

Spatial coordination, agglomeration payment and land-use management: From percolation to conservation



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Plan

1. Introduction
2. Spatial model
3. Ecological model
4. Uniform payment
5. Simplification – percolation theory
6. Aggregation bonus
7. Correlated environmental costs
8. Summary



Introduction

Aim:

- System of subsidies leading to a spatial distribution of conservation efforts that is ecologically relevant

Objectives:

- Construct a framework encompassing ecological and economic modelling
- Evaluate a strategy of uniform subsidies
- Evaluate aggregation bonus approach
- Apply to wetlands



Introduction

Main assumptions:

1. Habitats are heterogeneous
2. Connected habitats are more valuable
3. Spatial coordination is important in designing conservation areas

Approach:

1. Land-use approach by planning conservation at the landscape level
2. Incentive design to reach the social target:
 - Interconnected conserved habitat
 - Maximum size of connected habitat
 - Lowest cost of conversion
3. Agglomeration bonus
 - Additional premium paid depending on neighbour decision
 - Selecting 'best' spatial coordination

Introduction

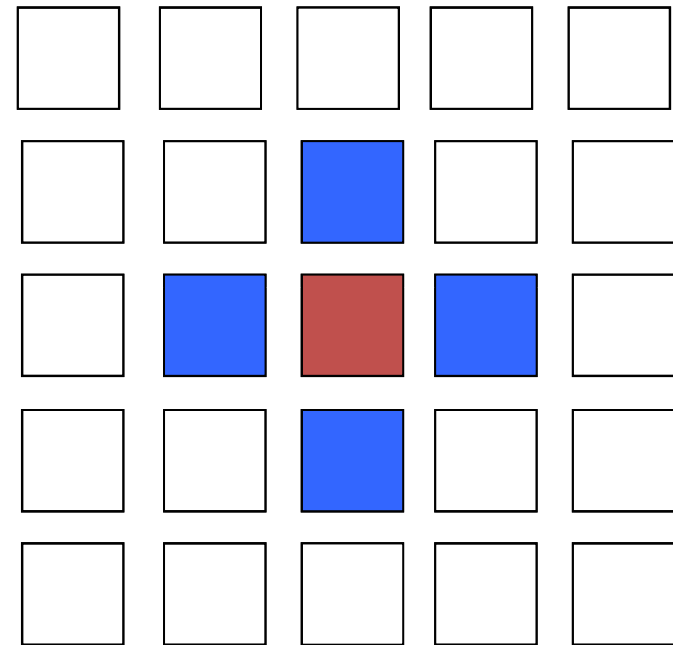
1. Two characteristic scales:
 - Landscape level (wetlands): conservation outcome
 - Individual level (farmer, field): stimulus
2. Two approaches:
 - Simulation of an ecological model
 - Simple model based on percolation
3. Goal is to create connected cluster of conserved patches
 - Need to define ‘connectiveness’

Drechsler et al (2010): proximity measure (distance-dependent kernel)

Here: at least one ‘wet’ farm/patch within the immediate neighbourhood

Spatial model

- Network of sites located on a square lattice
- $25 \times 25 = 625$ sites for illustration
- von Neumann neighbourhood with 4 nearest neighbours



- Each site can be occupied by individuals
 - insects
 - birds
 - animals
- Population dynamics
 - births, deaths and competition
 - migration

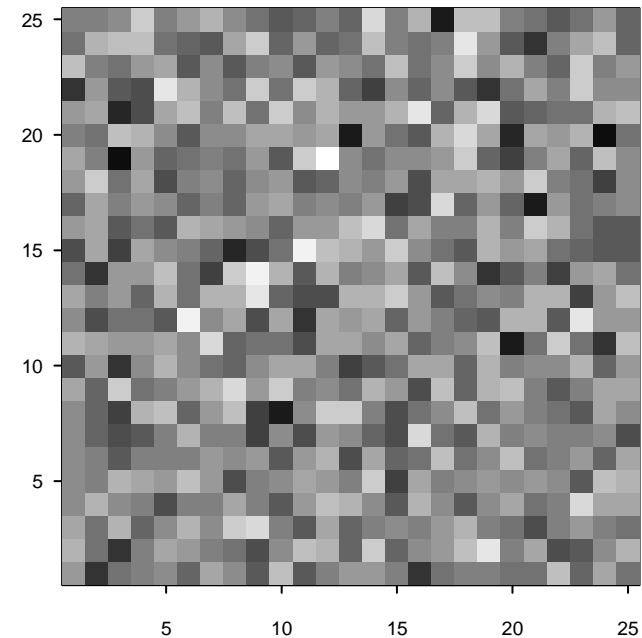
Spatial model

- Each site is in two ‘states’ :
 - unconverted
 - converted
- Sites differ in the costs of conversion

Cost-benefit analysis:

