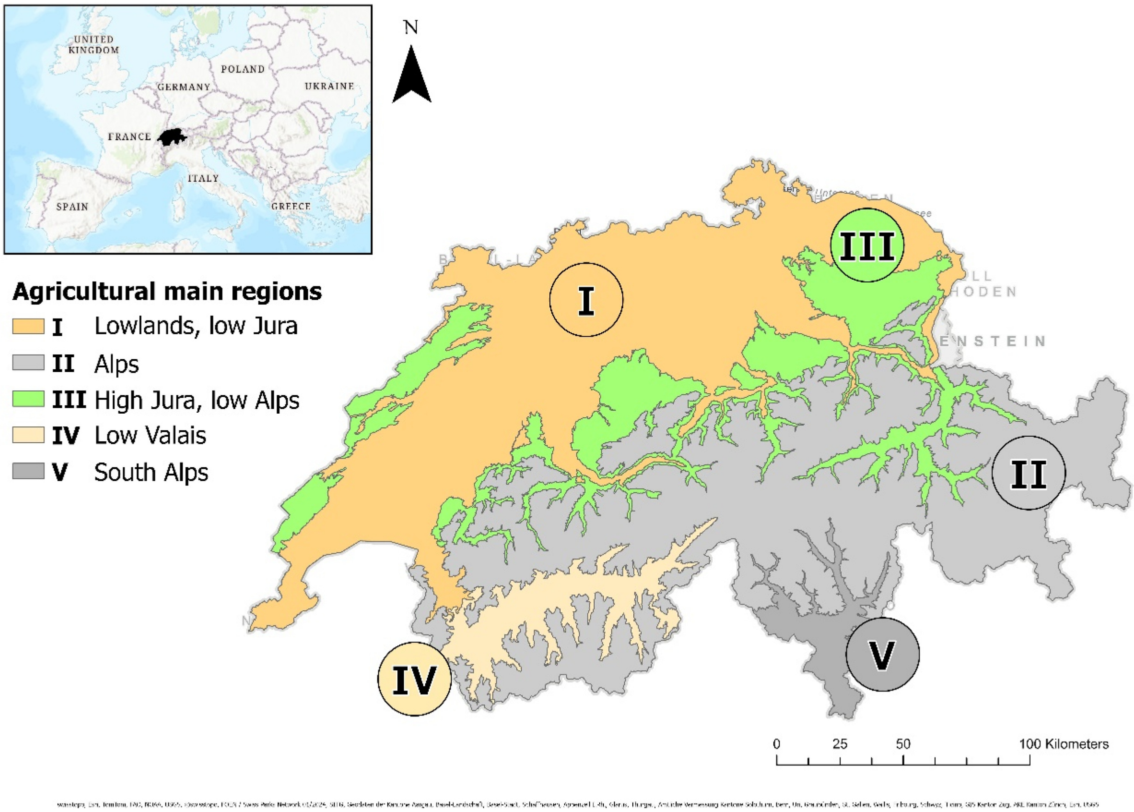

FIGURE 2 Map of the five Swiss agricultural main regions. (I) Lowlands-Low Jura, (II) Alps, (III) High Jura-low Alps, (IV) Low Valais, (V) South Alps.

The tool was fed with detailed publicly available agricultural land use data for all of Switzerland for the year 2021 (FOAG, 2021). The dataset consists of more than 3 million spatially explicit polygons of individual agricultural fields containing detailed information on 149 different land use categories (Data S1) with information on ecological focus area (EFA) for each polygon (yes/no). We combined this dataset with information on organic and extenso management, based on farm-level AGIS (Swiss agricultural political information system) data, which contains farm IDs that can be bound to the individual polygon fields belonging to each farm (FOAG and FOEN, 2021). Organic management refers to fields farmed according to the label regulations for organic farming, while extenso management is a national agri-environmental measure that promotes cereal and rapeseed production with reduced pesticide input (Bundesrat, 2013). This resulted in 149 land use categories, which were summarized to 63 categories with similar crop type/land use and agricultural activities (e.g., winter wheat and spelt) to enter the SALCA-BD tool (see Data S1 for all 149 classes and translation to 63 classes of similar agricultural activities). Standard agricultural activity procedures were allocated to each category, distinguishing between conventional, organic and extenso management types. Special or rare cultures that could not be included within SALCA-BD, such as tobacco or Christmas trees, were excluded from the analysis. The SALCA-BD scores for birds were computed for each standard activity regime and bound to the spatial field layer. Finally, we rasterized polygon-level scores by using a 25 m × 25 m grid.

2.2 | Potential distribution of Swiss priority bird species

Species distribution models (SDMs; Guisan & Thuiller, 2005) were run for a selected set of bird species (Data S1) which were listed as AEO species by the government (Walter et al., 2012). SDMs are commonly used in ecological research to map, assess, and evaluate the realized ecological niche of all kinds of species (Guisan & Thuiller, 2005). There are five different "agricultural main regions" of Switzerland with distinct conditions for agriculture, that are connected to the national environmental targets. Some AEO species only occur in specific regions. Figure 2 shows the Swiss agricultural main regions (Agroscope, 2016).

Out of all AEO bird species, we selected the subset of 27 species (Data S1) that occur in all agricultural main regions, to make the indicator (a) comparable to SALCA scores (that generalize the impact on species groups) and (b) comparable across Switzerland. *Corvus monedula* was excluded, as there were not enough data available to model the species.

SDMs for the 27 selected AEO bird species were built using the N-SDM software (Adde et al., 2023), which integrates a "global" model quantifying species response to bioclimatic conditions across their entire range, with a "regional" model that includes finer-scale habitat predictors specific to Switzerland. Two sets of species occurrence records were utilized for inside (regional) and outside (global) Switzerland. For records within Switzerland, data were obtained from the Swiss Species Information Center InfoSpecies (www.infospecies.ch) on August 23, 2021, with a resolution of 25 m (https://doi.org/10.15468/htjezm). These records spanned from 1980 to 2021. Species occurrence data were retrieved for all months of the year, regardless of breeding status. This was relevant because the covariates used in the models were not designed to capture the seasonal dynamics of the species' potential distribution. To address spatial clustering, the records were spatially disaggregated, ensuring at least 200 m between any two points. For records outside Switzerland, data were obtained from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/) for the same species and timeframe on October 27, 2021 (https://doi.org/10.15468/dl.zwp3dx). These GBIF records were spatially disaggregated, with a minimum distance of 1 kilometer between points. Additionally, 10,000 random background pseudo-absences were generated for each species to contrast with the occurrences. Candidate environmental covariates ($n = 2001$) for modeling each species' distribution were sourced from the "SWECO25" database (v.1.0) (Külling et al., 2024) and automatically selected using the "covsel" procedure (Adde et al., 2023). The "covsel" algorithm includes filtering for multicollinearity ensuring that spatially correlated variables are not retained in the models to minimize the risk of spatial autocorrelation. Bioclimatic variables were downscaled to 25 m from a 1 km resolution using local regressions with an elevation model to account for topography and localized climatic phenomena (Broennimann, 2023; Külling & Adde, 2023; Külling et al., 2024). The dataset underwent a robust validation procedure with observational data, demonstrating high accuracy across both lowland and mountainous regions. Furthermore, in addition to the bioclimatic data, land use and cover variables were measured, tested, and selected at varying radii around observation points (ranging from 25 to 5 km). This approach was specifically designed to capture broader environmental contexts and account for the mobility of bird species, ensuring that habitat information is integrated at scales appropriate for species that interact with their environment beyond the immediate observation point. Model selection and evaluation were conducted using a consensus "Score" metric, which averages the AUC′ (or Somers' D, calculated as AUC * 2–1), the maxTSS, and the CBI (Adde et al., 2023). Ensemble SDMs were built using the five modeling algorithms available in N-SDM: Generalized Linear Model (GLM), Generalized Additive Model (GAM), Maxnet (MAX), Random Forest (RF), and light Gradient Boosted Machine (GBM). The output predictions from the five modeling algorithms were mapped across Switzerland on a 25 m resolution grid and combined by averaging the five maps for each species. All details on the parameters used for fitting and evaluating the models were documented using the ODMAP protocol (Zurell et al., 2020) (Data S2). For more information on the candidate covariates and N-SDM settings, see Data S3 and S4, respectively.

