Spatially Optimal Habitat Management for Natural Pest Control Services

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Introduction

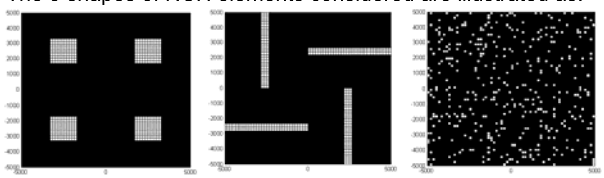
The control of pests by their natural enemies represents an important ecosystem service that maintains the stability of agroecosystems and has the potential to mitigate pest control costs both to private producers and to society. Relatively undisturbed non-crop habitats (NCH) such as hedgerows and woodlots in agricultural landscapes provide important resources for natural enemies, such as food for adult natural enemies, alternative prey or hosts, hibernation sites and shelter from adverse conditions (Landis et al. 2000). Empirical evidence from recent ecological research shows that pest suppression is positively correlated with the proportion of NCH in the landscape. Bianchi and van der Werf (2003) explore the effect of the shape, area, and fragmentation of NCH elements on the control of aphids by *C. septempunctata* using a spatially explicit simulation model. No prior studies, however, have investigated economically optimal spatial habitat configuration for natural enemies of crop pests.

This study develops a spatial optimization model to explore the potential for private adoption of habitat management for the enhancement of natural control services. Specifically, we investigate spatial manipulation of NCH in a simulated landscape to optimize net returns from natural pest control. We parameterize the model using i) coefficients inspired by the soybean aphid-lady beetle relationship estimated from Michigan field trial data, and ii) data from secondary sources. The key research questions include:

1. *What is the optimal proportion and shape of NCH in the landscape?*
2. *How do the outcomes differ between conventional farming system and an organic farming system?*

Model

- Grid map for an agricultural landscape (10^4x10^4 m^2) that is comprised of 4 homogenous farms, arranged in 2x2 checkboard The 3 shapes of NCH elements considered are illustrated as:



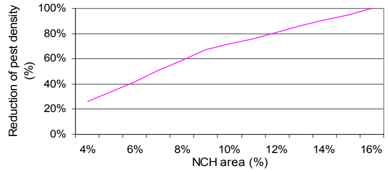
Squares | Strips | Archipelago

Ecological model for the distribution of pest control services:

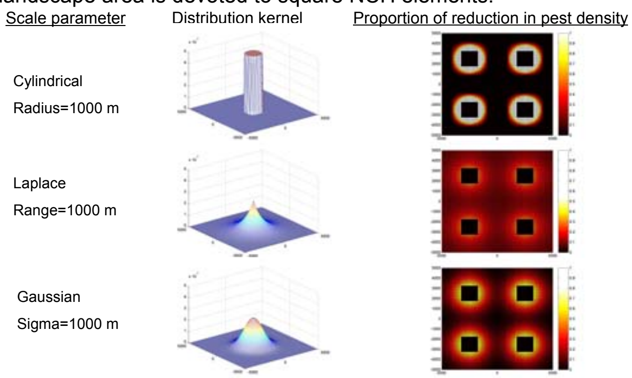
- Assuming natural enemy density (or the services provided) does not depend on the size of NCH (i.e., no scale dependence):
  - *Density of pest control services ("impact") =1 per unit area of NCH*
  - *"Total impact" per NCH element = (Density of pest control services) * (Area of NCH element)*

- Total impact of each NCH element is dispersed into surrounding crop area according to a probability distribution. We consider 3 options of distribution kernels: cylindrical, rotated exponential (or Laplace), and 2-D normal (Gaussian) distributions.

- Quantification of the relationship between average percentage reduction in pest density in crop field and the percentage of NCH in the landscape is derived from Bianchi and van der Werf (2003).