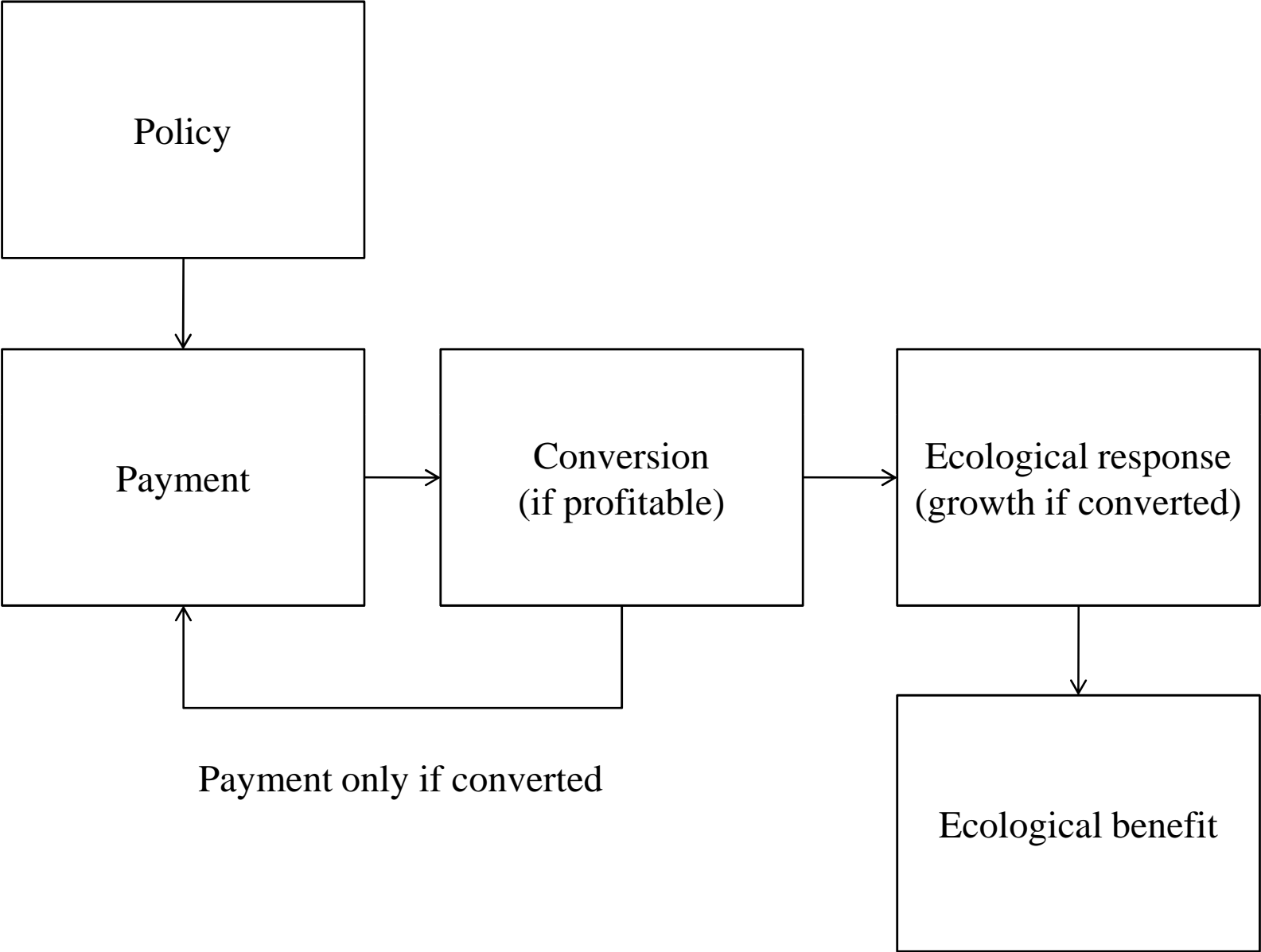
1. Each conversion costs a
 - *Foregone profits* forms main part of this cost
2. Conversion costs are distributed randomly
 - independently
 - with spatial correlation

