Effect of Different Management Techniques on Bird Assemblages on Rice Fields in the Republic of Korea

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Research Article

Keywords: bird assemblages, habitats, intensive practices, pesticide use, Korea

Posted Date: May 27th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-551000/v1

Abstract

Many bird species rely on the ecological functions of rice field microhabitats. However, recent intensive practices are causing rice fields to provide fewer suitable habitats. This study examined bird microhabitat usage and the effects of intensive use of chemical substances on it. Eco-friendly and conventional rice fields were surveyed from January 2014 to December 2016, and the species presence, the number of birds, and the location of observed microhabitats were recorded. It was found that shorebirds and herons used more eco-friendly rice paddies with fewer or no chemical substances, while waterfowl used the paddy microhabitat more than the other microhabitats, regardless of the amount of chemical substances used. It was confirmed that land birds used ditches or roads in conventional rice fields more than those in fields that used chemical substances. Chemical substances affected bird assemblages differently. Consequently, bird assemblages used habitats differently depending on the farm crop cultivation as well as food abundance. These results provided valuable information useful for managing rice fields that serve as habitats for birds.

Introduction

Rice fields are spatially monotonous [1, 2], yet they are valuable habitats for several species, including aquatic plants, benthic invertebrates, and vertebrates [1, 3]. They also provide essential alternative habitats for a range of species, including those in need of conservation, particularly due to the loss of natural habitats [4, 5]. Rice production has greatly increased in recent years due to intensive practices for maximizing crop yield, but the habitat quality and biodiversity of rice fields have been decreasing [6–10]. Intensive practices can be characterized by the excessive use of chemicals, such as herbicides and pesticides, the expansion of farming areas, and the use of advanced machinery [11]. These intensive practices have been implemented worldwide and have gravely decreased the biodiversity of various organisms, such as birds, mammals, amphibians, and invertebrates [12–16]. Rice fields can play an important role in maintaining or increasing biodiversity; however, their habitat quality is largely determined by farming methods.

Rice fields can be structurally divided into paddy, levee, road, and ditch, with each component providing habitats with different ecological functions [6, 17–19]. The paddy accounts for the largest area and can support the highest richness and abundance compared with the other habitat types [20, 21]. This space can be used by various avian species depending on whether the paddy fields are flooded or dry, which varies according to the cultivation season [20, 21]. The boundary between paddies is known as the levee. It provides a stable habitat that compensates for the decreased habitat function of the paddy when the density of rice is high during the growing season, which can prevent the access of avian species [17, 22, 23]. Roads expand other habitats, such as levees and ditches, and form terrestrial ecosystems [6, 24]. Ditches are paths that allow irrigation of the paddy, form aquatic ecosystems, and shape the structures of the unique aquatic community, depending on the source of agricultural water, such as reservoirs and rivers [6, 24].

Chemical substances are intensively used in conventional rice fields, and it is well documented that they can directly kill avian species or indirectly reduce the abundance of food sources when used excessively [25–28]. Moreover, the effects of chemicals on habitat use vary among avian species [29]. In contrast, eco-friendly rice fields minimize or remove the use of pesticides. Choi *et al.* [30] reported that common greenshanks *Tringa nebularia* preferred eco-friendly paddies, while the habitat use of wood sandpipers *Tringa glareola* was not significantly affected by the use of chemical substances. However, previous studies have only evaluated the effects of chemicals on the paddies, and no study has examined their effects on the habitat use of avian species (i.e., paddies, levees, ditches, and roads).

The objective of this study was to evaluate the effects of chemical substance usage among intensive practices (i.e., eco-friendly vs. conventional) on bird assemblages using rice field microhabitats. In particular, we aimed to examine (1) the characteristics of the bird assemblages using the paddy as a habitat and (2) the differences in the microhabitat types used by the bird assemblages in eco-friendly and conventional fields, to broaden the understanding of habitat structure and usage patterns of avian species in rice fields.

Results

We observed a total of 64,736 individuals of 113 species: 22 shorebird species (822 individuals), 11 heron species (9,538 individuals), 15 waterfowl species (45,036 individuals), 53 land bird species (9,116 individuals), and 12 other waterbird species, including cormorants, gulls, cranes and watercock (224 individuals) (see Supplementary Table S2). The average number of individuals was the highest in October (6,973 individuals) and the lowest in June (439.3 individuals). The average number of species was the highest in May (29.7 species) and the lowest in January (15 species) (Fig. 1).

Pattern from the self-organizing map

The 36-month survey data was divided into four clusters using a self-organizing map based on the 113 bird species observed in the eco-friendly and conventional rice fields (Fig. 2). Clusters 1 and 3 were bird assemblages observed in eco-friendly rice fields (Fig. 3; the proportion of eco-friendly rice fields, cluster 1 = 100%, cluster 3 = 80%). Clusters 2 and 4 were evenly composed of birds observed in eco-friendly rice fields and those observed in conventional rice fields (Fig. 3; cluster 2, eco-friendly rice fields = 46.88%, and eco-conventional rice fields = 53.13%; cluster 4, eco-friendly rice fields = 43.75%; and conventional rice fields = 56.25%). These clusters were significantly different (Fig. 2; multi-response permutation procedure (MRPP), A=0.14, P = 0.002). Land birds accounted for the proportion of individuals (2.77–28.95%) and species (43.96–63.80%) in all clusters (Fig. 4). In the waterbird assemblages, the proportion of individuals and species for shorebirds (29.54% and 34.07%), herons (67.33% and 36.99%), and waterfowl (95.46% and 31.68%) were highest in clusters 1, 2, and 3, respectively (Fig. 4).