Finally, maps obtained for all individual bird species ($n = 27$) were averaged to obtain an aggregated priority species layer which was then used in the following analyses. Continuous values were stacked, as they retain the full range of habitat suitability information, providing detailed and ecologically realistic view of species richness. This approach avoids using (sometimes arbitrary) thresholds and better captures habitat gradients than binarized predictions, offering richer insights for prioritization. The resolution of the output average species layer was 25 m × 25 m, with prediction values ranging between 0 and 100 (low to high habitat suitability).

2.3 | Hot spot analyses

The aim of the hot spot analyses was to identify zones with high and low values for both SALCA-BD scores (0–50 = high to low predicted impact) and SDMs outputs (0–100 = low to high potential distribution), when compared to their neighboring cells. The method has been used in other studies to delineate zones with significantly high or low values for SDM maps (Cleasby et al., 2020; Schank et al., 2017). Hot spot analyses were conducted using the "Optimized Hot Spot Analysis" tool of the software ArcGIS pro (Esri Inc., 2023). The tool analyses the input data to create a map of statistically significant hot and cold spots using Getis-Ord Gi* statistics (Getis & Ord, 1992). Hot spots correspond to raster cells with significant higher (for potential distribution) or lower (for impact of agricultural activities) values than the surrounding cells. The analysis was conducted using (a) management impact (SALCA-BD scores) and

(b) potential distribution (averaged-SDM values for birds), resulting in two distinctive output maps (Figure 1, maps M2 and S2). These maps allowed identifying hot and cold spots at three significance levels (99%, 95%, 90%) and nonsignificant cells. The result was corrected for multiple testing and spatial dependence following the False Discovery Rate correction method (Esri Inc., 2023). We summarized the number of hot and cold spot cells per agricultural main region for (a) impact of agricultural activities and (b) potential species distribution.

2.4 | Cluster analyses

We applied a clustering approach to identify distinct clusters with various combinations of values for impact of agricultural activities and potential species distribution. Clustering analyses were conducted using the "Multivariate Clustering" tool of ArcGIS pro (Esri Inc., 2023), which was used to find clusters of similar data attributes using the *K*-means algorithm (Jain, 2010). The clustering analysis was conducted using the hot/cold spot significance maps obtained for impact of agricultural activities (M2) and species potential distribution jointly (S2). The clustering process was repeated for 2–30 clusters and the optimal number of clusters was set based on Pseudo-*F* statistics. This value illustrates the similarity within clusters and difference between clusters for each potential number of clusters. Higher values of *F* stats stand for a better fit of similarity/dissimilarity, indicating the optimal number of clusters. Pseudo-*F* statistics obtained for the 30 clustering runs are displayed in Data S1. There was a high increase in the *F* stats value until up to nine clusters, followed by a flattening of the curve. We therefore set the number of clusters to 9 when conducting the multivariate clustering analysis.

We finally overlaid the resulting cluster map with land cover and landscape information (e.g., agricultural main region, land cover, proportion of ecological focus area). The aim of this step was to link the land use composition driven by real-life agricultural practice with the different clusters to derive practical recommendations. Land cover was summarized to five main categories (arable, grassland, orchard, linear elements—including flower strip/fallow/margin/ruderal/stonewalls/hedge/paths, water).

3 | RESULTS

3.1 | Impact of agricultural activities on birds (M1)

The SALCA-BD scores ranged between 6.9 (high impact) and 50 (low impact), with a mean of 13.48 ± standard deviation of 5.73. Especially, the lowlands and the valley bottoms in the Alps, Low Valais, and South Alps were found to have many high-impact cells, while more low-impact cells could be found in higher elevation of the more mountainous regions High Jura/Low Alps, Low Valais, Alps, and South Alps (Figure 2). However, in the lowlands there were also scattered low-impact cells, creating a heterogeneous pattern between high- and low-impact cells, while there were nearly only low-impact cells in the High Jura/Low Alps, Low Valais, Alps, and South Alps.

3.2 | Potential distribution modeling of Swiss priority bird species (S1)

The averaged potential distribution map of all 27 AEO bird species (Data S1) had cell values ranging between 0 (lowest potential) and 98.1 (highest potential) with a mean of 20.32 ± 17.5. All single models obtained for the 27 species had a cross-validated Score value above 0.89, which indicated high predictive performances. The lowland was predicted with a mix of high and low potential cells. High potential cells could especially be found in a belt from Lake Geneva to the Seeland area surrounding Lake Neuchatel, Lake Murten, and Lake Biel. There were also higher potential cells in the High Jura mountains (western part of region III) and very high potential cells in the Low Valais. In contrast, low potential cells could be found in the eastern the High Jura/Low Alps, while the Alps and Low Valais only showed limited potential cells in the valley bottoms.

3.3 | Hot/cold spots of impact of agricultural activities and potential distribution (M2, S2)

The patterns of the hot spot analyses followed the general patterns of the potential distribution map but included the spatial relationships as compared to the neighboring cells. High impact of agricultural activities (hot spots) was mainly predicted for the lowland and the valley bottoms of the Alps, South Alps, and the Low Valais. Low impact (cold spots) was predicted for the High Jura/Low Alps and higher elevations in the Alps, South Alps, and Low Valais. In contrast to the impact map, high potential (hot spots) was predicted for the plateau region (southern lowland), as well as for western High Jura, Low Valais, and major areas of the Alpine valleys. Low potential (cold spots) was predicted for mideastern lowlands, as well as eastern High Jura/Low Alps, and some higher elevation the Alps. The results of the hot spot analyses are mapped in Data S1.

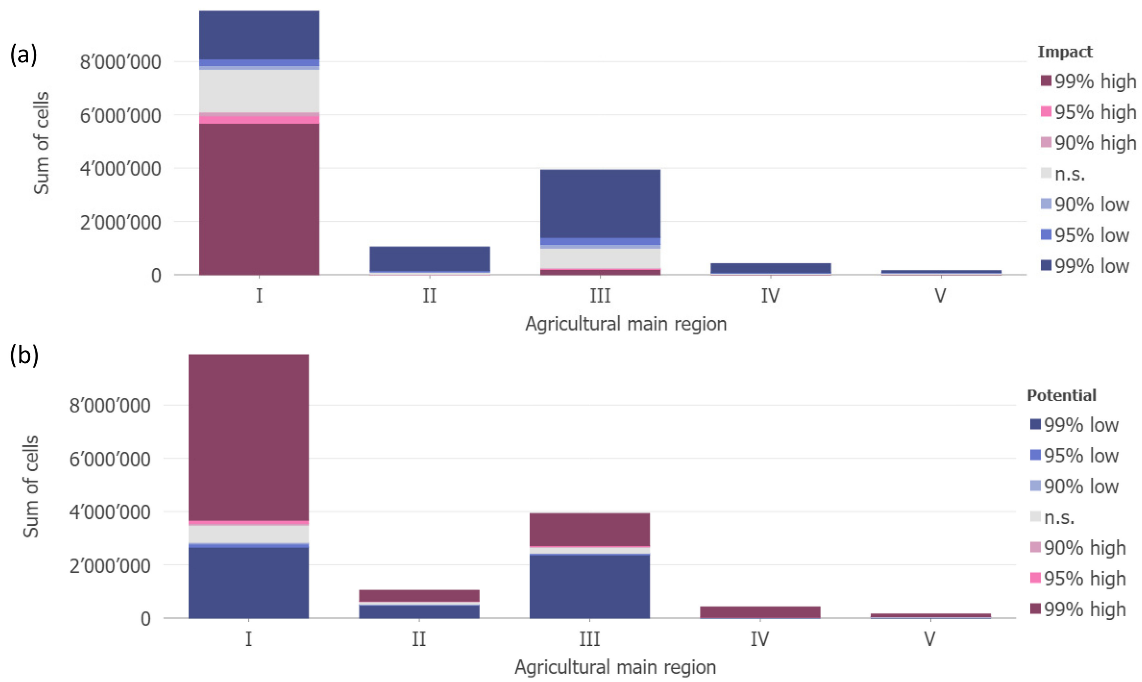

FIGURE 3 Number of hot and cold spot cells (Getis-Ord Gi* statistics significantly high and low values)) in Swiss agricultural main regions I–V, for impact of agricultural activities (cold spot = low impact) (top) and potential distribution (cold spot = low potential) for AEO bird species (bottom). The legend on the right side indicates the confidence interval for the hot and cold spots and the respective meaning for impact/potential.

