Effects of Landscape Context and Management on Insect Diversity and Biological Pest Control

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Abstract: Landscape context and management intensity are major determinants of biodiversity patterns in agricultural landscapes, particularly those associated with biological pest control. In Haean, South Korea, we investigated the influence of landscape and management on the diversity of insect natural enemies and on their performance for pest control at multiple spatial scales. Results show that enemy diversity is generally higher in complex landscapes and in organic fields, and that different enemy guilds react to the landscape at different scales. Herbivory rates show a positive relationship with the abundance of natural enemies; a further exclusion experiment aims to clarify the direction and nature of this relationship and associated multitrophic interactions. In a separate experiment, herbivory rates are shown to increase with increased fertilizer input, while the presence of enemy pressure led to 20-60% decreased damage in all four fertilizer treatments.

Keywords: *insect diversity, biological pest control, landscape ecology, multitrophic interactions, scale*

1. Introduction

Landscape, in terms of the amount and configuration of non-crop habitat, and land use intensity, are known to be driving factors of population dynamics in agricultural systems (Tscharntke et al., 2008). Thus, they may influence the provision of the ecosystem service of biological pest control. However, the specific impacts of landscape and land use intensity on predatory and parasitoid organisms in crop fields are little known.

Furthermore, the efficiency of biological pest control is influenced by interactions between multiple trophic levels. Omnivory among predator species and diversity differences between natural enemy assemblages may lead to either positive or negative effects on pest control (Duffy et al., 2007). Despite a number of experiments in controlled environments, interactions are seldom predictable and highly context-dependent. It is essential to consider these interactions, and their effects on pest control, as part of a complex and dynamic environment (Hillebrand and Matthiessen, 2009; Thies et al., 2008). In particular, in addition to affecting species distributions, landscape context and management intensity may also influence predator interactions and their effects on pest control efficiency.

The studies reported here were undertaken in an agricultural landscape in South Korea. In particular, we examined the hypotheses that 1) natural enemy diversity is higher in organic fields and in landscapes with higher proportions of non-crop habitats; 2) crop damage is also lower is such landscapes and negatively correlated with enemy abundance; and 3) positive effects of enemy diversity and higher efficiency of biological control occurs in a) landscapes with higher proportions of non-crop habitats and b) in more intensively managed fields with higher additions of fertilizer.

2. Materials and Methods

2.1 Study Area – Haean Catchment

(see Tenhunen et al. TERRECO Geographical Setting in the proceedings)

2.2 Experiment 1: Impact of Landscape and Crop Management on the Spatial Distribution of Natural Enemies (2009)

2.2.1 Experimental Site Selection

In 2009, 32 crop fields of the Haean catchment were selected to vary in landscape context, crop and management type (Figure 1). Fields of the same crop were a minimum of 500 m apart in order to minimize spatial autocorrelation. Crops belonged to four of the major species cultivated in the Haean catchment, namely rice, potato, bean, and radish. Landscape context varied between 17 and 82% non crop area in a 500 m radius around fields, and management was either conventional or environmentally friendly (referred to as “organic”) farming.

2.2.2 Natural Enemy Sampling

Natural enemies were sampled between June and September 2009 using clusters of three coloured pan traps for flying insects (blue/white/yellow UV paint), funnel traps for ground-dwelling insects and, in a subset of sites, bird point counts.

Flying insects were sampled in clear weather by exposing 3 pan trap clusters per plot for 24 hrs, at vegetation height. Trap height was adjusted throughout the season to match increasing crop height. At least 5 sampling rounds were performed per plot. Funnel traps were activated to sample ground-dwelling insects for 2 ten-day periods (end-July to mid-August; mid-August to end-August). Trapped insects were collected by rinsing sieved catches with 82% ethanol and placing them for storage in 180ml Whirl-Pak® bags.

Insect natural enemies were then sorted and identified to family or species level in the University of Würzburg, Germany, focusing on Parasitica, Syrphidae and Carabidae, using the references listed p. 7.

Bird point counts were performed in clear weather by a team of 4 observers between 4 and 7 am, i.e. during maximum daily activity. Counts recorded species heard, number of individuals and occupied habitat. Counts were performed twice in 20 of the same insect sampling sites.

Identification of arthropod species and families was based on Brohmer, 2006 (general Fauna), Goulet and Hubert, 1993 (Hymenoptera), Grissell and Schauff, 1990 (Hymenoptera), Han et al., 1998 (Diptera), and Van Veen, 2004 (Hoverflies).