Usage characteristics of eco-friendly and conventional rice fields

We found no spatial autocorrelation in waterbird guilds, whereas the land bird guild represented spatial autocorrelation. Thus, the generalized linear mixed model (GLMM) analysis showed that the relationship between habitat type and cultivation method varied according to bird guild (Table 1). Habitat type, cultivation method, and the interaction between habitat type and cultivation method were related to distribution in shorebirds and herons. However, only habitat type was related to distribution in the waterfowl. The number of shorebirds and herons observed in eco-friendly rice fields was more than twice that observed in conventional rice fields (Fig. 5). Regardless of cultivation treatment, most shorebirds, herons, and waterfowls were observed in paddy fields, while most land birds were observed in ditches (Fig. 6). Generally, herons and waterfowl were more observed in the eco-friendly rice field than in the conventional rice field, whereas more shorebirds were observed on the levee in the conventional rice field than on that of the eco-friendly fields. More land birds were observed in all the conventional rice field microhabitats, except for the levee microhabitat (Fig. 6).

Table 1

Moran's I test for spatial autocorrelation and results of generalized linear mixed models used to examine the impacts of cultivation methods and habitat types on the abundance of bird assemblages in rice fields. For analyses of the bird assemblages, the response variable is the number of individuals in each field. The explanatory variables are the habitat types (paddy, levee, ditch, and road) and practice methods (eco-friendly and conventional), and the random variable is the survey period and field location. The bold fonts represent statistical significant

Bird assemblages	Moran's I test				Generalized linear mixed models					
	Observed	Expected	SD	P-value	Variables	Estimate	SE	χ^2	df	P-value
Shorebirds	-0.020	-0.008	0.017	0.490	Habitat	1.126	0.134	0.692	3	< 0.001
					Practice methods	1.113	0.302	4.484	1	0.032
					Habitat × Practice methods	1.613	0.290	4.497	3	0.034
Herons	0.002	-0.001	0.003	0.170	Habitat	0.037	0.147	125.970	3	< 0.001
					Practice methods	0.451	0.125	95.798	1	< 0.001
					Habitat × Practice methods	1.136	0.128	172.630	3	< 0.001
Waterfowl	0.006	-0.003	0.007	0.190	Habitat	0.357	0.518	36.529	3	< 0.001
					Practice methods	2.401	0.398	2.760	1	0.10
					Habitat × Practice methods	2.511	1.648	2.202	3	0.33
Land birds	0.012	-0.003	0.006	0.010	Habitat	1.604	0.160	189.210	3	< 0.001
					Practice methods	1.073	0.180	0.112	1	0.74
					Habitat × Practice methods	1.554	0.175	28.333	3	< 0.001

Discussion

The bird communities observed in rice fields were divided into four assemblages (clusters), according to the similarity of species and population composition, which had clearly different usage patterns. Birds were observed year-round, and the shorebirds, herons, and waterfowl (waterbirds) showed seasonal migration characteristics. Moreover, habitat type and cultivation method affected different bird assemblages differently, due to differences in ecological characteristics and microhabitat use (i.e., paddy, levee, ditch, and road). These characteristics were depended on the time of arrival of the different waterbird assemblages in the rice fields [17, 18, 23]. Shorebirds use the rice field as a stopover for a short period in May; herons obtain food during or after breeding (June–September); and waterfowl stay during the winter in the rice fields, from October to April [17, 18]. Moreover, the rice fields provide different habitat environments for each season, maximizing their usage by waterbird assemblages that arrive in each season [31]. Consequently, it is believed that bird assemblages using rice fields are clearly distinguished because of differences in the season of rice-field use and microhabitats [31]. Farmers prepare to cultivate rice in early May by watering the rice field [23, 32, 33], and shorebirds use rice fields during this period [23, 32, 33]. The amount of animal prey increases rapidly during the growing season of rice (June – September) and herons are continuously observed during this period [23, 32, 33]. From October to April, rice is harvested, and waterfowl feed on the remaining down grain, increasing their use of the rice field [23, 32, 33]. Therefore, the rice field provides a suitable habitat environment for the use of each bird assemblage at different times of the year. Interestingly, land birds use the available resources in the rice field year-round without any particular seasonality.

Rice field microhabitats (paddy, levee, ditch, and road) provide unique habitat qualities, and birds use them differently according to their characteristics [6, 17–19]. All bird assemblages identified in this study used all the rice field microhabitat types, and each microhabitat fulfilled different functions for water and land birds. Waterbirds, such as shorebirds, herons, and waterfowl, mostly used paddies, whereas land birds used more frequently ditches or roads. The paddy, heavily used by waterbirds, accounts for the largest area of the rice field, and showed abrupt changes during the rice cultivation process [20, 21, 23]. Moreover, aquatic and terrestrial ecosystems alternate in the paddy fields [20, 21, 23]. Due to these characteristics, various food sources for waterbirds, such as benthic organisms and down grains, are available repeatedly and periodically, maintaining frequent paddy use by waterbirds that feed on those.