Figure 3 illustrates the number of hot and cold spot cells per significance level for (a) impact of agricultural activities and (b) potential species distribution distinguished by Swiss agricultural main regions (see Figure 2). The highest number of high-impact cells was found in the lowland (region I), with 57.5% of significantly high impact cells (99%, blue), and only 18.0% low-impact cells (99%, purple). In contrast, 62.8% of the lowland (I) was classified as high potential cells (99%, purple) and only 27.0% as low potential (99%, blue). The lowland was by far the biggest region in terms of surface, with more than 10 million cells, compared to less than 150,000 in the Low Valais (IV). The lowest number of high-impact cells was found in the Alps (II), with only 0.42% high-impact cells and 85.1% low-impact cells. For the Alps (II), 38.6% of cells had a high potential and 46.3% had low potential. Substantial amounts of cells were also nonsignificantly high or low, making up 8.2–28.5% for impact of agricultural activities and 2.2–9.8% for potential distribution in regions I–V.

3.4 | Focus zones for AEO birds

Figure 4 shows the main output of the clustering analysis, with the different clusters being displayed visually on a focus map of Switzerland.

The nine clusters had different combinations of low/high impact of agricultural activities and low/high species potential distribution. For example, cluster 1 had a low agricultural activity impact and low species potential distribution, while cluster 3 had a high species potential distribution and high agricultural activity impact. Cluster 3 was the biggest cluster (31%) in terms of surface, mainly distributed across the lowland (44%; see Figure 2) with more than 4.5 million cells, followed by cluster 5 (18% of farmland, 21% of High Jura/Low Alps, and 75% of Low Valais) and 2 (17.4% of farmland, 43% of High Jura/Low Alps) with each more than 2.5 million cells. Finally, cluster 6 and 1 had less than 200,000 cells each. The two biggest clusters had the highest potential for species distribution: 3 (pink), and 5 (green). Cluster 4, which also had one of the top potentials for species distribution was commonly found as a transition layer between and around clusters 3 and 5. Cluster 3 was associated with a high impact of agricultural activity, but cluster 5 was associated with a low impact of agricultural activity ("low impact–high potential"). As expected, the high impact of agricultural activity in the lowland (clusters 3 and 9) fits to the main agricultural production area of Switzerland. In contrast, peripheral areas like High Jura/Low Alps and Low Valais showed lower intensities of agricultural activity (e.g., cluster 5). However, there were also surprisingly

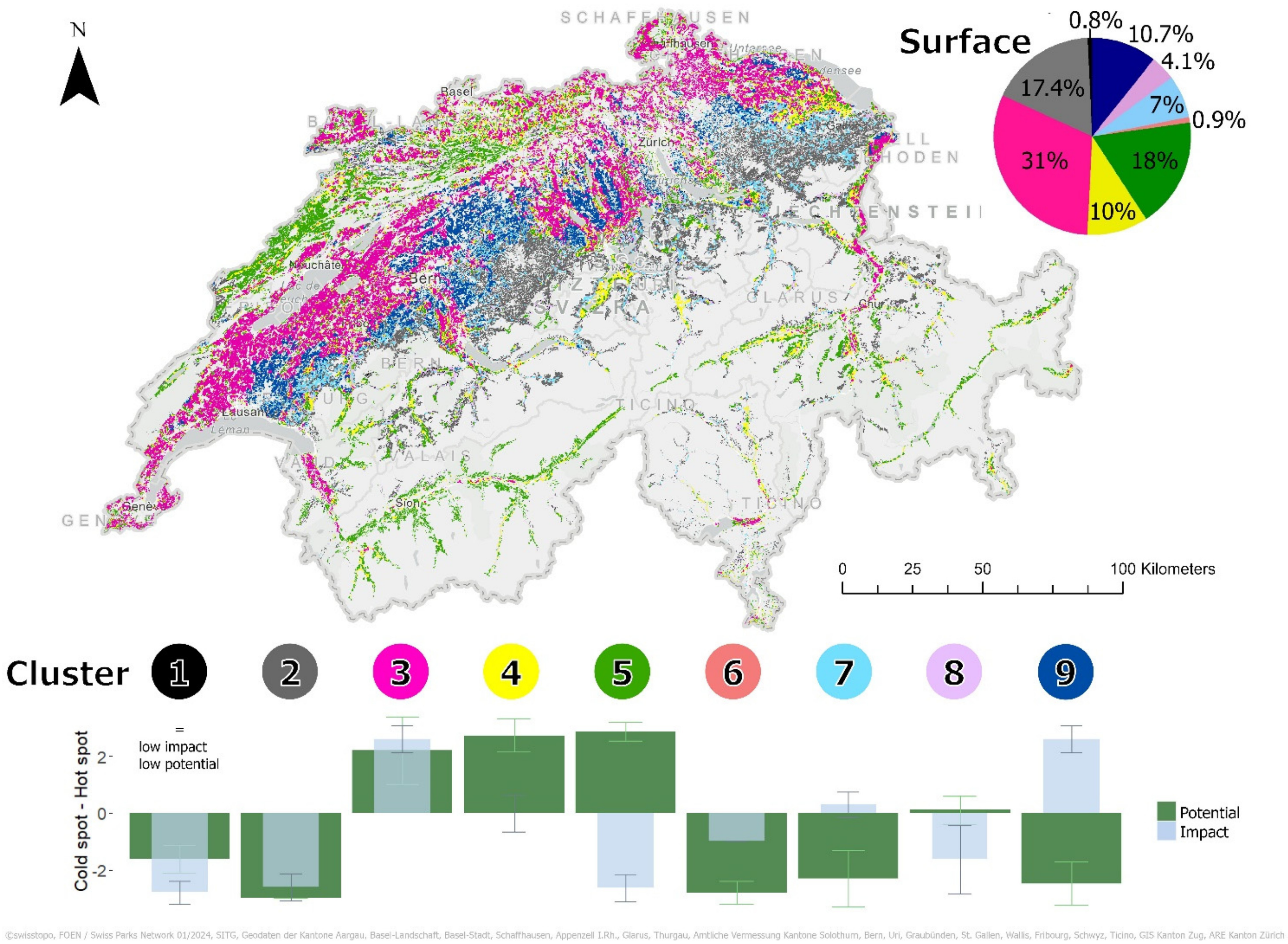

FIGURE 4 Focus map of hot/cold spots of impact of agricultural activities and potential distribution for AEO birds (top). For each cluster the mean significance level for Hot (1 = 90%, 2 = 95%, 3 = 99%) / Cold spots (−1 = 90%, −2 = 95%, −3 = 99%) of management impact and potential distribution for AEO birds is shown (bottom). Standard deviation is indicated with bars. Hot spots are equivalent to high management impact and high potential distribution.

high amounts of zones with low impact and low potential (cluster 2, 43% of the Alps and 45% of the High Jura/Low Alps), as well as low impact zones (cluster 5) scattered across the lowland (13.12%).

Figure 5a shows the land use composition of each cluster. The biggest clusters in terms of land surface were 3 (31%) and 5 (18%). High management zones with high potential (cluster 3) mainly consisted of arable land (76%), with lower shares of grassland (23%) and other land use types. In contrast, low impact zones with high potential (cluster 5) mainly consisted of grassland (86%), with low share of arable land (9%), but a relatively high share of linear elements (3%) and orchards (2%), comparable to zones with low impact and low potential (cluster 2, with 5% linear elements, 0.4% orchard). The presence of biodiversity promotion area (BPA, Swiss ecological focus area), reported for each cell in the different clusters, is shown in Figure 5b. Low-impact zones with high potential (cluster 5) had the highest share of BPA with 34% of cells, many of them in grassland, followed by 32% of cells in cluster 1 and 27% of cells in cluster 2, both zones with low impact and low potential. In zones with low impact and no significant potential (neither high nor low), 24% of cells were classified as BPA. In contrast, only 8.4% of the cells in high-impact zones with high potential (cluster 3) were classified as BPA. The lowland (see Figure 2) had the lowest number of BPA cells (13.2%), while the Alps (48%) and Low Valais (46%) had the highest.

