Agriculture, Ecosystems and Environment 200 (2015) 219–234

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Farmlands with smaller crop fields have higher within-field biodiversity

Lenore Fahrig [a,*], Judith Girard [a], Dennis Duro [a], Jon Pasher [b], Adam Smith [b], Steve Javorek [c], Douglas King [a], Kathryn Freemark Lindsay [a], Scott Mitchell [a], Lutz Tischendorf [a]

[a] *Geomatics and Landscape Ecology Research Laboratory, Carleton University, 1125 Colonel By Drive, Ottawa, Ontario K1S 5B6, Canada*
[b] *National Wildlife Research Centre, Environment Canada, 1125 Colonel By Drive, Ottawa, Ontario K1A 0H3, Canada*
[c] *Atlantic Food and Horticulture Research Station, Agriculture and Agri-Food Canada, 32 Main Street, Kentville, Nova Scotia B4N 1J5, Canada*

ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form 4 November 2014
Accepted 16 November 2014
Available online xxx

Keywords:
Landscape heterogeneity
Landscape complexity
Landscape composition
Landscape configuration
Edge density
Agricultural intensification

ABSTRACT

Simple rules for landscape management seem elusive because different species and species groups are associated with different land cover types; a change in landscape structure that increases diversity of one group may reduce diversity of another. On the other hand, if simple landscape–biodiversity relationships do exist despite this complexity, they would have great practical benefit to conservation management. With these considerations in mind, we tested for consistent relationships between landscape heterogeneity and biodiversity in farmland (the cropped areas in agricultural landscapes), with a view to developing simple rules for landscape management that could increase biodiversity within farmland. Our measures of farmland heterogeneity were crop diversity and mean crop field size, where increases in crop diversity and/or decreases in mean field size represent increasing landscape heterogeneity. We sampled the abundance, and alpha, gamma and beta diversity of birds, plants, butterflies, syrphids, bees, carabids and spiders, in crop fields within each of 93 1 km × 1 km agricultural landscapes. The landscapes were selected to represent three gradients in landscape composition and heterogeneity: proportion of the landscape in crop, mean crop field size and Shannon crop type diversity of the farmland. We found that mean crop field size had the strongest overall effect on biodiversity measures in crop fields, and this effect was consistently negative. Based on our results we suggest that, if biodiversity conservation in crop fields is a priority, policies and guidelines aimed at reducing crop field sizes should be considered.

1. Introduction

Landscape management is critical for biodiversity conservation (Lindenmayer et al., 2008; Tscharntke et al., 2012). However, landscape management is hindered by an inherent conundrum: different species and species groups are associated with different land cover types, so a landscape that increases diversity of one species group may reduce diversity of another, leading to low cross-taxa congruence of species diversity across sites (Hess et al., 2006; Wolters et al., 2006; Gagné and Fahrig, 2011). Since a given landscape can be structured in only one way, we must address the question, is it possible to manage landscapes to simultaneously benefit different species and species groups with different land cover associations?

One potential solution to this dilemma is to encourage landscape management policies that increase landscape heterogeneity, without necessarily delving into particular species habitat relationships (*e.g.* Montigny and MacLean, 2005; Kati et al., 2010; Lindsay et al., 2013). Landscape heterogeneity has two distinct components; compositional heterogeneity is higher when there are more land cover types and when these are more evenly represented in the landscape, and configurational heterogeneity refers to the degree of spatial complexity of the landscape pattern, irrespective of the cover types present (Duelli, 1997; Fahrig and

* Corresponding author. Tel.: +1 613 512 2600x3856.
E-mail addresses: lenore_fahrig@carleton.ca (L. Fahrig), jude.girard@gmail.com (J. Girard), dennis.duro@glel.carleton.ca (D. Duro), Jon.Pasher@ec.gc.ca (J. Pasher), Adam.Smith@ec.gc.ca (A. Smith), Steve.Javorek@agr.gc.ca (S. Javorek), doug_king@carleton.ca (D. King), Kathryn.Lindsay@ec.gc.ca (K.F. Lindsay), Scott_Mitchell@carleton.ca (S. Mitchell), lutz.tischendorf@gmx.net ? (L. Tischendorf).

http://dx.doi.org/10.1016/j.agee.2014.11.018
0167-8809/

Nuttle, 2005). There are reasons to expect positive effects of both components of heterogeneity on biodiversity (reviewed in Fahrig et al., 2011). A diversity of cover types (compositional heterogeneity) should provide habitat and resources for a larger variety of species, and when these different cover types are more interspersed with each other (configurational heterogeneity), species that use more than one cover type should benefit through 'landscape complementation' (*sensu* Dunning et al., 1992; *e.g.* Pope and Fahrig, 2000; Ethier and Fahrig, 2011).

Despite these arguments, actually managing for landscape heterogeneity is still constrained by two species-specific considerations. First, any description of landscape heterogeneity requires a decision on thematic resolution of the landscape map: which and how many different land cover types, *e.g.* forest types, crop types, or wetland types, should be identified as separate cover types? Ultimately the answer to this question should depend again on the particular species or species group, each of which responds to a different set of cover types in the landscape, resulting in different measures of 'functional heterogeneity' (*sensu* Fahrig et al., 2011). The second species issue results from the 'area-heterogeneity trade-off' or the 'intermediate heterogeneity hypothesis' (Kadmon and Allouche, 2007; Fahrig et al., 2011), which argues that, within a fixed area, increasing compositional heterogeneity by increasing the number of cover types simultaneously reduces the area of each individual cover type. This should lead to a peaked biodiversity–heterogeneity relationship, since landscapes with very high heterogeneity will not contain enough of most cover types to maintain viable populations of the species associated with those cover types. Where on the heterogeneity axis this peak occurs should depend not only on the particular measure of heterogeneity but also on the particular suite of species considered (Allouche et al., 2012).