Land birds use roads and ditches more than paddy fields. Roads and ditches have well-developed diverse herbaceous plants, such as farm crops, reeds, and silver grass, which can be used as foraging or resting spaces [17, 18], whereas the paddy is a space for growing rice, a single crop, and has a monotonous vegetation structure [17, 18]. It has been reported that a higher biodiversity of herbaceous species, including crops, attracts more diverse taxa [3], such as bird feeding spiders, butterflies, and surface roaming insects [34, 35]. Therefore, land birds use roads and ditches that offer a more diverse habitat [3].

It is necessary to identify the detailed characteristics of each bird assemblage to understand their use of rice fields and the effects of cultivation methods. Each bird assemblage showed different usage characteristics due to the complex interactions of habitat type and cultivation method. This is closely related to the characteristics of the habitat environment, formed as a result of the interactions between habitat types and cultivation methods. The eco-friendly cultivation paddies, which are used frequently by shorebirds, have a higher diversity of benthic organisms, a potential food source, than the conventional cultivation paddies [36, 37]. Even though these paddies had similar shapes to conventional fields, shorebirds used them considerably more because of the larger amount of available food. In contrast, shorebirds used levees in conventional cultivation fields more than levees in eco-friendly cultivation fields, which could be related to accessibility. Shorebirds have a habit of foraging or resting in an open environment [38, 39]. In the area studied, the levees were managed in different ways according to the cultivation method. In eco-friendly fields, weeds were either left untouched or removed using a weeder, i.e., without a complete removal; whereas in conventional fields, herbicide was used, allowing for complete removal [40]. The levees in the conventional fields presented an open shape, which shorebirds prefer, and thus used more. Herons used the paddy, levee, and road habitats in the eco-friendly fields more than the habitats in the conventional fields. These habitats provided more abundant potential food sources for the herons than the conventional habitats [36, 41]. Moreover, herons rarely used the ditch habitat because it was narrow and low in height, making it difficult for herons to access compared to other habitats [17, 18]. Waterfowl also used habitats in eco-friendly fields more than those in conventional fields. This could be because some paddies in the eco-friendly fields were watered even after harvesting. Watered paddies are an important feeding ground for various waterfowl in winter [42–44], and they were observed concentrated around the watered paddy. Although land birds used all habitat types, they used conventional cultivation areas more than eco-friendly cultivation areas, contrary to waterbirds. Certain farm crops grown in the conventionally cultivated rice fields at the study site (cultivated using pesticides) and were not grown in the eco-friendly fields. These farm crops provided land birds with more diverse habitats in the conventional fields than in the eco-friendly fields, and they allowed land birds to forage or rest more [35].

It has previously been found that rice cultivation techniques, such as chemical substance use and crop cultivation around the paddy, could affect birds using rice fields [21, 26, 38, 42, 45, 46]. The results of this study also support these findings, as it was found that waterbirds preferred eco-friendly fields due to a large amount of potential food. It was also found that land birds preferred to use fields that cultivated a higher number of plant crop species, which provided more diverse habitats, even if chemical substances were used. This increased habitat diversity was possible using pesticides, which allowed various other farm crops to be grown. However, it does not mean that the pesticide use is important. The various habitat structures created by the crops are important, and it would be better to have a variety of habitat structures without the use of pesticides.

In conclusion, this study reported that bird assemblages in rice fields differ based on the agricultural techniques used, as these affect the characteristics of the habitat. As natural wetlands disappear, paddies provide alternative habitats for various birds. Rice paddies are artificial wetlands that can be changed drastically through active human management over a short period of time, compared to natural wetlands. Therefore, it is very important to understand the ecological characteristics and structure of the paddy wetlands. The results of this study will be valuable for establishing management plans for various avian species that use rice fields. Consequently, seeking and implementing clear and systematic management plans for rice field habitats can contribute to the immediate protection and conservation of birds. Future studies are needed to confirm whether the effects of cultivation methods at the community level would also be valid at the species level.

Materials And Methods

Study sites

This study was conducted in rice fields located in Nanjido-ri, Seokmun-myeon, Dangjin-gun, Chungcheongnam-do (37° 02'N, 126° 30'E: the midwestern region of Korea). The rice fields were reclaimed in 1979, and developed by the Large-scale Comprehensive Agricultural Development Project, with a total area of 3,904 ha. Rice has been initially cultivated using conventional methods in all areas, and since 1999, it has been cultivated using eco-friendly methods in some areas (574.2 ha). The eco-friendly and the conventional rice fields were adjacent to each other, separated by roads, and were irrigated by the same ditch (KRC Report, 2008). For this study, 446 lots of eco-friendly rice fields and 442 lots of conventional rice fields were selected. The mean lot area was 0.45 ha ± 0.07.

The habitat types of rice fields were divided into paddies, levees, roads, and ditches. Cultivation activities (e.g., plowing, harrowing, and rice planting) were carried out throughout the season in this area, and some eco-friendly rice paddies were watered after rice harvesting. Levees and roads were managed differently between eco-friendly rice fields and conventional rice fields. Generally, eco-friendly management included both low-pesticide and organic farming, otherwise, they were defined as conventional management. Weeds on the levee and road of the eco-friendly rice fields were either left or physically removed using a weeder, while those on the conventional rice fields were removed using a chemical herbicide. In rice fields, levees and roads have a large area to cultivate farm crops. Sixteen types of farm crops (e.g., soybeans, sesame, corn, leeks, perilla, napa cabbage, and spinach) were cultivated on conventional levees and roads. Eco-friendly levees or roads did not grow farm crops even though some rice fields used pesticides. The ditches were made of concrete, but some ditches, such as drainage ditches, were made from soil in both eco-friendly and conventional rice fields. Reeds (*Phragmites australis*) or silver grasses (*Miscanthus sinensis*) were grown in ditches made from soil. Although some eco-friendly rice fields used pesticides (tiadinil), most of them did not (about 20 lots). Conventional rice fields use pesticides containing tiadinil, clothianidin, pyrazosulfuron-ethyl, or fentrazmide in all areas (Supplementary Table S1).