4 | DISCUSSION

We identified regions with cold and hot spots of high and low impact of agricultural activities and potential distribution for the Swiss agricultural surface. A cluster analysis combined these two factors to a focus map (Figure 4) which can be used to delineate trade-offs and synergies

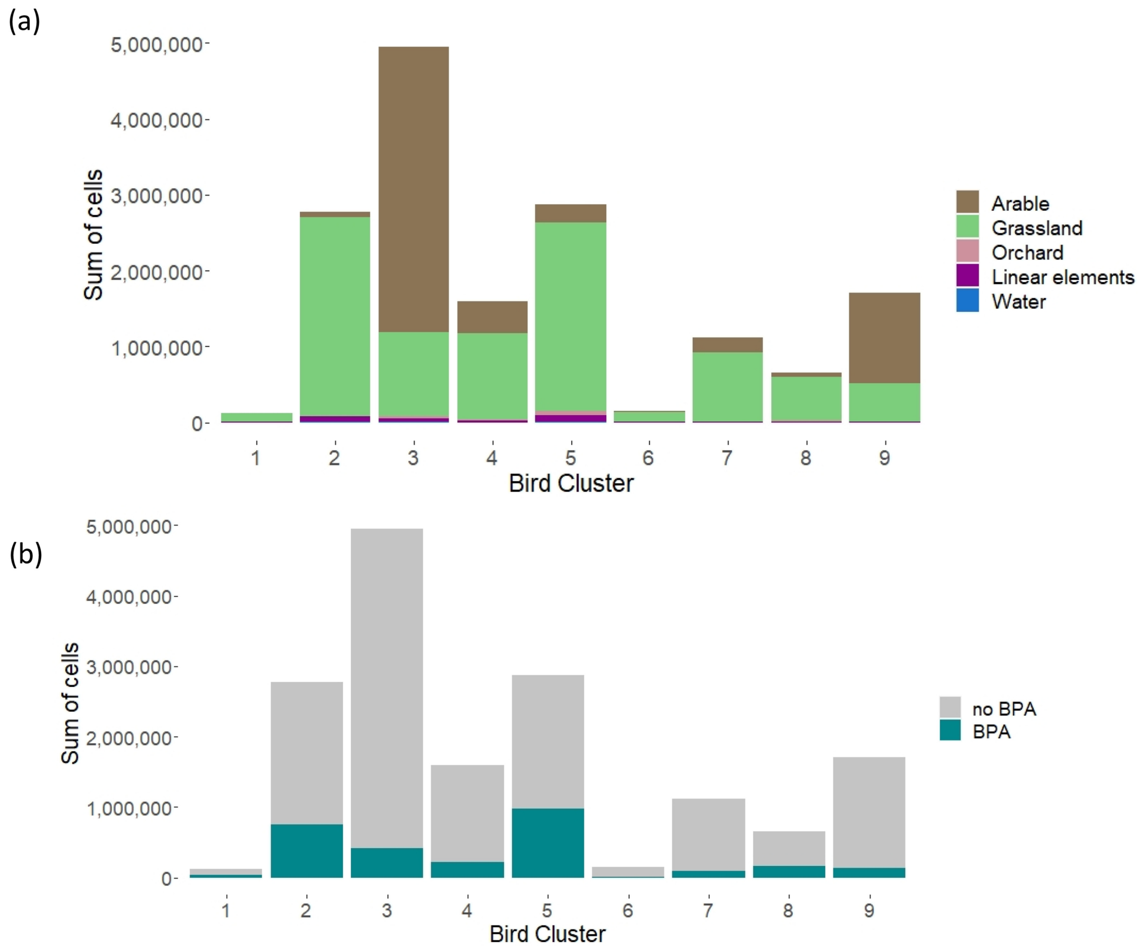

FIGURE 5 (a) Sum of cells (25 × 25 m) per land use type for each cluster, aggregated to 5 classes (arable, grassland, linear elements, orchard, water). (b) Sum of cells without and with biodiversity promotion area (BPA) for each cluster.

between impact of agricultural activities and the effect on the group of AEO bird species studied. Finally, the clusters were underlaid with detailed information on land use composition linking to real-life agricultural practice for deriving practical recommendations.

4.1 | Hot/cold spots of potential distribution and impact of agricultural activities for AEO birds

For birds, the lowland showed a high potential on the hot/cold spot maps, but most fields were managed in a rather high impact way (see region 1; Figure 3a). This is supported by the fact that the lowland is the main production region in Switzerland (FOAG, 2021) and shows the highest species occurrence in landscape elements and refuges (Jeanneret et al., 2021; Zingg et al., 2019). While the region per se was predicted to be largely suitable for AEO species, there are also strong negative effects of land-use intensity on birds, as shown for example by the national monitoring data (Knaus et al., 2018; Meier et al., 2022). Accordingly, SALCA-BD, which was used by the Swiss Federal offices to monitor a subset of Swiss farms and has shown a negative biodiversity trend with raising impact during the last years (ZA-AUI, https://apps.agroscope.info/sp/za-aui/1/app/datenreihe?lang=D).

For the Alps and High Jura/Low Alps, the models predicted dominantly low species potential, associated with mainly low impact of agricultural activities. This might be because we chose agriculture-related environmental objective—AEO species to assess species potential distribution rather than all possible species, and because the aggregated maps revealed the average spatial pattern for all the species considered (Knaus et al., 2018). However, it could also provide potential for high impact of agricultural activities with high yield levels and without harming the species considered. The Low Valais and South Alps were predicted to have both high potential and low-impact activities, but their relative agricultural surface is very small compared to the other regions. Nevertheless, the intensity of agricultural

TABLE 1 Summary on the biggest two clusters identified and their characteristics.

Goal	Cluster	Arable land %	Grassland %	Linear elements and orchard %	Regions	BPA %	Surface %
Promotion	3	76.0	22.6	1.4	Mainly 1 (Lowlands, Low Jura)	8.4	31
Conservation	5	9.0	86.3	5.2	Mainly regions 4 and 3 (Low Valais, High Jura, Low Alps)	33.8	18

Note: See Figure 2 for a map of the regions, Figure 4 for a map of the clusters, and Figure 5 for the land cover for each cluster. BPA, biodiversity promotion area.

activities should not be raised if aiming to conserve good conditions for AEO birds (low impact). This result is supported by the high importance of traditionally extensively managed meadows in these regions, as shown, for example, for grasshoppers (Klein et al., 2020) and the rare Scops owl (Theux et al., 2022), a regional priority bird in Valais.

As a summary, zones with low impact of agricultural activities can be distinguished into zones where low or high potential was identified for the AEO species. Zones with high potential should be managed in a way which is fostering AEO species (retaining low intensity of agricultural activities and a high amount of semi-natural structures). Zones with low potential seem not to be suitable to foster these AEO species, but this is only true for the species that we considered in this study (e.g., it would not be necessarily the case for others, e.g., wetland or water streams specialists (Knaus et al., 2018)). The Swiss main production region (lowland) was shown to mostly provide high potential for AEO species, while the current agricultural intensity of agricultural activities only provides limited area of low impact for priority species. According to recent literature (Garibaldi et al., 2020), this might not be enough to support a functioning biodiversity and foster AEO species in this region.

4.2 | Focus zones for the conservation of AEO birds

The lowland, which is the biggest region of Swiss agriculture in terms of surface, harbored the bird cluster with most cells (Table 1; "Promotion"; with high impact and high potential) and was mainly composed of arable land. This result showed that focus zones with high potential for the selected species are not necessarily the ones that are already protected or under extensive management, as found for example previously also in the UK (Cunningham et al., 2021). However, it is important to note, that the lowland was not covered by only one intensive-agriculture cluster (cluster 3), but that clusters associated with lower impact agricultural activities were also represented (clusters 4 and 5). 13.21% of the cells in the lowland were listed as BPA, while 13.12% of the cells in the lowland were classified as low impact and were largely overlapping. This result illustrates the high importance of BPAs that are mainly composed of linear elements like hedges, flowering structures but also less intensively managed grasslands, all of which are known to be highly important for birds (Jeanneret et al., 2021; Klein et al., 2023; Zingg et al., 2018). Recent literature has called for a minimum of 20–25% of semi-natural areas to safeguard farmland biodiversity (Garibaldi et al., 2020; Tscharntke et al., 2021). This leaves room for improvement in the agricultural lowland, and concurrently internationally up to 30% of the total land surface have been pledged to be protected until 2030 (UNEP, 2022). For example, BPAs like biodiversity promoting (extensive) management and semi-natural structures could be placed to a bigger extent, to improve the environmental conditions for AEO birds. However, the big question remains—where should these 30% be? While this study focused on the optimal placement of biodiversity focus zones for AEO birds, future studies should also incorporate additional factors, such as, for example, soil quality or agricultural yield to improve regional landscape planning. Clusters 1, 2, and 6, which all show low potential and low impact, make up 19.1% of the study area. BPA can also be found in these clusters, which means that these BPAs are inefficient in supporting most AEO species considered in this study. Previous studies have shown that one of the major problems of Swiss agricultural subsidies for biodiversity is the inefficient placement and quality of many structures (Meier et al., 2021), which could be backed by our result. Therefore, these clusters could potentially provide room for intensification of management without harming the AEO species studied. Future studies could consider trade-offs between national AEO species (covered in this study) and regional AEO species, which might still benefit from the low impact of agricultural activities.

