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Plant functional diversity in agricultural margins and fallow fields varies with landscape complexity level: Conservation implications

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ABSTRACT

A consensus has been established that functional traits rather than taxonomic diversity play a fundamental role in linking biodiversity with ecosystem processes and associated services. This study from Finland addressed an issue of relative values of fallow and field margin biotopes in conservation of plant functional diversity (based on six functional traits of relevance to ecosystem services, and diversity of multiple traits) in agricultural landscapes differing in their structural complexity. Relative covers of plant species were surveyed in sampling plots located in perennial fallow fields and three types of perennial margins (margins between crop fields, along forest edges and by river) in three types of landscape context (simple, intermediate and complex). Fallow fields significantly contributed to the total functional diversity only in simple landscapes. The river margins provided the greatest functional diversity, especially in reproduction and regeneration traits while crop margins were consistently characterized by the lowest functional diversity. Substantial functional diversity of fallow patches in simple landscapes was due to high abundance of functional species, while that of river margins stemmed from presence of unique species. The plant functional diversity progressively declined with agricultural landscapes becoming simplified. The study indicates non-cropped biotopes having complementary roles in ensuring multifunctionality of agro-landscapes and confirms importance of biotope mosaic for functional diversity.

Introduction

The economy-driven progression of agricultural production into more intensive and specialized forms leads to the deterioration in the ecological state of agricultural ecosystems (Stoate et al. 2009). Among other impacts, this drives homogenization of the agricultural landscapes (Benton, Vickery, & Wilson 2003). One of the commonest counteractive options is preservation, establishment and management of field margin biotopes, which, in the EU, is mainly done through the agri-environmental contracts and cross-compliance baseline (IEEP 2008). Ecological benefits of linear habitats as reservoirs of beneficial invertebrates, predators of pest species or crop pollinators have been widely appreciated (Marshall, Joenje, & Burel 1994; Cole, Brocklehurst, Elston, & McCracken 2012). Another common agri-environment option at farm scale is fallowing, that is, removal of whole field parcels from production. Fallowing of a certain portion of a field area had been an obligation across the EU until 2008, when it was abolished (i.e. CAP set-aside; Hart & Baldock 2011). Many countries, including Finland, offer payments for voluntary fallowing of fields with an objective of enhancing biodiversity (Kovács-Hostyánszki et al. 2011; Toivonen, Herzon, & Helenius 2013).

A hypothesis considering the relationship between effectiveness of agri-environment schemes and landscape complexity (Tscharntke et al. 2005) sets local farm management into a landscape perspective. Accordingly, efficiency of agri-environmental allocations depends on level of landscape complexity, which is defined at three levels based on cover of semi-natural areas: cleared (<1% of semi-natural habitats, lowest diversity); simple (1–20%); and, complex (>20%, highest diversity). The intermediate level, that is simple landscape, is predicted to be optimal to agri-environmental management, which has generally been corroborated in a meta-analysis (Batáry et al. 2011). Most recently, the framework has been extended to consider provisioning of ecosystem services (Tscharntke, Batáry, & Dormann 2011).

A consensus has been established that species functional traits play a fundamental role in linking biodiversity with ecosystem processes and services (Díaz & Cabido 2001; Hooper et al. 2005; Reiss et al. 2009). For instance, there are well-established links between plant leaf traits (e.g. LDMC) and nutrient cycling providing ecosystem supporting service (Garnier et al. 2004; Poorter

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& Garnier 1999; Reich, Walters, & Ellsworth 1992); diversity in plant life forms is a strong surrogate to assess variation in plant net primary productivity delivering regulating service (Lieth & Whittaker 1975; Saugier, Roy, & Mooney 2001). However, studies on impacts of agri-environment management on biodiversity still focus mainly on taxonomic species diversity rather than species' functional properties. Yet, it has been suggested that in production systems, landscape-moderated conservation of total species richness or abundance of red-data listed species will not necessarily optimize ecosystem services (Kleijn et al. 2011).

Functional diversity can be measured by functional composition of multiple traits using functional diversity indices (e.g. functional richness, functional evenness). Indices that mix richness and evenness, such as RAO's index (Botta-Dukát 2005), have also been used extensively (Díaz et al. 2007; Flynn et al. 2009; Mason, Mouillot, Lee, & Wilson 2013). Assessment of landuse effects on indices composed by functional traits relevant for key ecosystem functions can therefore provide insight on how to optimize land management for maintaining multiple ecosystem services.

This study focused on functional diversity of vascular plants in fallow and margin biotopes along a spatial gradient from simple to complex landscape context. The key research questions were: (1) How does functional biodiversity compare among different biotopes of margins and fallows? More specifically: (i) How do relative roles of margins and fallows change with increased landscape complexity? and (ii) Do relative contributions of two biotope types to functional diversity differ from those to taxonomic diversity? (2) How does the overall landscape-level functional diversity change under different landscape context?