Bird and habitat survey

Birds were surveyed once a month for three years, from January 2014 to December 2016. The survey was conducted between 6 a.m. and noon while visiting eco-friendly rice fields (446 lots) and conventional rice fields (442 lots); alternatively, along the road; and all birds observed on the left and right sides were recorded. To minimize the misidentification of birds, the observation area was limited to one lot (approximately 100 m in length) adjacent to the road, A total of 888 surveys were conducted per month.

Birds that were flying or sitting on utility poles or wires were excluded from the record, but rapacious birds and swallows (*Hirundo rustica*) were recorded even if they were flying. The recorded birds were divided into waterbird guilds and land bird guilds based on field observations and habitat use obtained from previous studies [17]. Waterbirds were further subdivided into shorebirds, herons, and waterfowl. The habitat type of the flying swallows was recorded as a paddy. For rapacious birds, the habitat used for food acquisition or resting was recorded as the habitat type. To minimize the bias due to the weather, the survey was not conducted on rainy or snowy days.

Statistical analysis

This study used a self-organizing map, an artificial neural network using unsupervised learning, to identify the characteristics of bird assemblages observed for three years from 2014 to 2016 [47]. The data (number of individuals: 113 species × 2 cultivation methods × 36 surveys) were assigned to the input layer of the self-organization map after log-transformation (log(1+number of individuals)) due to the differences in the number of individuals of each species. The number of output layer neurons was determined by the heuristic rule of $5\sqrt{n}$

as suggested by Vesanto *et al.* [48], where n is the number of data points in the input layer (72 surveys). The final model generated 42 output neurons (six horizontal and seven vertical). After self-learning of the self-organizing map, neurons were classified into groups based on the similarity of each neuron. The distance between neurons was measured by the Euclidean distance, and groups were classified using the Ward linkage method [49]. An MRPP was performed to evaluate significant differences between groups.

A generalized linear mixed model (GLMM, Poisson distribution, and log link) was used to evaluate the effects of habitat type (i.e., paddy, levee, ditch, and road) and cultivation methods (eco-friendly and conventional) on the number of birds per bird guild. Spatial autocorrelation analysis was conducted to examine the spatial characteristics of the data before applying the GLMM. When the result of the spatial autocorrelation analysis was significant, a GLMM analysis was conducted by applying spatial autocorrelation. In the GLMM, the number of birds per bird guild was designated as a response variable, and habitat type and cultivation method were considered as fixed effects. The timing of the survey and the location of each lot were treated as random effects.

All analyses were performed using R statistical software V 3.6.1 [50]. The “kohonen” [51], the “vegan” [52], the “lme4” [53], and the “spam” packages [54] were used for the self-organizing map analysis, MRPP, GLMM without autocorrelation, and GLMM with autocorrelation, respectively.

Declarations

Data availability

All collected data are provided in the supplementary information or available upon request directed to corresponding authors.

Acknowledgments

We thank the landowners who allowed us to work in their rice fields.

Author contributions

Conceived of or designed study (GC, SJS and HKN); Performed research (GC, MSD, SJS and HKN); Analyzed data (HKN, MSD and GC); Contributed new methods or models (GC and HKN); Wrote the paper (GC, MSD, SJS and HKN).

Competing interests

The authors declare no competing interests.