2.2.3 Weed, Herbivory and Biomass Sampling

In order to relate natural enemy distribution to crop damage and yields, additional sampling of weeds, herbivory rates and crop biomass was performed in a subset of plots.

Weeds and fresh biomass at harvest were sampled in three quadrats (weeds: 4 m², biomass: 1 m²) matching the three pan trap clusters at 1 m, 10 m and 20 m into the field. Weed species name, % cover, average height and flowering plants were recorded.

In addition, crop herbivory was estimated using twelve 4 m² quadrats per field, placed in a perpendicular cross at 1 m, 10 m and 20 m into the field from each edge. In each quadrat, leaves were collected randomly (potato: 20 leaves, radish: 10, bean: 15), measured for fresh biomass, then scanned and herbivory rates measured digitally using Adobe Photoshop CS3 to estimate the ratio of removed to total leaf area.

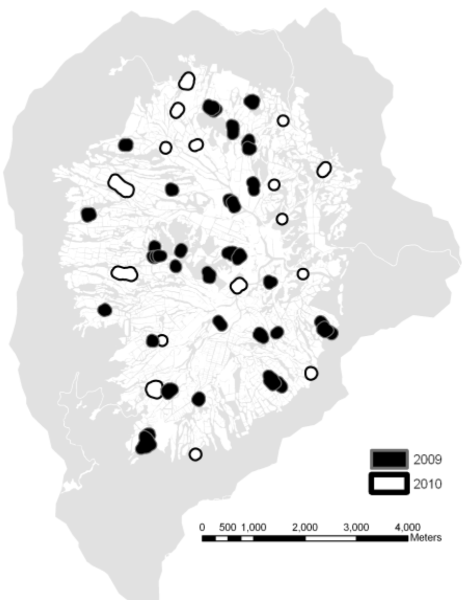

Figure 1. Spatial distribution of sampling plots in 2009 and 2010. Black (2009) and white (2010) symbols indicate 100m buffer zones around each plot.

2.3 Experiment 2: Influence of Landscape Context on Interactions between Enemy Species

2.3.1 Site Selection

In 2010, 18 fields were selected in and around the Haean catchment (Figure 1), where experimental plots were installed. Fields were separated by at least 600 m and followed a gradient of landscape complexity ranging from 0.5 to 75% forest cover in a 500 m radius around fields. Fields were chosen to follow preferential criteria: i) certified environmentally-friendly (EF) crop management; ii) cultivated crop is a Brassicaceae; iii) semi-natural edge characterized by tall grasses and shrubs, a locally characteristic habitat.

However, low availability of local EF fields and of Brassicaceae crops led to include both 5 additional conventional fields, and 3 additional field types (potato, green onion and fallow).

2.3.2 Experimental Plots

Experimental plots were set up within a 20 m² surface rectangle in a corner of each field. They were fertilized and the soil was prepared according to local EF regulations. All plots were planted between July 7th and July 14th with locally grown, EF seedlings of European cabbage *Brassica oleracea* var. *capitata*. Plots were managed exclusively by hand throughout the growing season and no control agents were applied either in or within a 1 m wide buffer zone around the plots (except total exclusion treatment – cf. 2.3.3).

2.3.3 Predator Exclusion Treatments

Seven predator exclusion treatments were installed in each experimental plot. We considered three predator “guilds” in this experiment: ground-dwellers (carabids & staphylinids), flying insects (syrphid flies, parasitoid and predatory wasps), and insectivorous birds. Each treatment, consisting of 4 plants, was designed to exclude one or several of these guilds in order to isolate their interactions:

i) Total exclusion of herbivores and predators (Tex);

ii) Exclusion of predators, but inclusion of Herbivores (H);

iii) Herbivores + Flying predators (HF), exclusion of birds and ground-dwellers;

iv) Herbivores + Ground-dwellers (HGD), exclusion of birds and flying insects;

v) Herbivores + Flying insects + Ground-dwellers (HFGD), exclusion of birds;

vi) Herbivores + Birds + Flying insects (HBF), exclusion of ground-dwellers;

vii) Open control without exclusion (O).

Exclusion treatments were installed in all plots after a growth period of 20 days around a row of 4 cabbages, using combinations of a) chicken wire with 1 cm mesh size for bird exclusion, b) fine polyester mesh with 0.8 mm mesh size for exclusion of flying insects, c) 3 mm thick, 40 cm wide plastic sheets, dug 15 cm into the ground and reaching up 25 cm on all sides of the cages, for ground dweller exclusion. In treatments excluding ground-dwellers, 2 pitfall traps were additionally maintained for the duration of the experiment. Cages were approximately 0.5W*1.5L*1H m; an opening at the top, kept shut for the duration of the experiment, was used during monitoring to access treated plants.

