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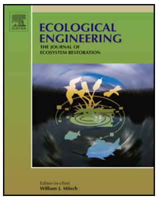

Response of carabid beetles to wetland creation in an intensive agricultural landscape

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ABSTRACT

In order to reduce the farming intensity and increase habitat heterogeneity, wetlands are often created in agricultural landscapes. This is because wetlands in agricultural landscapes can decrease sediment deposition, i.e., phosphorus and nitrogen, released as a result of cultivation and fertilization. Additionally, the creation of wetlands can improve heterogeneity within an agricultural landscape. We investigated the response of carabid beetles to restoration and creation of wetlands in a paddy field-dominated agricultural landscape in South Korea. Degraded wetlands, paddy fields, and dry fields (previous habitats) were converted to wetlands, including an abandoned paddy field that existed as a spontaneously restored wetland. Carabid beetle diversity significantly increased with wetland restoration and abandonment of farming practices, while the wetland creation did not have a significant effect. Carabid species composition, from nestedness and co-occurrence indices, did not show significant segregation patterns. Carabid assemblages in the previous habitats and current wetlands were similar to the previous habitats and current wetlands. Only flying carabid beetles showed a significant response to both wetland restoration and creation. Species capable of flight can migrate from surrounding habitats or closely connected habitat areas. Carabid abundance was only elevated with reduction of disturbance by wetland restoration and abandonment, although re-colonized carabid beetles were the dominant species in paddy fields and their landscape. The reduction of farming intensity creates the heterogeneity within restored wetlands and abandoned paddy fields, significantly improving carabid diversity. Our results suggest that in order to achieve the ecological benefits from restoration and creation of wetlands in paddy field-dominated landscapes, the farming intensity should be reduced. The complex configuration of agricultural landscapes can improve carabid diversity therein.

1. Introduction

Agricultural land refers to the percentage of arable land area, under permanent crop rotation, and under permanent pastures. Approximately 37.7% of the total land area of the world is agricultural. Current agricultural practices, including increases in the use of high-yield crop varieties, fertilization, irrigation, and pesticides, have caused a reduction in species diversity in the agricultural landscape (Matson et al., 1997; Rudel et al., 2009; Tscharntke et al., 2005).

Organic farming, which is characterized by the prohibition of the use of synthetic chemicals, often results in increased biodiversity in agricultural landscape (Fuller et al., 2005; Mäder et al., 2002). However, positive effects of organic farming are often more associated with practices and spatial heterogeneity in agricultural landscapes, because organic farming practices have frequently decreased uniformity and improved habitat heterogeneity (Tews et al., 2004). Agricultural landscapes with low farming intensity contain more natural crop types (e.g., abandoned fields, extensively grazed land and field margins) and crop production types (e.g., different field crops, intensively grazed lands and orchards) than agricultural landscapes with intensive farming. These cover types are distributed in a complex pattern and interspersed with others within the landscape, which is probably a key to sustaining biodiversity (Benton et al., 2003; Tews et al., 2004).

To reduce farming intensity and increase habitat heterogeneity, wetlands are often created in agricultural landscapes (Zedler, 2003). Wetlands in agricultural landscapes can reduce nutrient loadings and sediments, i.e., phosphorus and nitrogen, released from cultivation and fertilization although wetland including natural and artificial wetlands is major source of carbon dioxide and methane emission (Woltemade, 2000). Complex wetlands

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habitats incorporating aquatic and terrestrial forms can contribute to increased habitat heterogeneity and support biodiversity in uniformed agricultural landscape.

However, there is a significant biodiversity benefit from wetland creation in agricultural landscape with increased habitat heterogeneity reported from dry-fields (e.g. field crops, grazed lands and orchards) dominating agricultural landscapes (Céréghino et al., 2008; Thiere et al., 2009). The wetland is probably significantly heterogeneous habitat in these agricultural landscapes where there exist characteristics of dry habitats. In South Korea, agricultural landscapes are characterized by paddy fields (56% of total farming land). Paddy fields, as a flooded parcel of arable land, are temporal wetlands used for growing, because the cultivation of deep water rice is carried out in flooded conditions with the water level greater than 50 cm (20 in.) for at least a month (Lawler, 2001). The positive effect of restoration and creation of wetlands may be too insignificant to have much effect on the increase of biodiversity of the carabid beetle population as a whole.

We investigated the response of carabid beetles to both the restoration and creation of wetlands in paddy field-dominated agricultural landscapes in South Korea. Carabid beetles are useful for this type of study, as they respond predictably to heterogeneity of the landscapes and environmental change in agricultural landscapes (Aviron et al., 2005). They are sensitive to spatial and temporal changes in agricultural habitats caused by farming practices and land-use conversion, which affect both their taxonomic and ecological abundance (Östman et al., 2001; Purtauf et al., 2005). Specifically, carabid beetles were differentially distributed among wetland types such as riverine, estuary, and floodplain. In addition, carabid assemblages represented a wetland succession (Brose, 2003b; Do et al., 2011).