$$a \sim N(\mu, \sigma)$$



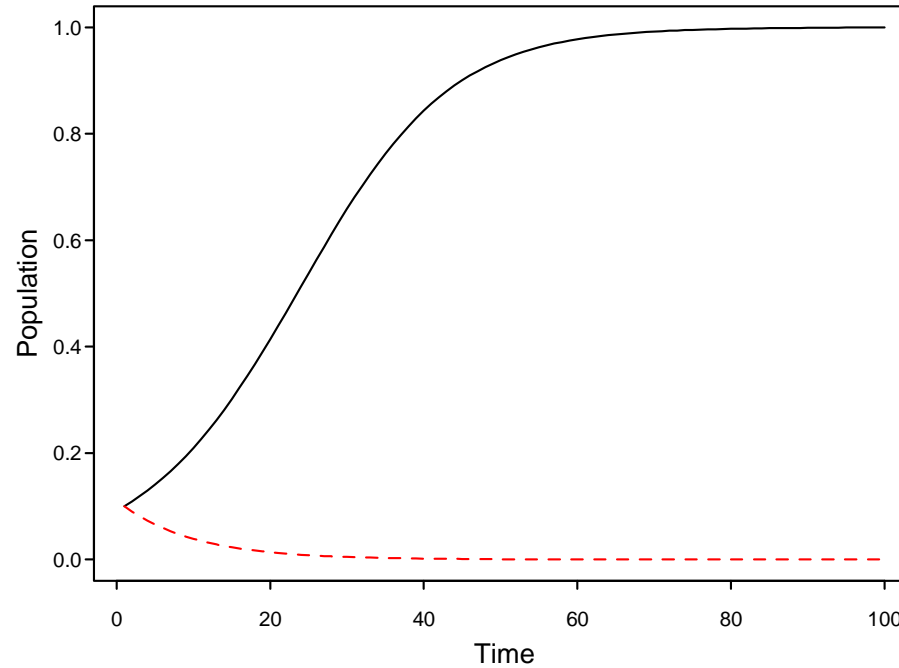
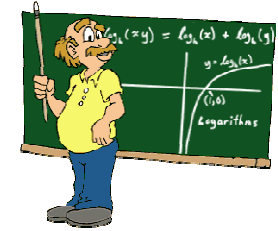
Grey scale corresponds to varying costs of conversion

Linking economics with ecology



Ecological model: Within-patch dynamics

Converted site = Conducive patch



$$y_{n+1} = \begin{cases} y_n + \beta y_n \left(1 - \frac{y_n}{K} \right) & ; \text{conducive patch} & \text{Logistic growth} \\ y_n - \beta y_n & ; \text{suppressive patch} & \text{Exponential decline} \end{cases}$$

Okubo

Conversion cost varies, but not conditions

Ecological model: Within-patch dynamics

- Long-term behaviour:
 - In conducive patches, species reach carrying capacity
 - In suppressive patches, species die out

- Uniform subsidy:
 - Pay each farmer a subsidy, providing he/she converts
 - Create a patchwork of sites on which species can survive
- Outcome:
 - Density of species = % of converted sites

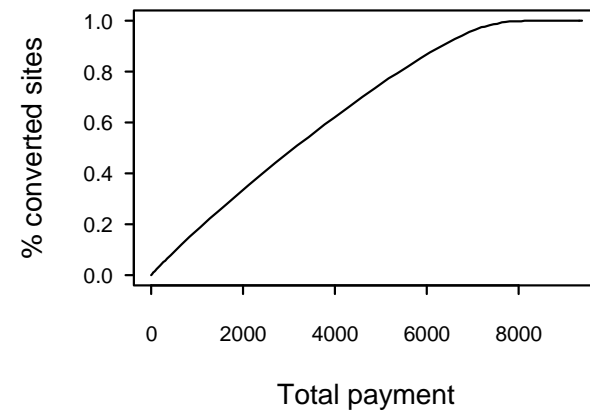
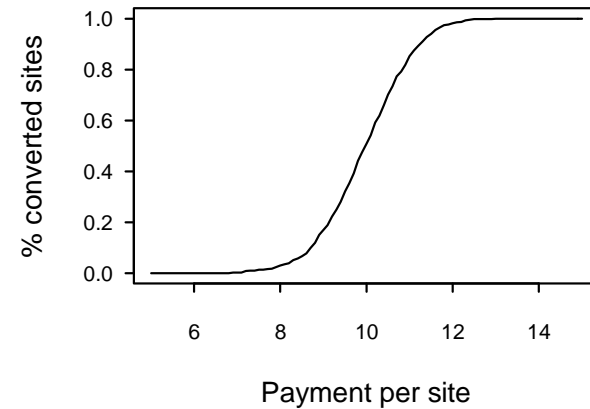
Uniform payment, no migration

- Payment c_1 made to all farmers who decide to switch to wetland
- No *explicit* spatial correlation
- All farmers for whom $c_1 > a$ will switch