Microclimatic differences between treatments were controlled by placing 2 Thermochron iButton® temperature loggers (Fuchs Elektronik, serial # DS1921G-F5#) in each plot, one in the open, the other inside a fine mesh treatment. These were activated between August 15th and 30th. Air humidity differences were tested using 2 Exoterra® digital hygrometers inside and outside fine mesh treatments, with 5 measurements on sunny days and 5 on rainy days.

Mesh transparency, the ratio between average light intensity inside and outside fine mesh treatments, was measured at 5 occasions per category using a LI-190 Quantum Sensor (Li-Cor®). In addition, differences in natural rates of oviposition between open and exclosed treatments were corrected by standardizing at three occasions the number of pests present on exclosed cabbages, using the average density values found in open treatments of the same plots.

2.3.4 Plot Measurements, Herbivory and Arthropod Monitoring

After an initial growth period of 20 days, 7 rows of 4 cabbages were randomly marked in each plot and all herbivores on these cabbages removed. Initial height, diameter, number of leaves and herbivory rate were measured on these plants. Exclosure treatments were then installed on all plots and arthropods were monitored three times at 10-day intervals between August and September. After a 60-day growth period, cabbages were once more measured for height, diameter, number of leaves and herbivory rate, then harvested and weighed for total fresh biomass.

During each round of arthropod monitoring, all plots were sampled within 5 days. Arthropods were monitored by carefully searching all leaves on both sides, taking care not to damage the plants. Arthropods were counted, identified and sorted to guild; larval instars and the number of parasitized larvae and aphids per plant were also recorded.

Initial and final herbivory and leaf area were measured on each cabbage using a standardized metal grid with 0.7*0.7 cm squares. Leaf area was measured by positioning the grid above each leaf and counting the number of squares occupied by the leaf surface. Conversely, herbivory was measured on each leaf by counting the number of squares *not* occupied by the leaf surface (Figure 2). Herbivory rates are the ratio of removed to estimated total leaf area.

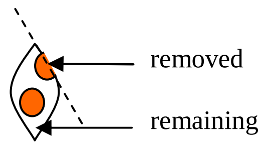

Figure 2. Leaf area removed by herbivory and remaining leaf area

Moreover, in order to clarify the relationship between biotic and abiotic factors affecting plant productivity, CN analyses were performed on soil and plant samples taken from each plot and treatment and dried in a drying oven at 80°C for 2-3 days.

2.4 Experiment 3: Influence of Management on Interactions between Enemy Species

This experiment was performed with identical methods to Experiment 2 (2.3), using however only 4 treatments installed in 16 quadrats of a single, conventionally managed radish field (*Raphanus sativus* var. *longipinnatus*). Quadrats varied in the amount of available fertilizer from 50 to 350 kg N/ha (4 levels with 4 replicates each). Predator exclusion treatments included i) Total exclusion, ii) Herbivores only, iii) Bird exclusion, iv) Open control.

The field was planted June 14th; treatments were activated at growth day 36 after initial herbivory measurement and monitored for arthropods between days 60 and 80. Radish was harvested and measured for final herbivory and biomass after 75 growth days on August 26th. Soil and plant samples were additionally taken and dried for subsequent CN analysis.

2.5 Landscape and Data Analyses

A polygon map of the Haean catchment was compiled in Arcview 9.3 based on available LandSat imagery, regional land use maps and extensive ground-truthing in 2009 and 2010, which included a detailed assessment of yearly crop and non-crop area distribution. Landscape parameters were extracted using Arcview 9.3 Toolbox and R Statistical Software 2.12.1 (R Development Core Team, 2010).

Data analysis is being performed using linear mixed models in R Statistical Software 2.12.1 (R Development Core Team, 2010).

3. Results

3.1 Data Availability

- Insects, birds, weeds, edge plants and herbivory in crops and some field edges, in a selection of plots with varying crop, management type and landscape context;
- Herbivory, leaf area, fresh biomass, arthropods, parasitism rate, soil & plant samples of cabbage from 18 different sites, and from each of 7 predator exclusion treatments per site;
- Herbivory, leaf area, fresh biomass, arthropods, parasitism rate, soil & plant samples of radish from 4 different fertilizer treatments, and from each of 4 predator exclusion treatments per fertilizer treatment.

