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Assessing the landscape-dependent restoration potential of abandoned farmland using a hierarchical model of bird communities

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ABSTRACT

Expansion and intensification of agriculture have led to an immense decrease in biodiversity. However, the area of abandoned farmland has been increasing globally in recent years and is expected to provide novel habitats for various organisms. Despite the promising potential for biodiversity conservation in agricultural landscapes, few studies have compared biodiversity among multiple land use types, including abandoned farmland. We examined the effects of major land use types (wetland, grassland, forest, farmland, abandoned farmland) and the surrounding landscape openness (proportion of wetland/grassland in the surrounding area) on the abundance and species richness of bird communities and four functional groups (wetland, grassland, farmland, and forest species) in the agricultural landscape of central Hokkaido in northern Japan. The abundance of wetland/grassland species in abandoned farmland tended to be intermediate between those of their original habitats (wetland and grassland) and other land uses (forest and farmland), and to be positively associated with the landscape openness. The abundance of forest species tended to be higher in forest areas than in areas with other land use types and was not associated with the landscape openness. The abundance and species richness of the bird community were predicted to be high in large abandoned farmland areas surrounded by open land. For wetland species, whereas total abundance was predicted to be primarily mediated by landscape openness, species richness was predicted to be primarily mediated by the farmland abandonment area. The abandoned farmland in our study area would not currently have a high conservation value for forest birds. However, the abandonment of farmland surrounded by open land would significantly improve the conservation of wetland/grassland birds in the agricultural landscape. Given the decline in the area of grassland, wetland, and low-intensity farmland, farmland abandonment provides an opportunity to conserve and restore the declining populations of wetland and grassland birds.

1. Introduction

Rapid human population growth over the past few centuries has resulted in the conversion of most of the Earth's land surfaces to human land uses, such as urban areas, transportation networks, and farmland (Ramankutty and Foley, 1999; Ellis, 2011). For example, approximately 80% of the world's wetlands, 40% of grasslands, and 20% of forests have been lost since the 1700s (Goldewijk, 2001; Davidson, 2014), resulting in an immense decrease in biodiversity (e.g., Newbold et al., 2015). Among the various factors associated with this biodiversity loss, the expansion and intensification of agriculture are considered to be the major drivers (Donald et al., 2001; Tilman et al., 2001). For example, Tanentzap et al. (2015) found that 53% of the threatened terrestrial species on the International Union for Conservation of Nature (IUCN) Red List were negatively affected by agriculture.

Since the 1900s, farmlands have been abandoned around the world and especially in developed countries due to declines in human population and agriculture (Ramankutty and Foley, 1999). Abandoned farmland can facilitate the recovery and succession of plant communities by providing novel habitats for many animals whose distributions were negatively affected by the past expansion and intensification of agriculture (Cramer et al., 2008; Pereira and Navarro, 2015). Therefore,

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it is suggested that not only preservation of the remaining natural habitats, but also management of cultivated and abandoned farmlands would be beneficial for organisms in agricultural landscapes (e.g., Tscharntke et al., 2005; Meli et al., 2014). Nevertheless, relative values among various land uses (e.g., active and abandoned farmland and the remnants of natural habitats) for organisms in agricultural landscapes remain unknown.

The abundance and species richness of organisms in agricultural landscapes are expected to vary depending on the surrounding environment (e.g., the quality of the matrix or the amount of surrounding habitat) (Dauber et al., 2003; Quesnelle et al., 2015; Ernst et al., 2017) via various ecological processes, such as the provision of additional feeding habitats (Dunning et al., 1992; Taylor et al., 1993). It would also be important to examine how the abundance and species richness of organisms for each land use type varies depending on the surrounding environment. Indeed, our previous study revealed that abandoned farmland with large amounts of surrounding wetland/grassland had a high abundance and species richness of wetland/grassland birds (Hanioka et al., 2018).

The objectives of the present study were to compare the abundance and species richness of birds among the major land use types in agricultural landscapes (i.e., wetland, grassland, forest, farmland, and abandoned farmland) and to assess their dependency on the surrounding landscape structure. We used recently developed hierarchical community models (HCMs), which allowed us to model rare and common species simultaneously (Iknayan et al., 2014; Warton et al., 2015; Ovaskainen et al., 2017), and therefore even functional groups and entire communities could be assessed (Dorazio et al., 2006; Yamaura et al., 2012b; Kéry and Royle, 2016). We specifically adopted abundance-based HCMs to evaluate the value of farmland abandonment not only to total bird abundance, but also bird species richness (Yamaura et al., 2016a,b; Yamaura and Royle, 2017).

In the analysis of field data, we first quantified the effects of local land uses and the surrounding landscape structure (landscape openness) on the abundance of individual bird species and the abundance and species richness of functional groups (wetland, grassland, farmland, and forest species) and whole communities. Then, based on the modeled environmental dependency of every species, we inferred how the potential of farmland abandonment to conserve bird abundance and species richness varied with the landscape structure. Finally, to visualize the significance of the modeling results, we constructed spatial maps of predicted bird abundance and identified areas with great conservation value (i.e., high bird abundance) for individual groups in the study area.