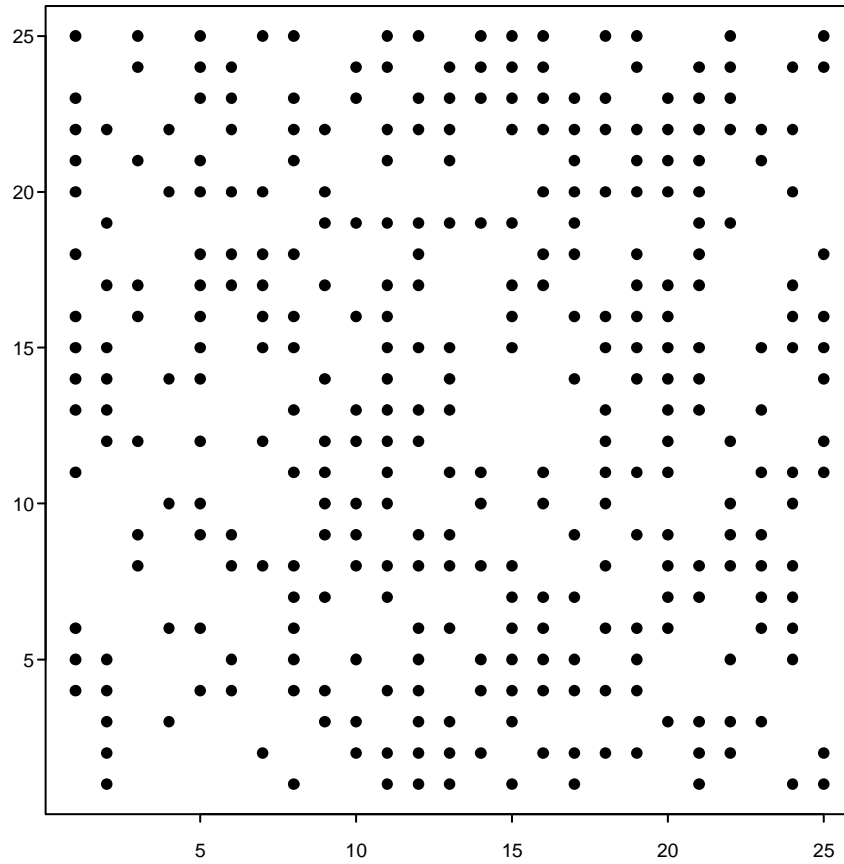
Objective: Maximise the area converted

$$P(a < c_1) = \Phi(c_1)$$

$$\text{Total payment} = c_1 N \Phi(c_1)$$



Uniform payment, no migration



Payment $a=10$

$$a \sim N(\mu, \sigma)$$

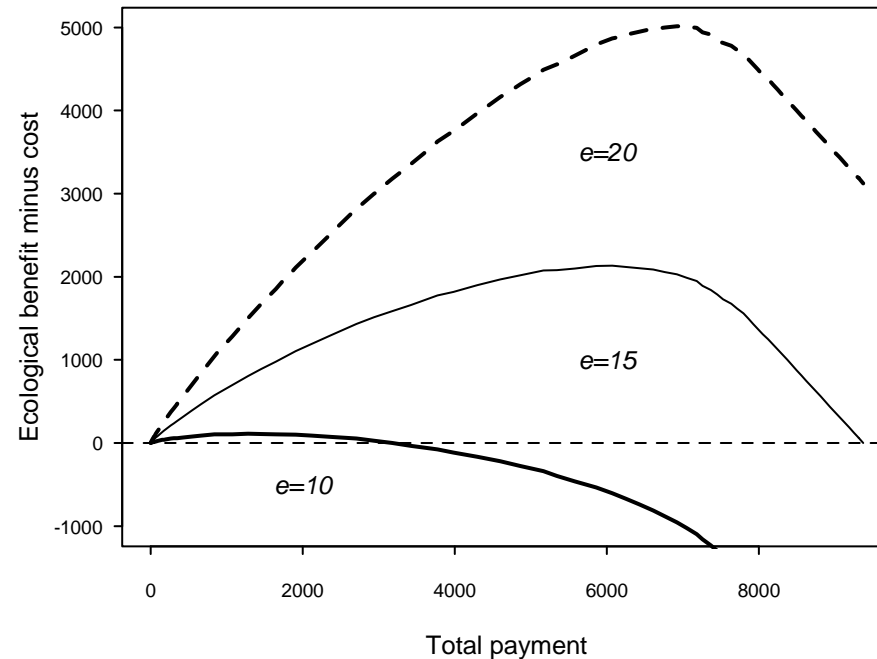
$$\mu = 10.0$$

$$\sigma = 1.0$$

Points represent sites converted (50%)

Uniform payment, no migration

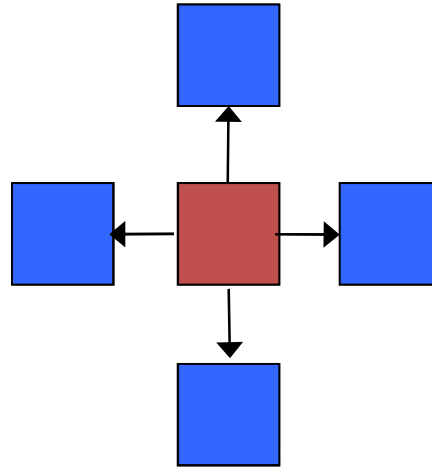
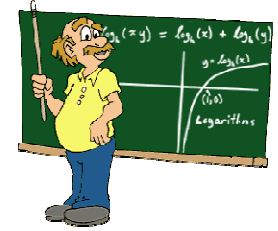
1. Ecological benefit:
proportion of sites converted
2. As the ecological benefit per site, e , increases, so does the total benefit minus costs;
3. There is an optimal total payment that leads to maximum ecological benefit



