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Impacts of edge density of field patches on plant species richness and community turnover among margin habitats in agricultural landscapes

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ABSTRACT

In intensive agricultural environments, arable field margins are important habitats as reservoirs of various beneficial wild species. Many studies of species diversity in field margins have focused on the local habitat level. However, relationships between the network of the margin habitats and species diversity are less studied.

Edge density index of field patches is a class-level landscape metric used as one measure of habitat network. This study focused on edge density index and its impacts on plant species richness and community turnover among the margins in agricultural landscapes. We examined how effectively the index of edge density can be used as a class-level indicator for species diversity in margins. This study introduces a method for indicating plant species diversity of the margin habitats by using an easily measured spatial indicator without comprehensive analysis of land use/land cover.

A total of 29 landscape-square pairs, each consisting of two 25 ha squares, were sampled across southern Finland. Vascular plant species were sampled in each square. In GIS, field patch edges were divided into two types: those within crop fields, referred to as *within-field edges*, and those between crop fields and non-crop lands, referred to as *non-crop field edges*.

By comparing the roles of three landscape groups (the two different edge types as well as all edges grouped together) in explaining plant species richness (at alpha and gamma level) and community turnover (at beta level) in the sampled landscape squares, we found that density index of non-crop field edges surrounded by contrast land use is an effective indicator of species diversity at beta and gamma level. This study suggested that field margins surrounded by contrast land use shall be considered as a priority landscape element in agricultural edge network design, whereas simply using the density of all field edges to indicate species diversity without separating the different effects of various edge types shall not be recommended.

1. Introduction

Agricultural intensification has led to a widespread decline in farm land biodiversity measured across many different taxa. In intensively farmed agricultural landscapes only small semi-natural habitats remain, typically as linear elements such as field margins/hedge rows. The value of these linear habitats as reservoirs for beneficial invertebrates, predators of pest species, and crop pollinators in the intensively farmed agricultural landscapes is becoming more widely appreciated (Helenius, 1995; Lagerlöf et al., 1992; Lagerlöf and Wallin, 1993; Kleijn and Verbeek, 2000; Moonen and Marshall, 2001; Baudry et al., 2000a; Le Coeur et al., 2002; Bokenstrand et al., 2004; Kuussaari et al., 2007). However, as agricultural activity intensifies, agricultural landscapes become homogenized and the semi-natural edge habitats diminish (Chamberlain et al., 2000; Marshall and Moonen, 2002; Burel and Baudry, 2005; Vickery et al., 2009; Pitkänen and Tiainen, 2001; Hietala-Koivu, 2003). In order to reduce the loss of species diversity in farmed landscapes, it is important to understand how edge habitats can be managed to maintain or enable species diversity.

Although many studies of species diversity in field margin habitats have been conducted, most of them focused on local scale margin habitat (Marshall and Moonen, 2002), whereas relationships between the network structure of margin habitats and species diversity are less studied (Hansen et al., 1992; Burel and Baudry, 2005). Marshall et al. (2006) identified the need for European agri-environment schemes such as payments to farmers to address water, biodiversity and landscape protection, to address landscape

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structure as well as habitat creation in maintaining farm land biodiversity. Kleijn et al. (2006) considered that schemes aiming to increase biodiversity in general, with the objective of improving ecosystem processes at regional scale, may be successful even when prescriptions are broad and farming is relatively intensive. Although some studies have been conducted on the importance and roles of field edge/margin networks at landscape scale, e.g. in the 'bocage' of northern France (Burel and Baudry, 1999; Baudry et al., 2000b; Le Coeur et al., 2002), knowledge of species diversity in edge networks is still lacking in contrast with that of local scale diversity (Grashof-Bokdam and van Langevelde, 2004).

A network of field margins may comprise various habitat types. In agricultural environments, field margins can be generally grouped into two types: margins within crop fields, and those between crop fields and other non-crop land-use covers, such as forests, waters, and grasslands. Different types of margin habitat have different characteristics of their physical environment, indicating different qualities of maintaining species diversity. Studies have indicated that margin type is relevant in affecting species diversity at local scale. For instance, Asteraki et al. (1995) examined ground beetle communities in relation to various characteristics of different types of field margin in order to assess which characteristic is important in maximizing carabid beetle species diversity. They found that the number of carabid beetle species is greater in the type of field margin containing hedge than fence edges. In another study (Benoit et al., 2001), field boundaries were divided into four different types and the use of boundaries by birds during breeding season was compared between types. They reported that the use of natural and windbreak types of field boundary was similar, while periodically cut or herbicide-treated types of field edge have fewer bird species and individuals than the former two types. In a Finnish agricultural landscape, Jauni and Hyvönen (2010) reported that alien weed species reached the highest level in frequently disturbed field and road margins, and the lowest levels in grasslands and forest margins.