3.2 Current and Expected Results

3.2.1 Experiment 1: Impact of Landscape and Crop Management on the Spatial Distribution of Natural Enemies (2009)

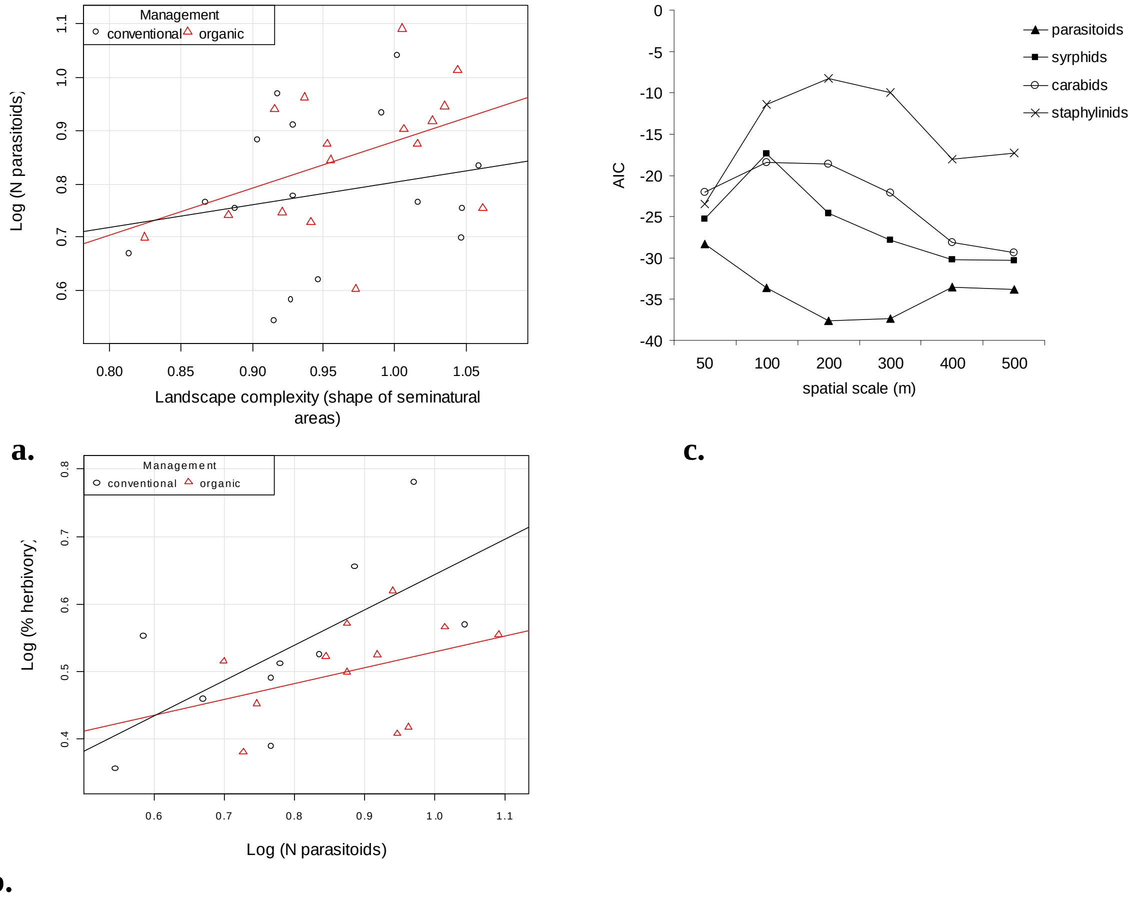

Figure 3. Results of the impact of landscape and management on insect distributions at a scale of 300 m around plots. a) Parasitoid natural enemies are more abundant in complex landscapes and in organic fields; b) Contrary to expectations, herbivory is positively correlated with parasitoid abundance; c) Spatial scale has differential effects on natural enemy guilds, with smaller and less mobile organisms (parasitoids) affected at smaller scales.