Total payment = $c_1 \times$ number of converted farms

Environmental benefit = $e \times$ number of converted farms

Between-patch dynamics

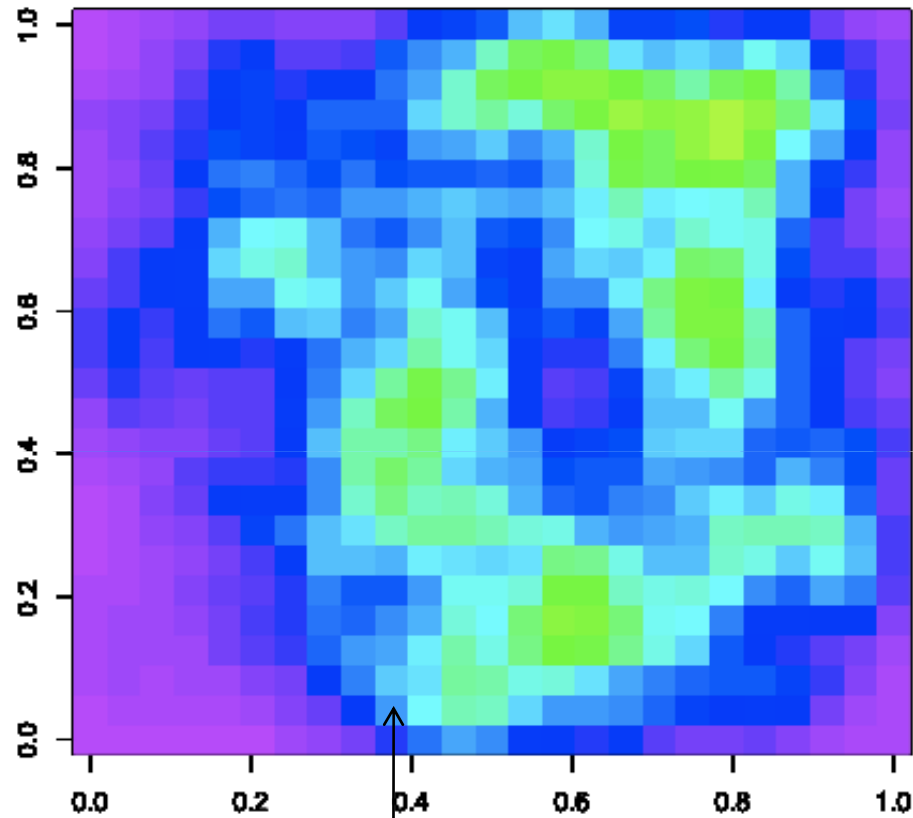


$$y_{n+1}(i) = \begin{cases} y_n(i) + \beta y_n(i) \left(1 - \frac{y_n(i)}{\kappa} \right) & ; \text{conductive patch} \\ y_n(i) - \beta y_n(i) & ; \text{suppressive patch} \end{cases}$$