Our results also showed that zones with low impact and high potential (Table 1; "Conservation") could be maintained for AEO birds. This cluster was mainly located in the Low Valais and High Jura/Low Alps. Especially (extensively managed) grasslands and semi-natural habitats should be maintained in these regions, as they have a high importance for birds (Bretagnolle et al., 2019; Jeanneret et al., 2021). Biodiversity promotion areas in these zones have high value for AEO birds and should be protected from degradation through changes of agricultural activity (e.g., intensification of an extensive meadow or removal of semi-natural structures). Fostering and protecting these habitats in zones of high species potential could help improve the situation for AEO birds. Accordingly, at the European level, there has recently been a call to focus conservation action on restoring semi-natural grasslands and extensive grasslands while as well improving the spatial planning and landscape-scale implementations (Pe'er et al., 2022). This means that it would be important to not concentrate the conservation areas in one region but to better distribute them in geographic space, while high attention must also be paid on the connectivity of these habitats (Birrer et al., 2007; Zingg et al., 2019).

4.3 | Limitations

Our study was based on two spatial tools: one to assess impact of agricultural activities and another to predict potential bird distribution across Switzerland. It is important to keep in mind that maps, tools and models are only simplified representations of reality usually focused on selected phenomena or applications (Bailey et al., 2007; Lausch et al., 2015). They are associated with different levels of uncertainty in terms of spatial (Overmars et al., 2014) as well as content accuracy (Neuendorf et al., 2021). For example, our analysis is limited to 25 m × 25 m raster cells, which means that the resolution of land use classes is limited to 25 m, while different grain size resolution might lead to different results (Meneses et al., 2018).

We also summarized land use categories (Data S1) and generalized them into standard activity regimes to be able to apply SALCA-BD and estimate impact of agricultural activities. With our data we were able to distinguish between different regimes at the land use class level, but we had no data about individual fields and their respective quality, which is also known to be of high importance (Zingg et al., 2019). SALCA-BD produces results by presenting averages for species groups such as "birds," while the demands and habitat requirements of some species may strongly deviate from these average predictions (e.g., fieldlark: Knaus et al., 2018). Also, species occurrence data used for fitting the SDMs were extracted from the GBIF and InfoSpecies databases, which remain subject to imperfect sampling due to partly spatial–temporal variation among observers, environmental conditions, and species' behaviors. Although the N-SDM platform includes state-of-the-art features for dealing with sampling biases (e.g., spatial disaggregation of occurrence records and neutralization of observational covariates such as site accessibility (Chauvier et al., 2021; Warton et al., 2013)), these could have affected our findings in terms of both predicted potential distributions and habitat associations (Baker et al., 2022; Inman et al., 2021; Kadmon et al., 2004).

In addition, estimating potential species distribution, we only used a subset of 27 AEO bird species out of 47 (FOEN and FOAG, 2008). We only considered the ones that were listed for all agricultural main regions, so that we could analyze all regions and generalize conclusions. This comes at the expense that our results are only valid for the set of species that we used and cannot be necessarily translated to other species. However, future analyses could be applied using the same methodology to further include or focus on regionally important sets of (AEO) species, to make the results more applicable for smaller spatial scales such as Cantons or Municipalities. Furthermore, this approach might on the one hand favor generalist species (in terms of habitat and biogeographical occurrence) while neglecting specialists, because specialists are usually dependent on specific habitats and food resources (Fuller, 2000). However, due to their restricted niche, specialists are rarer and have been largely replaced by generalists (Le Viol et al., 2012), leading to a bias in the interpretation of valuable habitats. In addition, we acknowledge that averaging the 27 potential distribution layers for each species into a single indicator prevented us from addressing species-specific requirements. This also applies for the breeding status of the species considered in this study, as the SDMs were built for the whole year, regardless of seasonal variations in species occurrences. As a result, the conservation measures derived from this indicator could be suboptimal for certain species. Finally, we emphasize that SDMs are useful tools for generating habitat suitability maps, from which information on species' potential distribution can be derived and used in conservation (Guisan et al., 2013). However, they do not provide exact information on the population status of the species or whether these populations can survive in the long term.

4.4 | Application of the results

Agricultural production and biodiversity depend on the same land and landscape but are often seen as conflicting (Batáry et al., 2017; Rodríguez & Wiegand, 2009; Scheper et al., 2023). In Switzerland, agricultural targets for 2050 (Bundesrat, 2022) define that Swiss agriculture should continue to produce more than 50% of the national food demand, despite a growing population. This is planned to be achieved by increasing labor productivity (+50% compared to 2020) and at the same time reducing greenhouse gas emissions (−40% compared to 1990). As natural resources and biodiversity are currently already under severe pressure, such an increase in food production, together with the risks of climate change, will likely increase these pressures. Yet, the promotion and conservation of biodiversity is very important and has also been set as a governmental goal (FOEN and FOAG, 2008). Consequently, these conflicting objectives—increasing agricultural production while preserving and fostering biodiversity—require solutions that offer as many synergies as possible. Our approach shows a way to balance and harmonize these conflicts through regional prioritization based on the respective local potential. Future follow-up studies could focus on different (sets of) species, and include additional factors, such as social and economic aspects or specific ecosystem services (e.g., carbon storage, pollination potential; Grêt-Regamey et al., 2017; Ramel et al., 2020), which could even be predicted directly from the modeled species (Rey et al., 2023).

Our focus map can be used on the one hand to assess and evaluate the current situation (conservation/preservation status of biodiversity, placement and effectiveness of BPA) and on the other hand to allow well-informed planning in the future. For the current situation, studies have shown that one of the major problems of Swiss agricultural subsidies for biodiversity is the inefficient placement and quality of many structures (Meier et al., 2021). Our approach can help to facilitate the placement of the BPA and therefore the overall effectiveness of these measures. At the point of future planning, our approach provides detailed knowledge of the situation on the ground at a small-scale spatial level, which can be used to make informed decisions and enable informed discussion between stakeholders on the one hand and between objectives on the other. Our approach is not intended to provide a decision on land use, nor on local needs or priorities. This is and remains the decision of the local people. However, we aim at supporting "good" and "balanced" decisions by providing decision makers with the necessary knowledge. Importantly, we found clusters where existing management should be maintained, because agricultural production is either less damaging to biodiversity or promotes biodiversity. But it is also important to note that there are as well clusters which show a low agricultural impact but also low potential for the species considered, illustrating that it is not enough to support high value structures (as biodiversity promotion areas), but that they should also be implemented at the most suitable locations (such as in cluster 3, 4 or 5 for the AEO birds considered here). Therefore, sophisticated spatial planning of future conservation actions is key to prioritize species conservation in agricultural landscapes.

5 | CONCLUSION

We identified focus zones for the conservation of Swiss AEO species in farmland using a new approach combining spatial outputs from both impact management analyses and species distribution models using spatial hot/cold spot scoring and clustering. The result is a spatially explicit Swiss-wide "focus map," signaling different combinations between the estimated impact on the birds through agricultural activities on them and the predicted aggregated potential distribution for the studied bird species. The resulting "focus map" (Figure 3) allows to identify areas that can be prioritized for future biodiversity action.

The map could be used by practitioners to identify locations that have a high potential to benefit AEO birds when enhancing habitat (i.e., new biodiversity promotion areas or restauration measures). Additionally, the map could also be used to identify which locations are beneficial to AEO birds under current agricultural activities and could thus be prioritized for conservation measures (i.e., retention through extensive management or protection of habitats). In future, species-specific maps could also be produced to allow for species-specific conservation management planning by practitioners.

Against the background of the results and in view of the objectives of the Federal Constitution and the Swiss Agricultural Vision for 2050, the future agricultural policy could think of new instruments that enable and encourage place-related management and adaptation to local conditions and potentials. Regional agricultural strategies that focus on regional challenges and opportunities can provide small-scale but workable solutions and chart a way forward that safeguards both food production and biodiversity.