Despite the above studies, due to the potential for species movement across different types of margin habitat in a network, it is not clear whether margin type affects species diversity at the network scale. A network of margin habitats can be considered as a set of inter-connected communities, which can be defined as a 'metacommunity' – a set of local communities in different locations between which species can migrate (Leibold et al., 2004). The core idea of the metacommunity is that species diversity across multiple scales, ranging from that at local sites (alpha level), through species turnover between the sites (beta level), to the regional scale (gamma level), interact in a given inter-connected habitat network (Holyoak et al., 2005). In the framework of metacommunity, overall species diversity can be affected by organism movement between habitats controlled by spatial arrangement (dispersal distance) among the interconnected metacommunities (Holyoak et al., 2005; Bedford and Usher, 1994; Olson, 1995). This spatial-oriented hypothesis shows a possibility that, within a given distance, species dispersal may cause multi-species source–sink movements across different types of habitat – the so-called "mass effect", which reduces the loss of local-level species diversity (without affecting regional diversity at beta level) by allowing species coexistence within a community (Holyoak et al., 2005). In agricultural landscapes, Forman and Baudry (1984) and Baudry (1988) showed that not only the structure of linear edge habitats, but also their connectivity and distance from wood edges, considered as sources, were relevant in explaining patterns of floral distribution in nearby field edges. Whittingham (2007) performed a review of the prediction of the effect of the management of small patches by agri-environment schemes, e.g. hedges and field margins, clarifying that spatial distance between patch and source breeding populations was important. The above studies indicate that there is potential for sink–source movement between different types of margin habitat, and imply that the mass effect may reduce composition dissimilarity among different types of margin habitat.

A niche-based hypothesis, referred to as the "species sorting effect", is another potential explanation of species richness in interconnected metacommunities (Holyoak et al., 2005). The species sorting effect describes variations in the abundance and composition of metacommunities due to the responses of species to environmental heterogeneity of local patches, rather than purely spatial effects, such that local patch conditions may favor particular species. This model represents the classical theories of the nichecentric era of Hutchinson (1957) and MacArthur (1972). In agricultural landscapes, different types of margin habitat involve different surrounding land use and have heterogeneous physical environments affecting species diversity. Based on the sorting effect hypothesis, environmental heterogeneity caused by varied land use surrounding field margins is expected to influence species turnover (beta level) among the metacommunities of margin habitats.

Edge density index of field patches is a class-level landscape metric used as one measure of habitat network (McGarigal and Marks, 1995). The present study focused on this index and its impacts on plant species richness (at alpha and gamma level) and community turnover (at beta level) among field margins in agricultural landscapes. We examined how effective the index of edge density may be as a class-level indicator of species diversity in margins. In this study, field patch edges were divided into two different types: those within crop fields (hereafter referred as *within-field edges*) and those between crop fields and non-crop lands e.g. watercourse, grassland, and forests (hereafter referred as *non-crop field edges*). Because of the mass effect across habitats in interconnected metacommunities, we first assumed that the two edge types were equal in explaining species diversity, and therefore edge type would not be an influential factor. This study does not aim to verify metacommunity theory of spatial vs. environmental effects in modeling species communities; rather, we use metacommunity models to explain our results.

This study was motivated by the need for an indicator of plant species diversity in margin habitats that uses easily measured class-level landscape data without comprehensive analysis of land use/land cover. Specific aims were: (1) to find out whether or not edge type is important when edge density indices are used to explain species diversity; (2) to examine how effectively the index of edge density can be used as a class-level indicator of species diversity in margins; and (3) to investigate how the class-level edge density index relates to other measures of land cover and land use diversity. Finally, we discuss potential implications of our results for edge network design in agri-environment schemes.

2. Methods and materials

2.1. Study areas

A total of 29 study areas have been randomly chosen in the MYTVAS project (Kuussaari et al., 2004). These areas are located along Finnish farming landscapes (Fig. 1) with minimum field area 20 ha (Kuussaari et al., 2004, 2007; Kivinen et al., 2006). Each of the 29 study areas has been sampled by a landscape square of area 100 ha. In 2003, farmed lands in each of the 29 study areas covered 28 ha on average, of which 71% were cereal cultivation and 29% pasture or grassland. The average field patch size was 1.4 ha (Tike, 2004).

2.2. Sampling method

Each of the 29 sampled landscape squares was further divided into four sub-squares of 25 ha from which two sub-squares were