- Distributed control effect (proportion of pest density reduction) per unit area of crop area is proportional to the "impact" per unit area of NCH and depends on the proportion of NCH in the landscape. For instance, in a 80x80 grid map where 10% of landscape area is devoted to square NCH elements:



Economic model for the optimization of land use:

- The economic objective is to maximize net returns to fixed factors (NR) from a simple soybean-corn rotation using habitat management to control a new soybean pest (e.g. soybean aphid).
- Baseline:
  - Conventional system: pesticide control
  - Organic system: no control
- Habitat management:

$$\underset{Area_{NCH},Shape_{NCH}}{Max} \quad NR = NR_{soy} + NR_{corn}$$

$$NR_{corn} = (p_{corn} \cdot y_{corn} - VC_{corn}) \cdot Area_{corn}$$

$$NR_{soy} = [p_{soy} \cdot y_{soy} - (1+\omega) \cdot VC_{soy}] \cdot Area_{soy} - OpportunityCost_{NCH}$$

$$OpportunityCost_{NCH} = (p_{soy} \cdot \bar{y}_{soy} - VC_{soy} - Cost_{spray}) \cdot Area_{NCH}$$

s.t.

$$y_{soy} = f(y_{soy\_max}, pest_{NCH\_mgmt}) \text{ (Cousens' hyperbolic yield func)}$$

$$\bar{y}_{soy} = f(y_{soy\_max}, [(1 - Efficacy_{spray}) \cdot pest_{initial}])$$

$$pest_{NCH\_mgmt} = g(Area_{NCH}, Shape_{NCH}, pest_{initial})$$

$\omega = h(Area_{NCH}, Shape_{NCH})$ is % change in variable cost (VC) due to NCH)

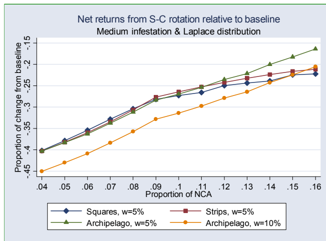
For organic system, $Efficacy_{spray} = 0, Cost_{spray} = 0$

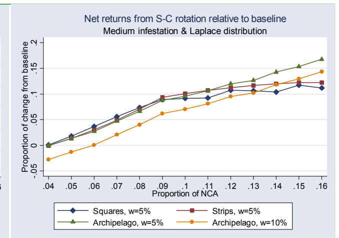
Key economic parameters used:
(UIUC 2003, Song et al. 2006)

	Conv	Org
P_{soy} ($/bu)	7	14
p_{corn} ($/bu)	2	4
y_{max_soy}(bu/ac)	44	35
y_{max_corn}(bu/ac)	155	135
VC_{soy} ($/ac)	104	104
VC_{corn}($/ac)	196	189
$Cost_{spray}$($/ac)	12	

Selected Numerical Results (Laplace dist)

- In the baseline, pesticide control proves to be cost-effective for conventional farms, saving 97% of the original (pest-free) NR. Organic farms, however, suffer from 28 to 36% of reduction in NR depending on the levels of pest infestation (low, medium, and high).





Conventional | **Organic**

- Given a 5% increase in variable cost (VC) (ω=5%), the adoption of habitat management in conventional systems leads to ≥16% of reduction in NR as compared to the baseline. In sharp contrast, the economic gains from establishing NCH are evident for organic farms, for which any proportion of NCH greater than 0.04 results in gains in NR regardless of the shape.
- At ω=5%, the optimal proportion of NCH is 0.16 and in the shape of archipelago for both farming systems. This solution remains valid even when archipelago is associated with greater increase in VC (ω=10%) (which is expected given the higher degree of field fragmentation associated with archipelago) than the other two shapes (ω=5%).
- At ω=5%, square NCH lead to the highest increase in NR for NCH proportions between 0.04 and 0.08 under both systems. Strip is the most desirable shape for proportion of NCH between 0.09 and 0.11. From 0.12 and up, archipelago is the best shape.

Discussion

- Non-crop habitat management is a promising pest management option for organic systems. The shape and area of habitats are important factors in spatially optimal land use decision.
- The advantage of archipelago over the other two shapes may change with assumptions about scale dependence. If natural enemy density increases exponentially with size of habitat, the aggregation of patchy habitats may become desirable.
- This ongoing research can benefit from improved parameterization (e.g., cost of habitat establishment). In addition, the relationship between the size of habitats and the density of natural enemies remains a highly relevant ecological question to be explored.
- The model developed here can be used to explore regional coordination issues which are especially relevant for landscape scale land management.

Reference

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Funded by the KBS Long-term Ecological Research project (NSF 0423647) and the Michigan Agricultural Experiment Station.

American Agricultural Economics Association Annual Meeting, Portland, Oregon, July 29-August 1, 2007