AUTHOR CONTRIBUTIONS

Noëlle Klein: Conceptualization; methodology; investigation; formal analysis; writing – original draft. **Antoine Adde**: Methodology; investigation; writing – review & editing. **Adrienne Grêt-Regamey**: Methodology; writing – review & editing; supervision. **Antoine Guisan**: Methodology; writing – review & editing. **Felix Herzog**: Methodology; writing – review & editing. **Philippe Jeanneret**: Methodology; writing – review & editing.

Sonja Kay: Conceptualization; methodology, writing – review & editing; supervision.

ACKNOWLEDGMENTS

Thanks to our colleagues Dr. Maarten van Strien, Dr. Erich Szerencsits, and Dr. Beatrice Schüpbach to provide valuable discussions and feedback on our methods and results. This work was part of the SALBES project funded through the 2017–2018 Joint BiodivERsA-Belmont Forum Call on "Scenarios of Biodiversity and Ecosystem services" (Grant: BiodivScen-157). Some co-authors were financially supported through the ValPar.CH project funded by the Swiss Federal Office for the Environment (FOEN) // Swiss Government under the project "ValPar.CH: Values of the ecological infrastructure in Swiss parks" of the Action Plan of the Swiss Biodiversity Strategy (Pilot Project A1.2).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data will be available upon request.

ORCID

Noëlle Klein https://orcid.org/0000-0001-9020-7192

REFERENCES

Adde, A., Rey, P. L., Brun, P., Külling, N., Fopp, F., Altermatt, F., Broennimann, O., Lehmann, A., Petitpierre, B., Zimmermann, N. E., Pellissier, L., & Guisan, A. (2023). N-SDM: A high-performance computing pipeline for nested species distribution modelling. *Ecography*, *2023*, e06540. https://doi.org/10.1111/ecog.06540

Adde, A., Rey, P.-L., Fopp, F., Petitpierre, B., Schweiger, A. K., Broennimann, O., Lehmann, A., Zimmermann, N. E., Altermatt, F., Pellissier, L., & Guisan, A. (2023). Too many candidates: Embedded covariate selection procedure for species distribution modelling with the covsel R package. *Ecological Informatics*, *75*, 102080. https://doi.org/10.1016/j.ecoinf.2023.102080

Agroscope. (2016). Umweltziele Landwirtschaft "Arten und Lebensräume". Retrieved from https://www.agroscope.admin.ch/agroscope/de/home/themen/umwelt-ressourcen/biodiversitaet-landschaft/oekologischer-ausgleich/umweltziele-landwirtschaft.html

BAFU and BLW. (2016). *Umweltziele Landwirtschaft* (Statusbericht 2016, Umwelt-Wissen Nr. 1633). Bundesamt für Umwelt.

Bailey, D., Billeter, R., Aviron, S., Schweiger, O., & Herzog, F. (2007). The influence of thematic resolution on metric selection for biodiversity monitoring in agricultural landscapes. *Landscape Ecology*, *22*, 461–473. https://doi.org/10.1007/s10980-006-9035-9

Baker, D. J., Maclean, I. M. D., Goodall, M., & Gaston, K. J. (2022). Correlations between spatial sampling biases and environmental niches affect species distribution models. *Global Ecology and Biogeography*, *31*, 1038–1050. https://doi.org/10.1111/geb.13491

Batáry, P., Gallé, R., Riesch, F., Fischer, C., Dormann, C. F., Mußhoff, O., Császár, P., Fusaro, S., Gayer, C., Happe, A. K., Kurucz, K., Molnár, D., Rösch, V., Wietzke, A., & Tscharntke, T. (2017). The former iron curtain still drives biodiversity-profit trade-offs in German agriculture. *Nature Ecology and Evolution*, *1*, 1279–1284. https://doi.org/10.1038/s41559-017-0272-x

Benton, T. G., Bryant, D. M., Cole, L., & Crick, H. Q. P. (2002). Linking agricultural practice to insect and bird populations: A historical study over three decades. *Journal of Applied Ecology*, *39*, 673–687. https://doi.org/10.1046/j.1365-2664.2002.00745.x

Birrer, S., Spiess, M., Herzog, F., Jenny, M., Kohli, L., & Lugrin, B. (2007). The Swiss agri-environment scheme promotes farmland birds: But only moderately. *Journal of Ornithology*, *148*, 295–303. https://doi.org/10.1007/s10336-007-0237-y

Breiman, L. (2001). Random forests. *Machine Learning*, *45*, 5–32. https://doi.org/10.1023/A:1010933404324

Bretagnolle, V., Siriwardena, G., Miguet, P., Henckel, L., & Kleijn, D. (2019). Local and landscape scale effects of heterogeneity in shaping bird communities and population dynamics: Crop-grassland interactions. *Agrosystem Diversity*, *2019*, 231–243. https://doi.org/10.1016/B978-0-12-811050-8.00014-5

Broennimann, O. (2023). CHclim25: A high spatial and temporal resolution climate dataset for Switzerland.

Bundesrat. (2013). Verordnung über die Direktzahlungen an die Landwirtschaft.

Bundesrat. (2022). Zukünftige Ausrichtung der Agrarpolitik.

Chauvier, Y., Zimmermann, N. E., Poggiato, G., Bystrova, D., Brun, P., & Thuiller, W. (2021). Novel methods to correct for observer and sampling bias in presence-only species distribution models. *Global Ecology and Biogeography*, *30*, 2312–2325. https://doi.org/10.1111/geb.13383

Cleasby, I. R., Owen, E., Wilson, L., Wake, E. D., Connell, P. O., & Bolton, M. (2020). Identifying important at-sea areas for seabirds using species distribution models and hotspot mapping. *Biological Conservation*, *241*, 108375. https://doi.org/10.1016/j.biocon.2019.108375

Crenna, E., Marques, A., La Notte, A., & Sala, S. (2020). Biodiversity assessment of value chains: State of the art and emerging challenges. *Environmental Science and Technology*, *54*, 9715–9728. https://doi.org/10.1021/acs.est.9b05153

Cunningham, C. A., Crick, H. Q. P., Morecroft, M. D., Thomas, C. D., & Beale, C. M. (2021). Translating area-based conservation pledges into efficient biodiversity protection outcomes. *Communications Biology*, *4*, 1–5. https://doi.org/10.1038/s42003-021-02590-4

Curran, M., De Souza, D. M., Antón, A., Teixeira, R. F. M., Michelsen, O., Vidal-Legaz, B., Sala, S., & Canals, M. I. (2016). How well does LCA model land use impacts on biodiversity?—a comparison with approaches from ecology and conservation. *Environmental Science and Technology*, *50*, 2782–2795. https://doi.org/10.1021/acs.est.5b04681

Donald, P. F., Sanderson, F. J., Burfield, I. J., & van Bommel, F. P. J. (2006). Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. *Agriculture, Ecosystems & Environment*, *116*, 189–196. https://doi.org/10.1016/j.agee.2006.02.007

Emmerson, M., Morales, M. B., Oñate, J. J., Batáry, P., Berendse, F., Liira, J., Aavik, T., Guerrero, I., Bommarco, R., Eggers, S., Pärt, T., Tscharntke, T., Weisser, W., Clement, L., & Bengtsson, J. (2016). How agricultural intensification affects biodiversity and ecosystem services. *Advances in Ecological Research*, *55*, 43–97. https://doi.org/10.1016/bs.aecr.2016.08.005

Esri Inc. (2023). ArcGIS Pro (Version 2.9.0).

FOAG. (2021). Nutzungsflächen—Minimale Geodatenmodelle Landwirtschaftliche Bewirtschaftung. Retrieved from https://geodienste.ch/services/lwb_nutzungsflaechen

FOAG and FOEN. (2021). FOS annual farm census data.

FOEN and FOAG. (2008). *Umweltziele Landwirtschaft—Hergeleitet aus bestehenden rechtlichen Grundlagen*. Umwelt-Wissen.

Fuller, R. J. (2000). Relationships between recent changes in lowland British agriculture and farmland bird populations: An overview. In *Ecology and conservation of lowland farmland birds*. BTO.