$$+ D \sum_{j \in \text{Nb}(i)} (y_n(j) - y_n(i)) \quad ; \text{movement}$$

Uniform payment, migration

Payment $a=10$



$$d = 0.1$$

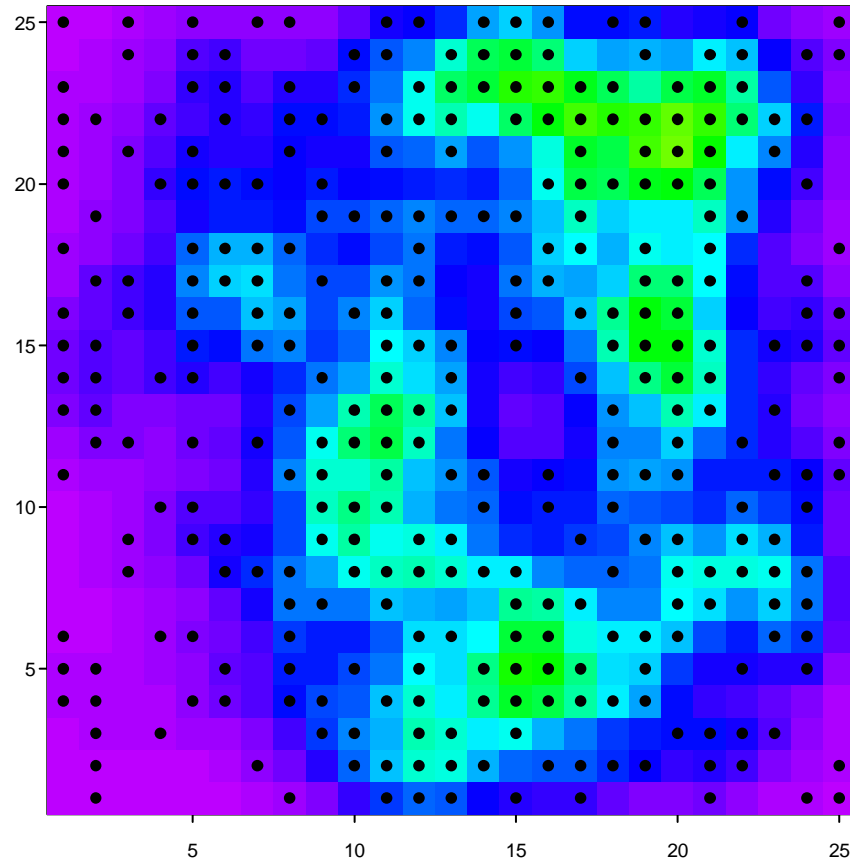
$$\beta = 0.1$$

$$\kappa = 1$$

Colour represents density of species

'Zero' boundary

Uniform payment, migration



Payment $a=10$

$$d = 0.1$$

$$\beta = 0.1$$

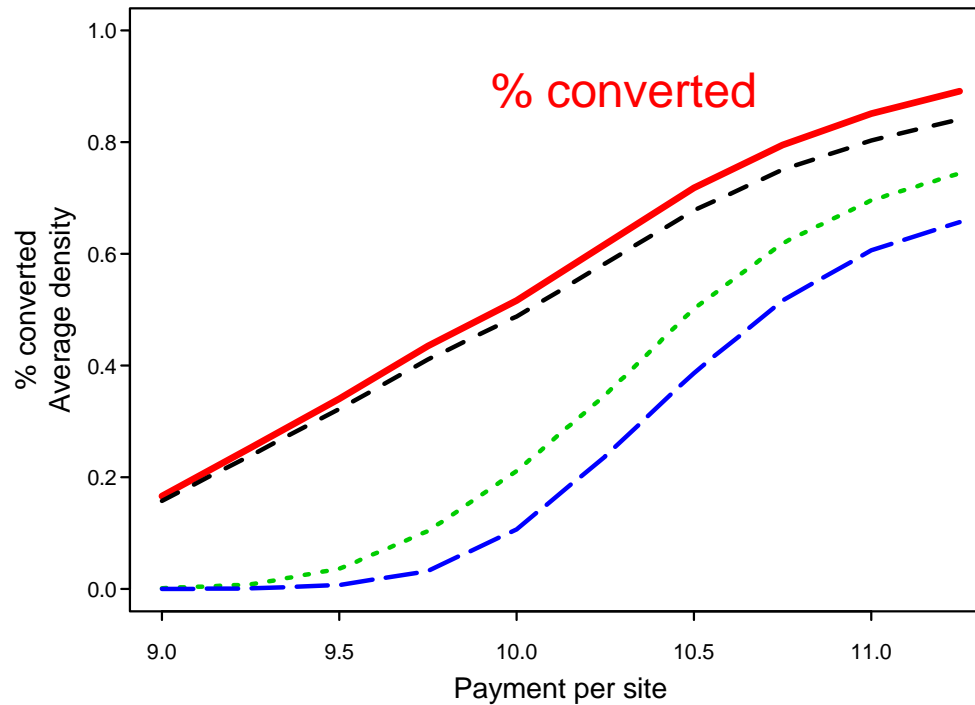
$$\kappa = 1$$

Many conversions are 'lost'

Points represent sites converted,
Colour represents density of species

Uniform payment, migration

Average density of species (all sites)