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Figures

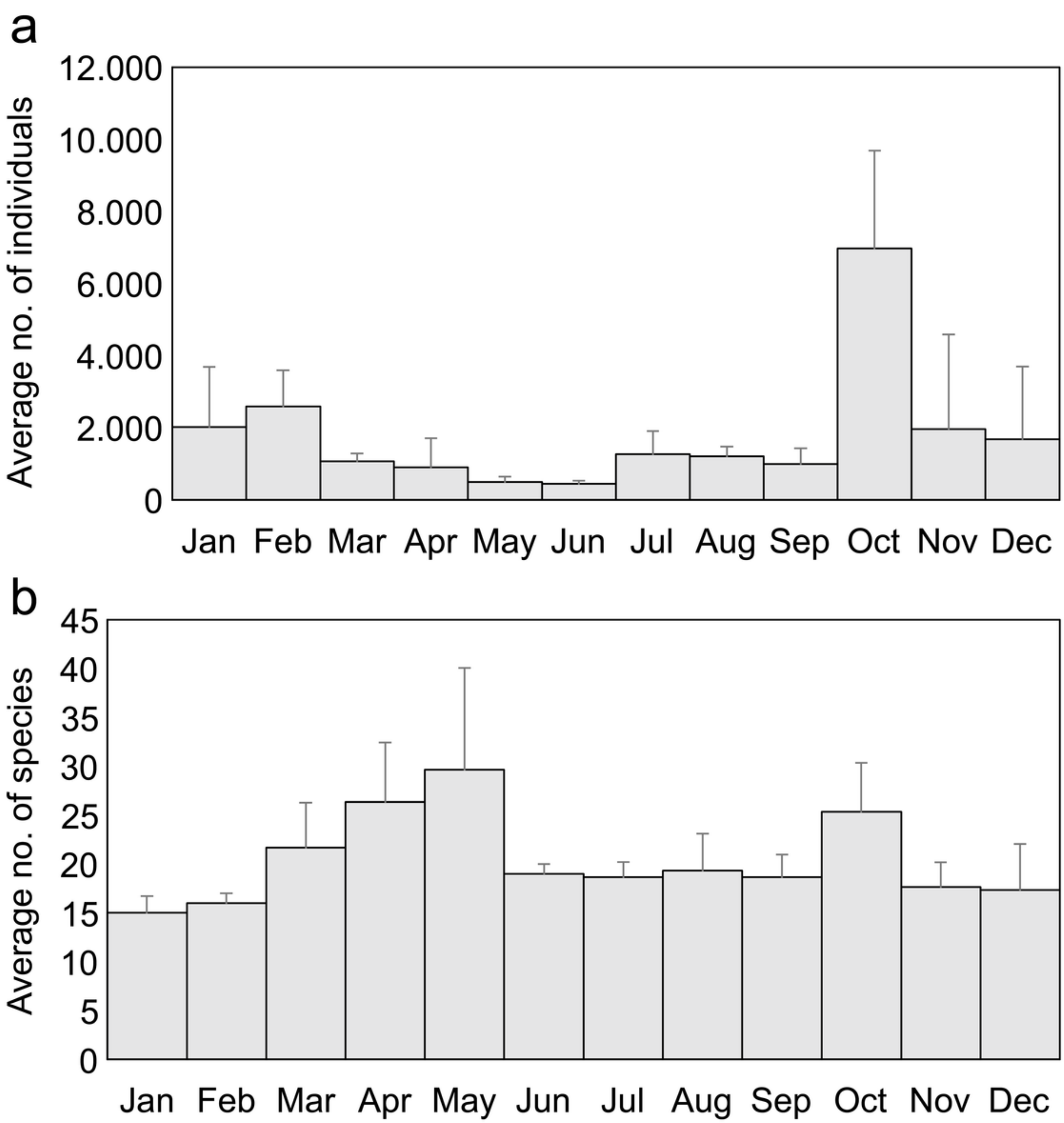

Figure 1

Seasonal change in the average number of (a) individuals and (b) species of birds in the rice fields of the midwestern part of South Korea. The error bars represent the standard deviation.

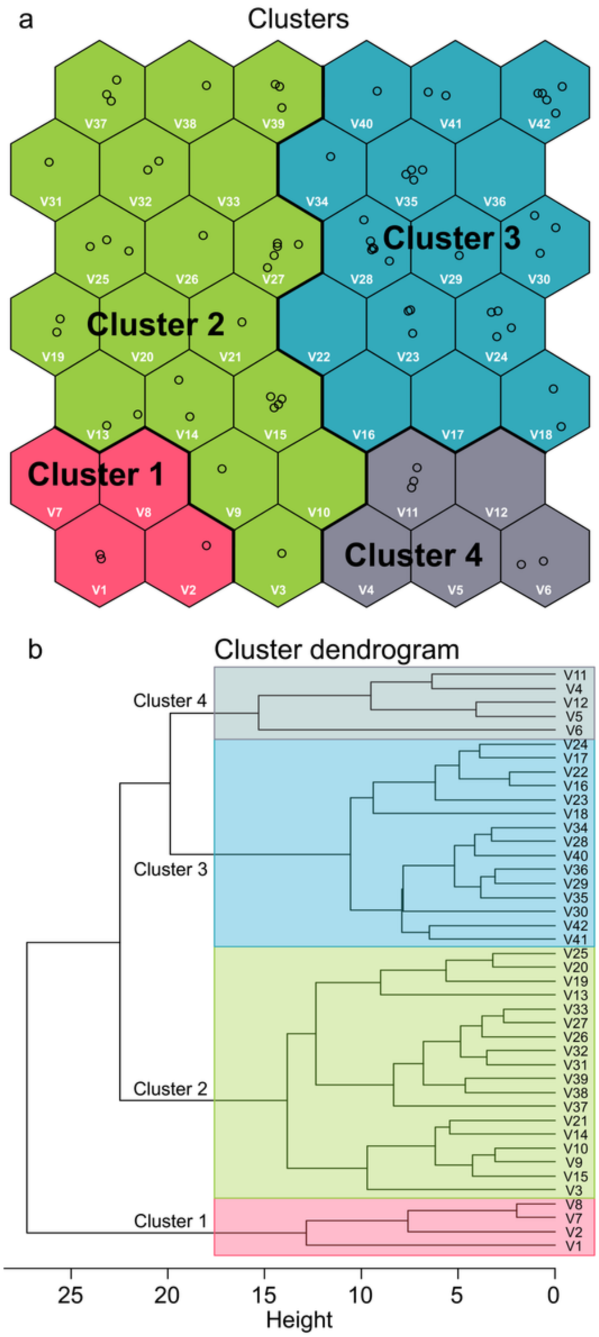

Figure 2

Classification of the input data (number of individuals: 113 species × 2 cultivation methods × 36 surveys) using the self-organizing map. (a) The 42 output neurons are arranged in a two-dimensional grid (7 × 6; V1~V42). (b) Neurons are grouped into four clusters, which are shown in different colors, using dendrograms produced using Ward's linkage method. The circles in the neurons indicate the input data.