Garibaldi, L. A., Oddi, F. J., Miguez, F. E., Bartomeus, I., Orr, M. C., Jobbágy, E. G., Kremen, C., Schulte, L. A., Hughes, A. C., Bagnato, C., Abramson, G., Bridgewater, P., Carella, D. G., Díaz, S., Dicks, L. V., Ellis, E. C., Goldenberg, M., Huaylla, C. A., Kuperman, M., … Zhu, C.-D. (2020). Working landscapes need at least 20% native habitat. *Conservation Letters*, *14*, e12773. https://doi.org/10.1111/conl.12773

Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance statistics. *Geographical Analysis*, *24*, 189–206. https://doi.org/10.1111/j.1538-4632.1992.tb00261.x

Gregory, R. D., Noble, D., Field, R., Marchant, J., Raven, M., & Gibbons, D. W. (2003). Using birds as indicators of biodiversity. *Ornis Hungarica*, *12–13*, 11–24.

Grêt-Regamey, A., Altwegg, J., Sirén, E. A., van Strien, M. J., & Weibel, B. (2017). Integrating ecosystem services into spatial planning—A spatial decision support tool. *Landscape and Urban Planning*, *165*, 206–219. https://doi.org/10.1016/j.landurbplan.2016.05.003

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

Guisan, A., Thuiller, W., & Zimmermann, N. E. (2017). *Habitat suitability and distribution models: With applications in R*. Cambridge University Press.

Guisan, A., Tingley, R., Baumgartner, J. B., Naujokaitis-Lewis, I., Sutcliffe, P. R., Tulloch, A. I. T., Regan, T. J., Brotons, L., Mcdonald-Madden, E., Mantyka-Pringle, C., Martin, T. G., Rhodes, J. R., Maggini, R., Setterfield, S. A., Elith, J., Schwartz, M. W., Wintle, B. A., Broennimann, O., Austin, M., … Buckley, Y. M. (2013). Predicting species distributions for conservation decisions. *Ecology Letters*, *16*, 1424–1435. https://doi.org/10.1111/ele.12189

Hastie, T. J. (1992). Generalized additive models. In *Statistical models in S*. Routledge.

Herzog, F., Dreier, S., Hofer, G., Marfurt, C., Schüpbach, B., Spiess, M., & Walter, T. (2005). Effect of ecological compensation areas on floristic and breeding bird diversity in Swiss agricultural landscapes. *Agriculture, Ecosystems and Environment*, *108*, 189–204. https://doi.org/10.1016/j.agee.2005.02.003

Hirzel, A. H., Le Lay, G., Helfer, V., Randin, C., & Guisan, A. (2006). Evaluating the ability of habitat suitability models to predict species presences. *Ecological Modelling, Predicting Species Distributions*, *199*, 142–152. https://doi.org/10.1016/j.ecolmodel.2006.05.017

Inman, R., Franklin, J., Esque, T., & Nussear, K. (2021). Comparing sample bias correction methods for species distribution modeling using virtual species. *Ecosphere*, *12*, e03422. https://doi.org/10.1002/ecs2.3422

IPBES. (2019). Global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services. Zenodo. https://doi.org/10.5281/ZENODO.3831673

Jain, A. K. (2010). Data clustering: 50 years beyond K-means. In *Pattern recognition letters, award winning papers from the 19th international conference on pattern recognition (ICPR)* (Vol. 31, pp. 651–666). Elsevier. https://doi.org/10.1016/j.patrec.2009.09.011

Jeanneret, P., Baumgartner, D. U., Freiermuth Knuchel, R., Koch, B., & Gaillard, G. (2014). An expert system for integrating biodiversity into agricultural life-cycle assessment. *Ecological Indicators*, *46*, 224–231. https://doi.org/10.1016/j.ecolind.2014.06.030

Jeanneret, P., Lüscher, G., Schneider, M. K., Pointereau, P., Arndorfer, M., Bailey, D., Balázs, K., Báldi, A., Choisis, J.-P., Dennis, P., Diaz, M., Eiter, S., Elek, Z., Fjellstad, W., Frank, T., Friedel, J. K., Geijzendorffer, I. R., Gillingham, P., Gomiero, T., … Herzog, F. (2021). An increase in food production in Europe could dramatically affect farmland biodiversity. *Communications Earth & Environment*, *2*, 1–8. https://doi.org/10.1038/s43247-021-00256-x

Kadmon, R., Farber, O., & Danin, A. (2004). Effect of roadside bias on the accuracy of predictive maps produced by bioclimatic models. *Ecological Applications*, *14*, 401–413. https://doi.org/10.1890/02-5364

Ke, G., Meng, Q., Finley, T., Wang, T., Chen, W., Ma, W., Ye, Q., & Liu, T.-Y. (2017). LightGBM: A highly efficient gradient boosting decision tree. In *Advances in neural information processing systems*. Curran Associates, Inc.

Kleijn, D., Kohler, F., Báldi, A., Batáry, P., Concepción, E. D., Clough, Y., Díaz, M., Gabriel, D., Holzschuh, A., Knop, E., Kovács, A., Marshall, E. J. P., Tscharntke, T., & Verhulst, J. (2009). On the relationship between farmland biodiversity and land-use intensity in Europe. *Proceedings of the Royal Society B: Biological Sciences*, *276*, 903–909. https://doi.org/10.1098/rspb.2008.1509

Klein, N., Grêt-Regamey, A., Herzog, F., van Strien, M. J., & Kay, S. (2023). A multi-scale analysis on the importance of patch-surroundings for farmland birds. *Ecological Indicators*, *150*, 110197. https://doi.org/10.1016/j.ecolind.2023.110197

Klein, N., Herzog, F., Jeanneret, P., & Kay, S. (2023). Validating farmland biodiversity life cycle assessment at the landscape scale. *Environmental Science & Technology*, *57*, 9184–9193. https://doi.org/10.1021/acs.est.2c09677

Klein, N., Theux, C., Arlettaz, R., Jacot, A., & Pradervand, J. N. (2020). Modeling the effects of grassland management intensity on biodiversity. *Ecology and Evolution*, *10*, 13518–13529. https://doi.org/10.1002/ece3.6957

Knaus, P., Antoniazza, S., Wechsler, S., Guélat, J., Kéey, M., Strebel, N., & Sattler, T. (2018). Schweizer Brutvogelatlas 2013–2016. In *Verbreitung und Bestandsentwicklung der Vögel in der*

Schweiz und im Fürstentum Liechtenstein. Swiss Ornithological Institute, Sempach.

Knaus, P., Sattler, T., Schmid, H., Strebel, N., & Volet, B. (2021). *Zustand der Vogelwelt in der Schweiz, Bericht 2021*. Schweizerische Vogelwarte.

Külling, N., & Adde, A. (2023). SWECO25: Land use and cover (lulc). https://doi.org/10.5281/zenodo.7981110

Külling, N., Adde, A., Fopp, F., Schweiger, A. K., Broennimann, O., Rey, P.-L., Giuliani, G., Goicolea, T., Petitpierre, B., Zimmermann, N. E., Pellissier, L., Altermatt, F., Lehmann, A., & Guisan, A. (2024). SWECO25: A cross-thematic raster database for ecological research in Switzerland. *Scientific Data*, *11*, 21. https://doi.org/10.1038/s41597-023-02899-1

Lausch, A., Blaschke, T., Haase, D., Herzog, F., Syrbe, R. U., Tischendorf, L., & Walz, U. (2015). Understanding and quantifying landscape structure—a review on relevant process characteristics, data models and landscape metrics. *Ecological Modelling*, *295*, 31–41. https://doi.org/10.1016/j.ecolmodel.2014.08.018

Le Viol, I., Jiguet, F., Brotons, L., Herrando, S., Lindström, Å., Pearce-Higgins, J. W., Reif, J., Van Turnhout, C., & Devictor, V. (2012). More and more generalists: Two decades of changes in the European avifauna. *Biology Letters*, *8*, 780–782. https://doi.org/10.1098/rsbl.2012.0496

Lüscher, G., Nemecek, T., Arndorfer, M., Balázs, K., Dennis, P., Fjellstad, W., Friedel, J. K., Gaillard, G., Herzog, F., Sarthou, J. P., Stoyanova, S., Wolfrum, S., & Jeanneret, P. (2017). Biodiversity assessment in LCA: A validation at field and farm scale in eight European regions. *International Journal of Life Cycle Assessment*, *22*, 1483–1492. https://doi.org/10.1007/s11367-017-1278-y

Maurer, C., Sutter, L., Martínez- Núñez, C., Pellissier, L., & Albrecht, M. (2022). Different types of semi-natural habitat are required to sustain diverse wild bee communities across agricultural landscapes. *Journal of Applied Ecology*, *59*, 2604–2615.

McCullagh, P., & Nelder, J. A. (1989). *Generalized linear models* (2nd ed.). Chapman & Hall.