$d=0.05$: very slow movement

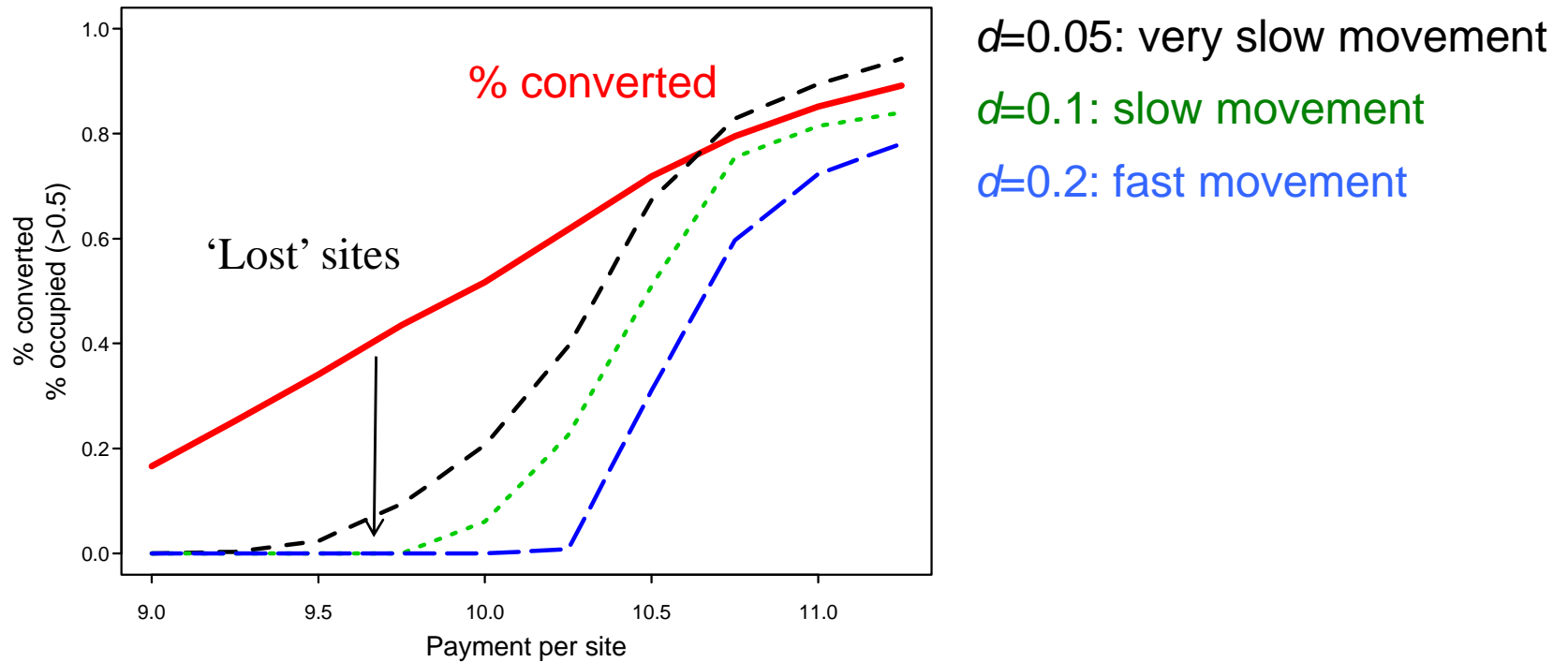
$d=0.1$: slow movement

$d=0.2$: fast movement

- Fast moving species require larger area and hence higher payment

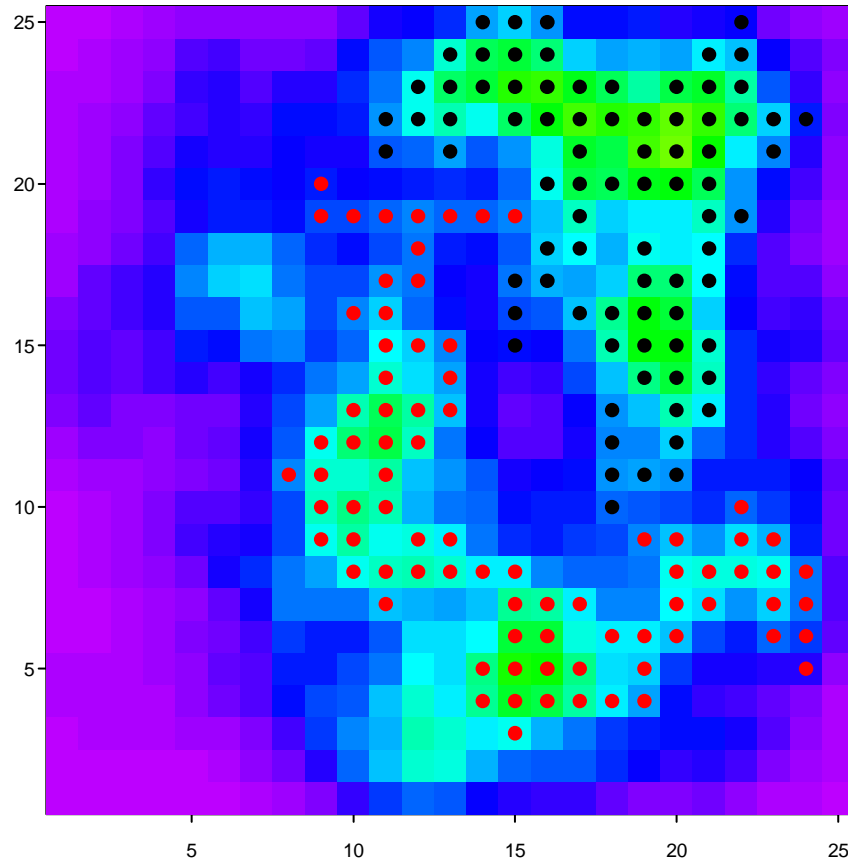
Uniform payment, migration

Proportion of sites with density of species above a threshold



- Threshold behaviour: need a minimum payment to have impact
- More sites occupied than converted - neighbours benefiting from conversion