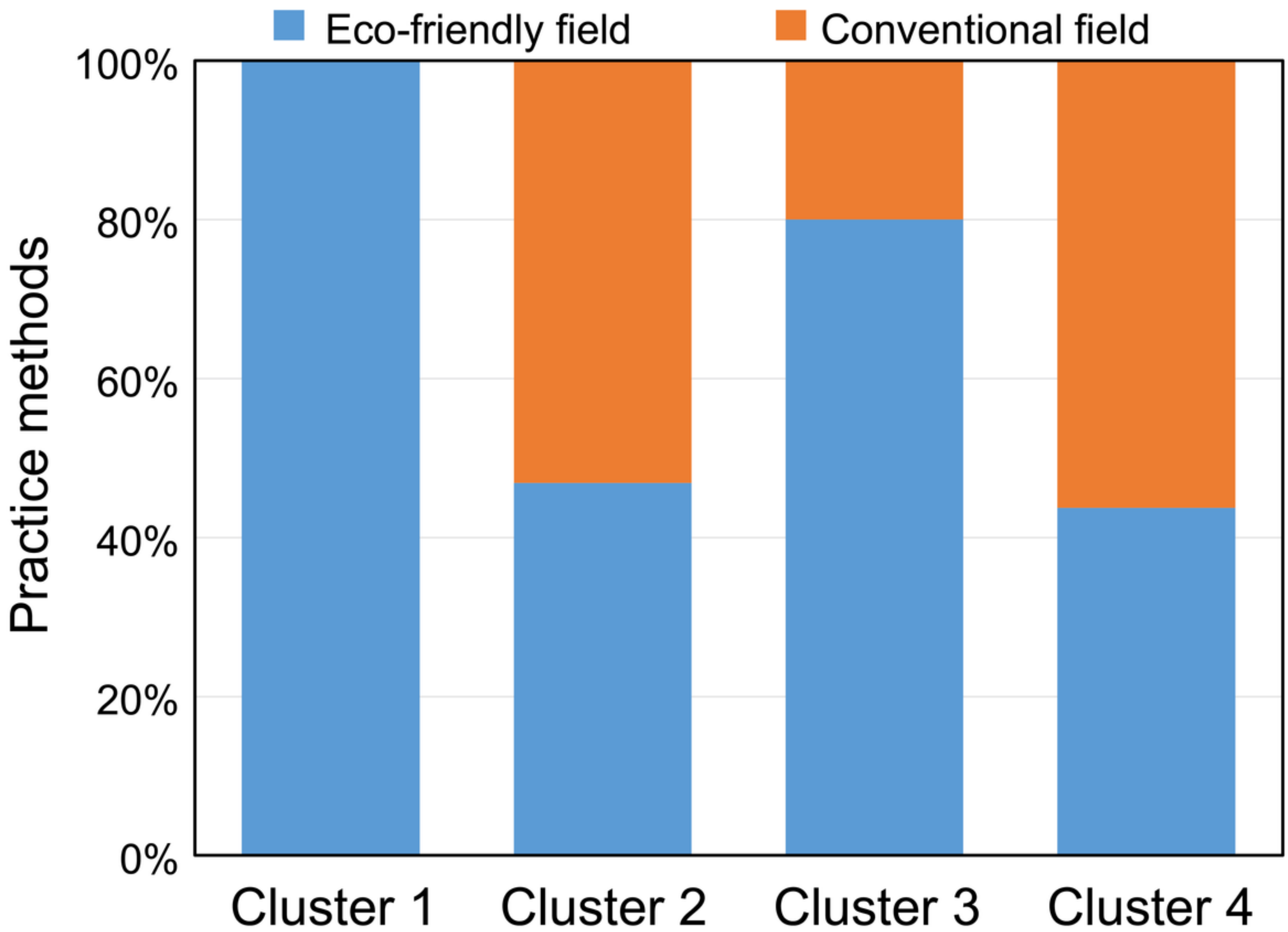

Figure 3

The difference in practiced method among four clusters defined by the self-organizing map.