It is known that farmland abandonment can negatively affect open land bird species in Europe (e.g., Sirami et al., 2008), and agricultural intensification also has negative effects (Donald et al., 2001; Flohre et al., 2011). Because farmlands are usually abandoned in marginal unproductive areas where traditional low-intensity farming is common (Queiroz et al., 2014), we hypothesized unimodal responses of wetland and grassland bird abundance to the post-management habitat trajectory for xeric (dry) sites (Fig. 1). According to this conceptual model, low-intensity (or extensively managed) farmland would provide optimal habitats for many wetland/grassland species, and management practices that change the farmland from this status will result in the decline of wetland/grassland species. The model is based on the premise that farmland abandonment in Europe shifts low-intensity (dry) farmland to forest land (Sirami et al., 2008). However, farmlands in our lowland landscape are situated in both mesic and xeric sites, and have been cultivated by intensive management (with machinery and chemical fertilizer: Appendix 1 in Supplementary material). Thus, we hypothesized that abandoned farmlands in our study region would succeed to semi-natural wetland/grassland, which may increase the abundance of wetland and grassland birds (Fig. 1).

2. Materials and methods

2.1. Study area

Our study area was located in the Ishikari and Iburi Districts of central Hokkaido in northern Japan (42°36′–43°06′N, 141°31–54′E, annual average precipitation: 929–1198 mm, average temperature: 6.7–7.6 °C; Japan meteorological Agency, Ministry of Land, Infrastructure, Transport, and Tourism http://www.jma.go.jp/jma/indexe.html; Fig. 2). Fewer than half of the wetlands that existed in Japan in the early 20th century (approximately 2110 km^2) now remain (821 km^2) (GSI, 2000). Our study area was dominated by wetlands in the 1900s, but most of these have been converted into farmland or residential areas (GSI: http://www.gsi.go.jp/ENGLISH/index.html; Hokkaido Regional Development Bureau, 2013). Additionally, the amount of abandoned farmland in Japan increased from 130,000 ha in the late 1980s to 400,000 ha in 2011 (MAFF, 2011). Our study area currently contains 2065 ha of abandoned farmland. This area is approximately equivalent to 70% of the area of the remaining wetlands in the study area, which are primarily located in its southern portion (Fig. 2a).

2.2. Definition of land use

We focused on six land uses: wetland, grassland, wet abandoned farmland, dry abandoned farmland, farmland, and forest. We divided abandoned farmland into either wet or dry based on the dominant vegetation, because differences in vegetation may affect the abundance and species richness of birds. Wetland was defined as uncultivated land dominated by wet grass species such as common reed (*Phragmites australis*), sedge (*Carex* spp.), and *Calamagrostis canadensis* subsp. *langsdorffi*. Grassland was uncultivated land dominated by dry grass species such as amur silver grass (*Miscanthus sacchariflorus*) and Japanese silver grass (*Miscanthus sinensis*). Wet abandoned farmland was historically cultivated but is now abandoned land dominated by wet grass species. Dry abandoned farmland was historically cultivated but is now abandoned land dominated by dry grass species. Farmland was arable land used as pasture, cropland, or paddy fields. Forest was uncultivated land dominated by trees.

2.3. Establishment of sampling plots

Based on a vegetation map (scale 1:25,000 and resolution: 25 m) provided by the Natural Conservation Bureau of the Ministry of Environment (http://www.biodic.go.jp), we created a land use map composed of the aforementioned six land uses and other unsuitable land uses (e.g., urban areas and open water) for the birds of interest. Then, we established 48 sampling plots of 2 ha each (width 100 m × length 200 m) to range the ratio of each land use from 0 to 1. We considered the center of the long side of each sampling plot to be the transect line (200 m), and recorded the birds observed in a 50-m band on each side of a 200-m long straight line. To ensure that the sampling plots were independent from each other (to avoid double counting of the same individuals), the plots were spaced 500 m apart (Ralph et al., 1993: radius of territory sizes for common species were basically < 100 m). This spatial separation was considered since spatial autocorrelation can greatly affect the analysis when spatial autocorrelation occurs both in response (birds in this study) and environmental variables (Legendre et al., 2002). We calculated the ratio of focal land uses (0–1) within each sampling plot. We generated 400-m buffers from the edge of each sampling plot (width 900 m × length 1000 m; the area of each buffer was 88 ha). We then measured the surrounding wetland/grassland ratio (0–1; hereafter termed 'landscape openness'), which included wetland, grassland, wet abandoned farmland, dry abandoned farmland, and farmland (except for paddy fields) in each buffer. We excluded paddy fields because their low vegetation