Since large habitats generally contain more species than small habitats (species-area-relationships, MacArthur & Wilson 1967) we hypothesized that whole-field patches (fallows) are more effective in promoting taxonomic diversity than narrow biotopes of linear type (margins). Furthermore, since in environments with low biodiversity plant communities are likely to be unsaturated, a positive linear relationship between taxonomic and functional diversities can be expected. Therefore, we foresaw that simple landscape biotopes of high taxonomic diversity would also contribute to greater functional diversity. In landscapes favoring high levels of taxonomic diversity, functional diversity reaches an asymptote (Sasaki et al. 2009). Therefore in complex landscapes, we expected fallows to contribute more to taxonomic diversity than functional: additional species would likely be functionally redundant.

Methods

Study area

The study area is located in Lepsämänjoki watershed in Nurmijärvi commune, 30 km north of Helsinki (60°23′–60°28′ N, 24°31′–24°43′ E) in southern Finland (Fig. 1). This flat drainage area is 214 km^2. Soil types are mostly sandy clay and fine sand. The area belongs to the southern boreal zone with a mean annual temperature of 4.4 °C (−7.6 °C–16.7 °C), mean precipitation is 65 mm (48 mm–70 mm) and the average duration of snow cover is 132 days. Main crops are spring cereals, row crops and silage (Tike 2012). All of these require intensive management making the study area a production-intensive landscape by Finnish standards.

Sampling design

Based on the main landuse types, we selected three landscape types typical for the area along a spatial gradient from simple to complex landscape:

(1) Simple landscape dominated by fields and with only crop margins (no river and very small forest patches);
(2) Intermediate landscape with a high cover of forest, and margins represented by crop margins and forest margins (no river);
(3) Complex landscape with a high cover of forest and a river, margins included crop margins, forest margins and river margins.

We surveyed fallow fields and three types of perennial margins: margins between crop fields; along forest edges; and, by the only river in the study area. Since neighboring crop types, slopes, and shading varied along the river, we treat the river samples as independent. All fallow fields were represented by grassland fallow type (Toivonen et al. 2013) established within the past 10 years (average age 5.4, range 4–9). All have been managed by annual mowing without biomass removal, chemical applications or grazing. We did not survey fallows younger than four years (typical rotation period for grassland in Finland) as well as the only grazed parcel. We digitized land-cover of the major types (field, forest, river, ditch, road and building) in the landscape squares in ArcGIS 9.3 (ESRI 2008) and calculated landscape metrics (Table 1) in Fragstats 3.3 for ArcGIS 9 (McGarigal et al. 2002). Digitized data on land use (including presence of fallow fields) came from the Land Use Register and the Information Centre of the Ministry of Agriculture and Forestry (Tike 2012). We deducted the age of the fallows from the same register for years 2001–2011.

For each landscape type, we sampled three landscape squares of 1 × 1 km (nine in total). In each landscape square, we chose at random three margin strips as sampling sites for each margin types. Accordingly, there were only crop margins in the simple landscape, crop and forest margins in the intermediate landscape, and crop, forest and river types in the complex landscape. The majority of margins were beside cereal fields (spring barley). Two crop margins and one river margin in the complex landscape were beside root vegetable fields. These and forest margins were about 0.5–2 m wide and river margins were about 3–8 m wide. In each sampling site, six or seven 1-m^2 plots were sampled at systematic intervals. Five fallow sampling sites, corresponding to age and management restriction, were chosen randomly in each landscape type. There was a non-directional difference in average ages (in the simple landscape: mean 5.2, range 4–7; intermediate: 4.8, 4–9; and complex: 6.2, 4–8). In each fallow site, four to eight 1-m^2 plots were sampled depending on field size so that the field area was covered systematically.

Not all species of vascular plants were fully (binomially) identified but some were placed within a genus and subsequently treated as a pseudo-species (e.g. *Taraxacum*, *Alchemilla*). Relative covers of species were estimated in each plot according to the logarithmic scale (1 ≤ 0.125%, 2 ≤ 0.5%, 3 ≤ 2%, 4 ≤ 4%, 5 ≤ 8%, 6 ≤ 16%, 7 ≤ 32%, 8 ≤ 64%, 9 > 64%). Species nomenclature followed Hämet-Ahti et al. (1998). All field workers undertook training in field methods.

Functional traits and diversity index

We calculated species richness per each site and landscape (taxonomic diversity). For functional diversity, we used six types of functional traits (Table 2) on the basis of their potential importance for ecosystem functions and associated ecosystem services (Díaz et al. 2005; Swinton et al. 2006), and following the recommendations of Cornelissen et al. (2003). Measurement of leaf dry matter content (LDMC) followed the method proposed by Vendramini et al. (2002). After cutting, leaf samples were stored in sealed plastic bags, which were slightly moistened, kept in cold boxes with ice bags and brought back to lab usually within 3–8 h. In the laboratory, the leaf samples were blotted dry to remove any surface water, weighed as fresh weight and then oven-dried in paper bags at 60 °C for two