Thus, development of simple rules for landscape management seems elusive due to the inherent complexities associated with species-contingent responses to landscape pattern. On the other hand, if simple landscape–biodiversity relationships do exist despite these complexities and contingencies, they would have great practical benefit to conservation management. With these considerations in mind, we tested for consistent relationships between landscape heterogeneity and biodiversity in farmland (the cropped areas in agricultural landscapes), with a view to developing simple rules for management that could increase biodiversity within farmland. We chose farmland specifically because the spatial patterning of farmland is largely under human control, and therefore susceptible to landscape management policies.

Over the past half-century, agricultural intensification has led to reduced biodiversity in farmed landscapes (Geiger et al., 2010; Flore et al., 2011; Kirk et al., 2011; Armengot et al., 2012). In fact, globally, about 60% of red-listed amphibians and birds, and between 10 and 20% of other red-listed taxa are threatened by intensive agriculture (Norris, 2008). Along with increased application of agri-chemicals, agricultural intensification has entailed important landscape changes. More intensive landscapes contain fewer crop types, grown in larger fields, than less intensive landscapes (Kareiva et al., 2007). In other words, agricultural intensification is reducing both the compositional heterogeneity and the configurational heterogeneity of farmlands.

The impact of this reduction in heterogeneity on farmland biodiversity is poorly understood, because most studies to date were not designed to estimate its effects on biodiversity specifically within the crop fields (*e.g.* Freemark and Kirk, 2001; Williams and Kremen, 2007; Doxa et al., 2010; Poggio et al., 2010; Smith et al., 2010; Smukler et al., 2010; Poveda et al., 2012; Power et al., 2012; Woltz et al., 2012; Lindsay et al., 2013). Given the growing need for food and the dominance of farmland in many parts of the world, it is important to consider the biodiversity represented in the farmed areas (crop fields) of agricultural landscapes, and whether this biodiversity can be augmented through policies aimed at changing the pattern of farmland. If a significant component of the effect of agricultural intensification on farmland biodiversity is due to reduced farmland heterogeneity, then perhaps policies and guidelines could be developed to augment farmland biodiversity by increasing farmland heterogeneity.

Our overall objective is to determine whether there are consistent patterns relating farmland heterogeneity to farmland species diversity. Does the diversity of widely differing species groups within crop fields vary in a consistent way with varying farmland heterogeneity? We consider the two types of heterogeneity, compositional and configurational heterogeneity, independently. A farmland with high compositional heterogeneity has many crop types (crop richness) and/or similar areal coverage of the crop types within it (crop evenness), and a farmland with higher configurational heterogeneity has smaller crop fields and a greater total length of field edges. Although both components of heterogeneity may positively affect biodiversity, the relative strength of their effects could be quite different, and this would have important implications for landscape management aimed at increasing biodiversity within crop fields. In particular, if biodiversity does show consistent responses to farmland heterogeneity across species groups, would it be more effective to implement policies that encourage a higher diversity of crop types, or that encourage reductions in crop field sizes?

2. Material and methods

2.1. Overview

We sampled biodiversity in crop fields within 93 1 km × 1 km agricultural landscapes, across an area of about 10,000 km^2 (1 million ha) in Eastern Ontario, Canada (Fig. 1). Agricultural land use dominates the area and is characterized by maize (21%), soybean (19%), forage crops (alfalfa, clover, hay; 30%), and wheat (3%) (Ontario Ministry of Agriculture and Food, 2011). We chose 1 km^2 sample landscapes because this is approximately the mean size of farms in the region, so it is a relevant scale for landscape management. Note, however, that the boundaries of our sample landscapes did not coincide with individual farms. The landscapes were selected to represent three gradients in landscape composition and heterogeneity – proportion of the landscape in crops (where 'crop' includes annual row crops and perennial crops such as hay), Shannon crop type diversity, and mean crop field size.

We surveyed biodiversity in the farmland (cropped) portions of the landscapes. This included mean alpha diversity, gamma diversity, beta diversity, and relative abundance per landscape, of seven species groups: birds, plants, butterflies, syrphids, bees, carabids, and spiders. These groups were selected (i) to capture a range of potential responses to landscape pattern, (ii) to represent a range of ecosystem services (cultural, supporting, pollination, and pest control), and (iii) for relative ease of sampling, given the scale of the project. Data acquisition was a large undertaking. The major components (details below) were: geomatics-based analyses for initial landscape quantification and selection, obtaining permission from and maintaining communications with 253 private land owners on whose properties we conducted the biodiversity sampling, field surveys of seven species groups, within- and post-season geomatics-related work and field validation to obtain detailed maps and derived landscape variables, and identification of arthropods returned to the lab. The work involved 27 people. Forty-six landscapes were surveyed in 2011, followed by an additional 47 landscapes in 2012.