We assumed that the restoration and creation of wetlands might not improve the heterogeneity in paddy field-dominated agricultural landscapes. The effect of restoration and creation of wetlands may not increase the population of carabid beetles. The specific objective of our study was to compare the carabid beetle population in current wetlands and previous agricultural landscapes dominated by paddy fields for assessing the effect of restoration and creation of wetlands.

2. Material and methods

2.1. Study sites

We selected degraded wetlands, paddy fields, and dry fields as previous habitats. These habitats had been changed to wetlands. Restored wetlands, created wetlands from paddy fields and dry fields, and abandoned paddy fields that spontaneously converted to wetlands after abandonment, were selected as current wetlands (Fig. 1).

Among the previous habitats, the degraded wetlands were dominated by some aquatic plants (e.g. *Phragmites communis* TRIN. *Typha angustifolia* L. and *Zizania caduciflora* (Turcz. ex Trin.) Hand.-Mazz.), while terrestrial and invasive plants (e.g. *Humulus japonicas* Sieboid & Zucc. Erigeron Canadensis L., *Ambrosia trifida* L.) were widely distributed within wetland area. The paddy fields had been used for cultivating semiaquatic rice (*Oryza sativa* L.) with intensive farming (e.g. fertilization, irrigation, and pesticides). Dry fields have been used to protect cultivation within riparian areas.

Wetlands (2.67 ha) derived from degraded wetlands (restored wetland) were restored by removing non-native species, removing polluted soils and substrates, planting aquatic plants and installing wooden walkways in 2011. Paddy fields were converted to wetlands (created wetland, 2.89 ha) for retaining permanent aquatic habitat in the wintering of 2008 as part of organic farming practices. Dry-field was converted to small wetlands (2.4 ha) in 2007 as part of an effort to improve riparian habitat with greenhouse removal. Abandoned paddy fields, spontaneously restored wetlands, were abandoned 4–6 years ago. The annual herbaceous species, such as *Erigeron annus*, *Artemisia princeps* var. *orientalis* and *Alopecurus aequalis* var. *amurensis*, were dominant. Some *Salix* species and *Alnus* species had invaded the abandoned paddy fields. Restored and created wetlands are open to the public and wooden walkways were installed around the wetland boundaries to allow wetland visitation.

2.2. Carabid sampling

Carabid beetles were sampled using pitfall traps (500 mL plastic jars with a 15-cm-diameter plastic funnel) partially filled with 100 mL ethylene glycol. Four pitfall traps were installed within the riparian area of degraded wetlands and restored and created wetlands. In paddy fields and abandoned paddy fields, the traps were installed along dikes. Traps were emptied once a month. Carabid beetles in previous habitats (e.g. degraded wetlands, paddy fields, and dry fields) were investigated from May to September of 2006 before restoration or creation began. Carabid beetles from restored and created wetlands and abandoned paddy fields were collected from May to September 2013.

Collected carabid species were divided into groups based on two ecological traits: humidity preference and flight availability. The humidity preference of carabid beetles was divided into xerophilous, mesophilous and hygrophilous species. A high proportion of xerophilous species in a habitat indicates high sun exposure and a very early successional stage of the habitat. Flight availability was divided into flight capable and flightless. This indicated the dispersal ability. Flightless carabid beetles have limited dispersal ability, which makes it difficult for them to introduce quickly or to colonize later on. The species were classified according to published literatures (Do et al., 2011, 2012b) and the Working Group for Biological Indicator Ground Beetles Database (2011).

2.3. Data analysis

We investigated the dominance structure of carabid beetles by constructing rank-abundance plots for the previous habitats (i.e. degraded wetlands, paddy fields, and dry fields) and restored and created wetlands. Differences in diversity indices (Shannon's diversity index) between the previous habitats and restored and created wetlands were evaluated using the *t*-test approach of Hutcheson (1970) for the Shannon formula, as described by Magurran (1988).

Differences in species composition of the previous habitats and current wetlands, respectively, were assessed from a nestedness analysis, using the nestedness temperature calculator (Atmar and Patterson, 1995). This measures whether faunal composition of different study sites form perfect subsamples from a larger common species pool (a nested pattern) or whether local peculiarities occur. A perfectly ordered or nested system, with no randomness, is characterized as maximally "cold" (0°), whereas a system with no order may be labeled as maximally "hot" (100°). A Monte Carlo simulation was used to test whether the data were significantly different from a random sample. The matrix was randomized 5000 times. The measurements of temperature from the observed data were then compared to the distribution of values from the randomized matrices.

The C-score (Stone and Roberts, 1990) and species combination scores (Pielou and Pielou, 1968) were used to study species co-occurrence patterns in presence–absence matrices using fixed sum row and column constraints (Gotelli, 2000). The observed C-score and species combination score were compared to the average scores generated from 5000 randomized matrices. Results are