Meier, E., Lüscher, G., Buholzer, S., Herzog, F., Indermaur, A., Riedel, S., Winizki, J., Hofer, G., & Knop, E. (2021). Zustand der Biodiversität in der Schweizer Agrarlandschaft: Zustandsbericht ALL-EMA. *Agroscope Science*, *2021*, 111.

Meier, E. S., Lüscher, G., & Knop, E. (2022). Disentangling direct and indirect drivers of farmland biodiversity at landscape scale. *Ecology Letters*, *25*, 2422–2434. https://doi.org/10.1111/ele.14104

Meneses, B. M., Reis, E., Reis, R., & Vale, M. J. (2018). The effects of land use and land cover geoinformation raster generalization in the analysis of LUCC in Portugal. *ISPRS International Journal of Geo-Information*, *7*, 390. https://doi.org/10.3390/ijgi7100390

Milà i Canals, L., Bauer, C., Depestele, J., Dubreuil, A., Freiermuth, R., Gaillard, G., Michelsen, O., Müller-Wenk, R., & Rydgren, B. (2007). Key elements in a framework for land use impact assessment within LCA. *International Journal of Life Cycle Assessment*, *12*, 5–15. https://doi.org/10.1065/lca2006.05.250

Neuendorf, F., Thiele, J., Albert, C., & von Haaren, C. (2021). Uncertainties in land use data may have substantial effects on environmental planning recommendations: A plea for careful consideration. *PLoS One*, *16*, e0260302. https://doi.org/10.1371/journal.pone.0260302

Overmars, K. P., Schulp, C. J. E., Alkemade, R., Verburg, P. H., Temme, A. J. A. M., Omtzigt, N., & Schaminée, J. H. J. (2014). Developing a methodology for a species-based and spatially explicit indicator for biodiversity on agricultural land in the EU. *Ecological Indicators*, *37*, 186–198. https://doi.org/10.1016/j.ecolind.2012.11.006

Pe'er, G., Finn, J. A., Díaz, M., Birkenstock, M., Lakner, S., Röder, N., Kazakova, Y., Šumrada, T., Bezák, P., Concepción, E. D., Dänhardt, J., Morales, M. B., Rac, I., Špulerová, J., Schindler, S., Stavrinides, M., Targetti, S., Viaggi, D., Vogiatzakis, I. N., & Guyomard, H. (2022). How can the European Common Agricultural Policy help halt biodiversity loss? Recommendations by over 300 experts. *Conservation Letters*, *15*, e12901. https://doi.org/10.1111/conl.12901

Phillips, S. J., Anderson, R. P., Dudík, M., Schapire, R. E., & Blair, M. E. (2017). Opening the black box: An open-source release of Maxent. *Ecography*, *40*, 887–893. https://doi.org/10.1111/ecog.03049

Ramel, C., Rey, P.-L., Fernandes, R., Vincent, C., Cardoso, A. R., Broennimann, O., Pellissier, L., Pradervand, J.-N., Ursenbacher, S., Schmidt, B. R., & Guisan, A. (2020). Integrating ecosystem services within spatial biodiversity conservation prioritization in the Alps. *Ecosystem Services*, *45*(101), 186. https://doi.org/10.1016/j.ecoser.2020.101186

Rey, P.-L., Vittoz, P., Petitpierre, B., Adde, A., & Guisan, A. (2023). Linking plant and vertebrate species to nature's contributions to people in the Swiss Alps. *Scientific Reports*, *13*, 7312. https://doi.org/10.1038/s41598-023-34236-2

Reynard, E., Grêt-Regamey, A., & Keller, R. (2021). The ValPar.CH project—Assessing the added value of ecological infrastructure in Swiss Parks. *Ecomont*, *13*, 64–68. https://doi.org/10.1553/eco.mont-13-2s64

Rodríguez, C., & Wiegand, K. (2009). Evaluating the trade-off between machinery efficiency and loss of biodiversity-friendly habitats in arable landscapes: The role of field size. *Agriculture, Ecosystems and Environment*, *129*, 361–366. https://doi.org/10.1016/j.agee.2008.10.010

Schank, C. J., Cove, M. V., Kelly, M. J., Mendoza, E., Farrill, G. O., Ninon, R. R., Jordan, C. A., González-maya, J. F., Moreno, R., Dobbins, M. T., Montalvo, V., Fort, J., Nielsen, C. K., Botello, F., Gilbert, J., & Miller, J. A. (2017). Using a novel model approach to assess the distribution and conservation status of the endangered Baird's tapir. *Diversity and Distributions*, *23*, 1459–1471. https://doi.org/10.1111/ddi.12631

Scheper, J., Badenhausser, I., Kantelhardt, J., Kirchweger, S., Bartomeus, I., Bretagnolle, V., Clough, Y., Gross, N., Raemakers, I., Vilà, M., Zaragoza-Trello, C., & Kleijn, D. (2023). Biodiversity and pollination benefits trade off against profit in an intensive farming system. *Proceedings of the National Academy of Sciences of the United States of America*, *120*, e2212124120. https://doi.org/10.1073/pnas.2212124120

Somers, R. H. (1962). A new asymmetric measure of association for ordinal variables. *American Sociological Review*, *27*, 799–811. https://doi.org/10.2307/2090408

Theux, C., Klein, N., Garibaldi, E., Jacot, A., Eichhorn, S., Guisan, A., & Pradervand, J. N. (2022). Food and habitats requirements of the Eurasian Scops Owl (*Otus scops*) in Switzerland revealed by very high-resolution multi-scale models. *Ibis*, *164*, 240–254. https://doi.org/10.1111/ibi.13007

Tscharntke, T., Grass, I., Wanger, T. C., Westphal, C., & Batáry, P. (2021). Beyond organic farming—Harnessing biodiversity-friendly landscapes. *Trends in Ecology & Evolution*, *2877*, 1–12. https://doi.org/10.1016/j.tree.2021.06.010

UNEP. (2022). Report of the conference of the parties to the convention on biological diversity on its fifteenth meeting (Part I).

Walter, T., Eggenberg, S., Gonseth, Y., Fivaz, F., Hedinger, C., Hofer, G., Klieber-Kühne, A., Richner, N., Schneider, K., Szerencsits, E., & Wolf, S. (2012). Operationalisation of the Agriculture-Related Environmental Objectives for "Species and Habitats" (AEO). ART.

Walter, T., Eggenberg, S., Gonseth, Y., Fivaz, F., Hedinger, C., Hofer, G., Klieber-Kühne, A., Richner, N., Schneider, K., Szerencsits, E., & Wolf, S. (2013). Operationalisierung der Umweltziele Landwirtschaft, Bereich Ziel-und Leitarten, Lebensräume (OPAL). *Art-Schriftenreihe*, *18*, 1–138.

Warton, D. I., Renner, I. W., & Ramp, D. (2013). Model-based control of observer bias for the analysis of presence-only data in ecology. *PLoS One*, *8*, e79168. https://doi.org/10.1371/journal.pone.0079168

Zingg, S., Grenz, J., & Humbert, J. Y. (2018). Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems and Environment*, *267*, 119–128. https://doi.org/10.1016/j.agee.2018.08.014

Zingg, S., Ritschard, E., Arlettaz, R., & Humbert, J. Y. (2019). Increasing the proportion and quality of land under agri-environment schemes promotes birds and butterflies at the landscape scale. *Biological Conservation*, *231*, 39–48. https://doi.org/10.1016/j.biocon.2018.12.022

Zurell, D., Franklin, J., König, C., Bouchet, P. J., Dormann, C. F., Elith, J., Fandos, G., Feng, X., Guillera-Arroita, G., Guisan, A., Lahoz-Monfort, J. J., Leitão, P. J., Park, D. S., Peterson, A. T., Rapacciuolo, G., Schmatz, D. R., Schröder, B., Serra-Diaz, J. M., Thuiller, W., … Merow, C. (2020). A standard protocol for reporting species distribution models. *Ecography*, *43*, 1261–1277. https://doi.org/10.1111/ecog.04960

SUPPORTING INFORMATION

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

How to cite this article: Klein, N., Adde, A., Grêt-Regamey, A., Guisan, A., Herzog, F., Jeanneret, P., & Kay, S. (2025). Identifying focus zones for the conservation and promotion of priority birds in Swiss farmland. *Conservation Science and Practice*, *7*(1), e13286. https://doi.org/10.1111/csp2.13286