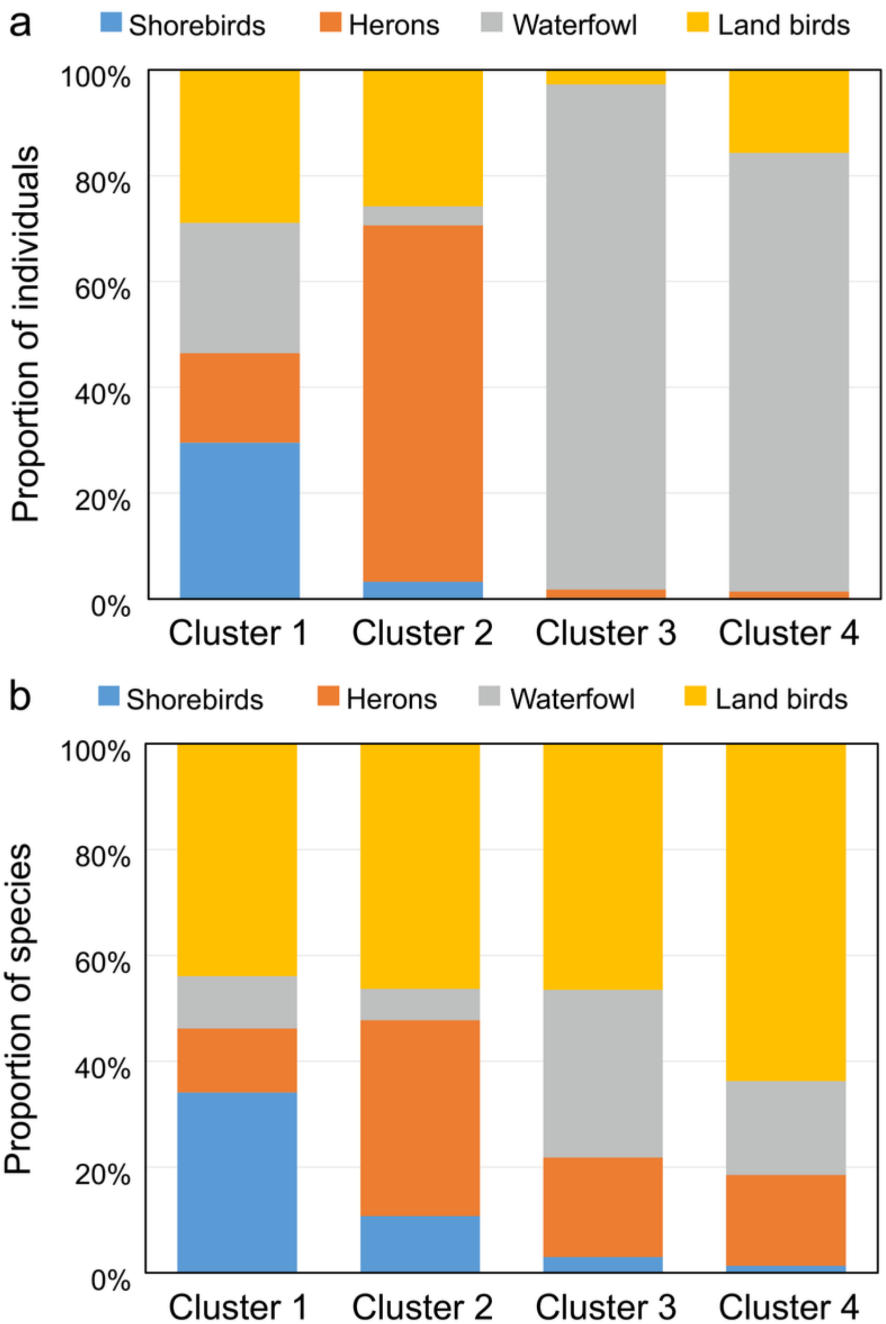

Figure 4

The difference in the relative number of (a) individuals and (b) species of bird assemblages among the four clusters defined by the self-organizing map (SOM).