3.2.2 Experiment 2: Influence of Landscape Context on Interactions between Enemy Species

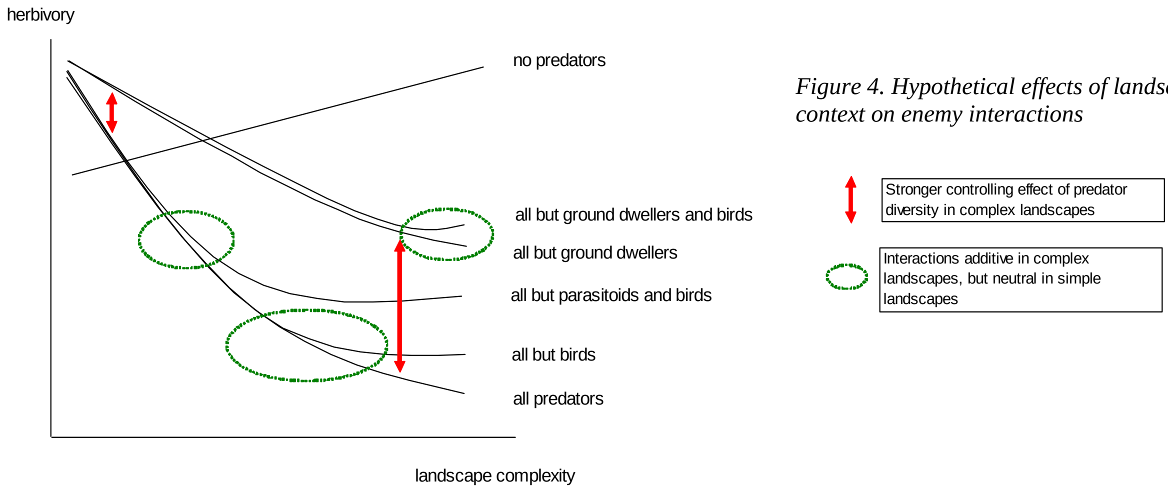

Figure 4. Hypothetical effects of landscape context on enemy interactions

3.2.3 Experiment 3: Influence of Management on Interactions between Enemy Species

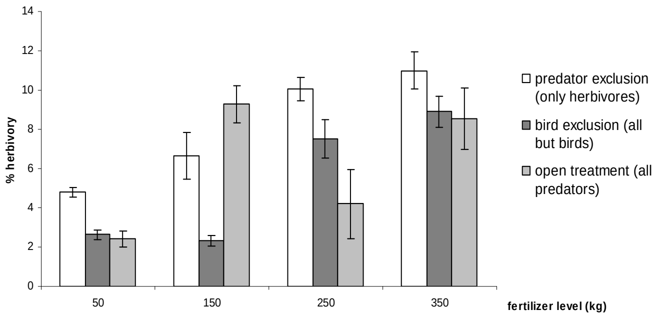

Figure 5. Effects of management on enemy species interactions, showing stronger herbivory in high fertilizer levels and changing directions of interactions between birds and other enemy guilds

Additional hypotheses in this experiment test the links between biological control and nutrient cycling processes, namely:

- The efficiency of nutrient cycling should be positively influenced by efficient biological control, translated as low damage rates.
- The relative contribution of abiotic processes (fertilizer) should be stronger than biotic processes (pest damage and biological control) for plant productivity.

4. Discussion

Field experiments and data collection were constrained by a number of conditions particular to the Haean catchment, notably:

- Weather constraints of unpredictable, intense rainfall during and after monsoon led to reduce pan trap sampling time from the classically used 48hrs to 24hrs; however this did not appear to strongly reduce sampling success. Pitfall trap success was conditioned by dramatic erosion of sandy soils around the rim of the traps.
- The complexities of plot selection were reinforced by a combination of cultural barriers, the difficulty to identify field owners, and the difficulty to involve local stakeholders.
- Experiments in crop fields were constrained by limited and variable time frames of the cropping season for each field, by the need to homogenize conditions between fields managed very differently, and by strong spatial heterogeneity of the catchment, particularly concerning soil and slope parameters, despite a relatively small geographic scale. The choice to plant and manage independent plots on the edge of fields contributed to standardize and control these conditions between plots, while the attention to maximum spread-out reduces spatial autocorrelation between plots.
- The political context of the Haean catchment limits the availability of satellite photography and detailed land use maps required for any spatial analysis of biodiversity and other services. Suboptimal levels of detail and high error in available maps made extensive ground-truthing, shape correction and photographic confirmation necessary, in order to attain the current degree of spatial certainty considered acceptable for analyses.

Experiments dealing with the effect of spatial environmental factors on multiple trophic levels and their interactions are rare. In this work we have attempted to isolate such effects while retaining the degree of complexity of a real-life agroecosystem. Although the complexity of this approach may hinder results, it represents a decisive stepping stone towards further methodological development and refinement of theoretical questions. Sampling and experimental results form the basis for spatially explicit models of biodiversity and biological control services in the Haean agroecosystem, in the context of future scenarios of land use change. They may also contribute significantly to modelling the tradeoffs between sustainability and production priorities in this region of national agricultural concern.

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