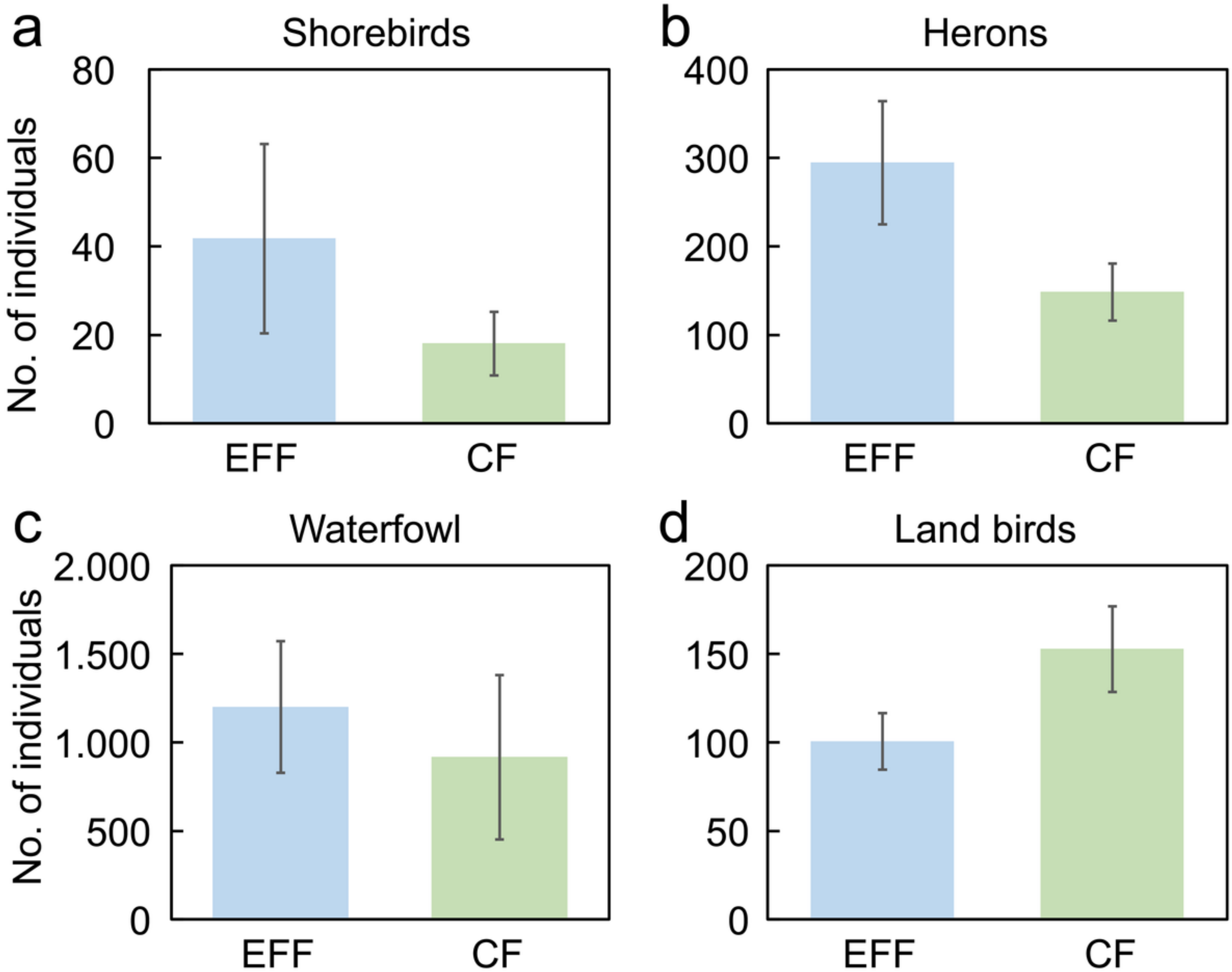

Figure 5

Average values of bird group abundance ((a) shorebirds, (b) herons, (c) waterfowl, and (d) land birds) between eco-friendly fields (EFF) and conventional fields (CF) according to main occurrence period (shorebirds: April-May, and August-September; herons: May-October; waterfowl: October-April; land birds: all seasons). The number above the bar graph indicates the sample size of the bird group. N=36 for each farming method.

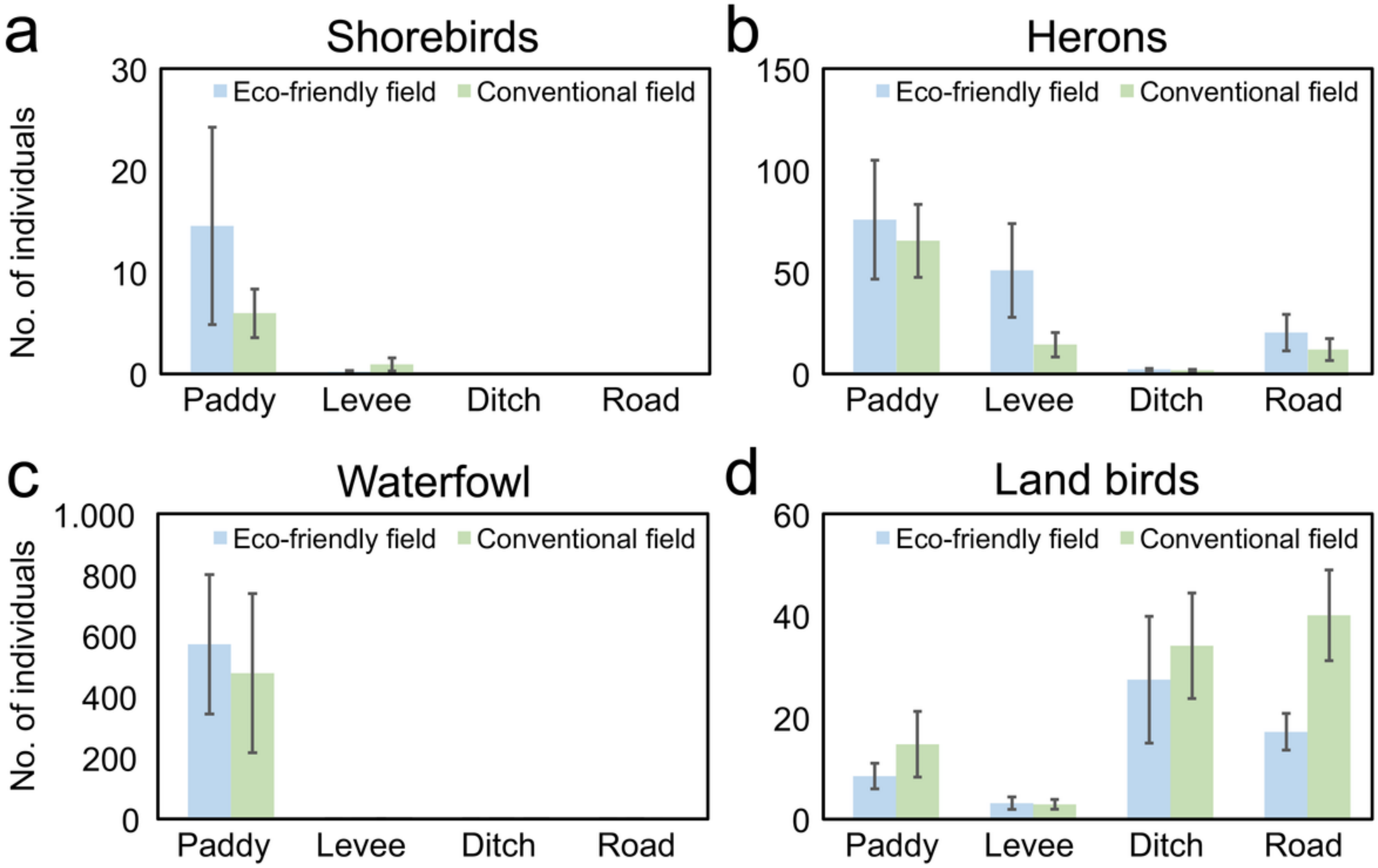

Figure 6

Average values of bird group abundance ((a) shorebirds, (b) herons, (c) waterfowl, and (d) land birds) in eco-friendly and conventional fields among habitat types (paddy, levee, ditch, and road). N=36 for each farming method.

Supplementary Files

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