Uniform payment, link to percolation



Payment $a=10$

$$d = 0.1$$

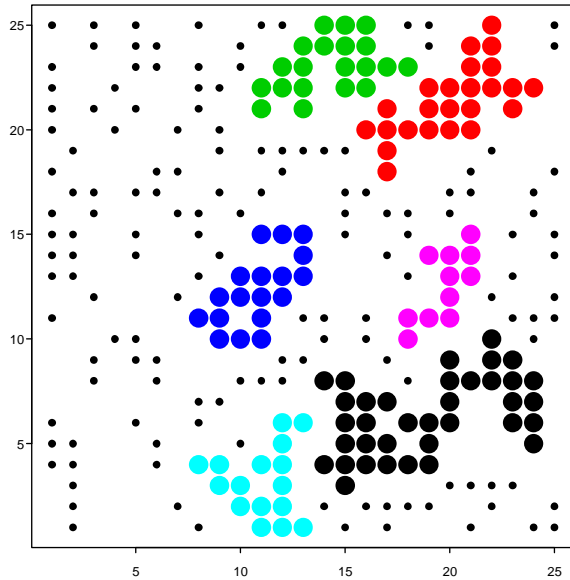
$$\beta = 0.1$$

$$\kappa = 1$$

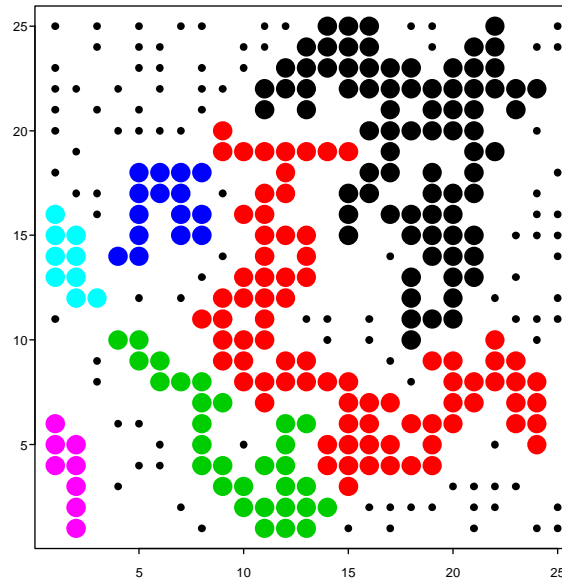
- Link to percolation:
 - Species concentrating on a set of *connected* sites
- Sites are *connected* via von Neumann neighbourhood
- Points represent two largest clusters of connected sites

Uniform payment, link to percolation

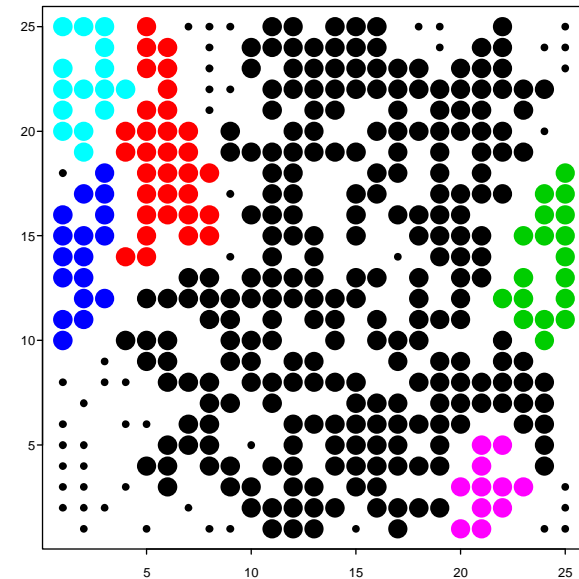
$a = 10.0$



$a = 10.25$



$a = 10.5$



- all sites converted shown as dots
- 6 largest clusters shown in different colours
- other sites are isolated

Uniform payment, link to percolation

- Percolation:
 - even a random distribution of conducive sites can create a large cluster of connected sites
 - providing the density of sites is high enough
- Percolation theory:
 - there is a critical threshold of density of converted sites above which a large cluster of connected sites appears
 - for 4 nearest neighbours and site percolation (as here), the critical threshold is ca 60% (59.27% for infinite system)
 - to achieve 60% converted sites we need to slightly exceed the average environmental cost (eg. 10.25 for $\mu=10$ and $\sigma=1$).
- But: how does this depend on model details?

Uniform payment, link to percolation

- Link to uniform payment:
 - uniform payment (without agglomeration bonus) is actually quite effective in creating a distribution of connected sites
- Percolation with 4 nearest neighbours can be seen as a lower bound (least ‘connectivity’):
 - hence, to create a connected cluster, we should pay slightly more than 50%
 - 50% = average conversion cost
(\approx profit foregone by converting to wetland)
 - if connection less strict, we might need to pay less
 - but is just one neighbour sufficient
- We need to quantify the interactions at the lowest level and ensure we get ecology right

Agglomeration bonus

- Payment c_1 made to all farmers who decide to switch to wetland
- Additional payment c_2 to those whose neighbours also convert
- All farmers for whom $c_1 > a$ will switch
- Additionally, farmers convert for whom $c_1 + c_2 > a$ and whose neighbours convert; both farmers receive $c_1 + c_2$

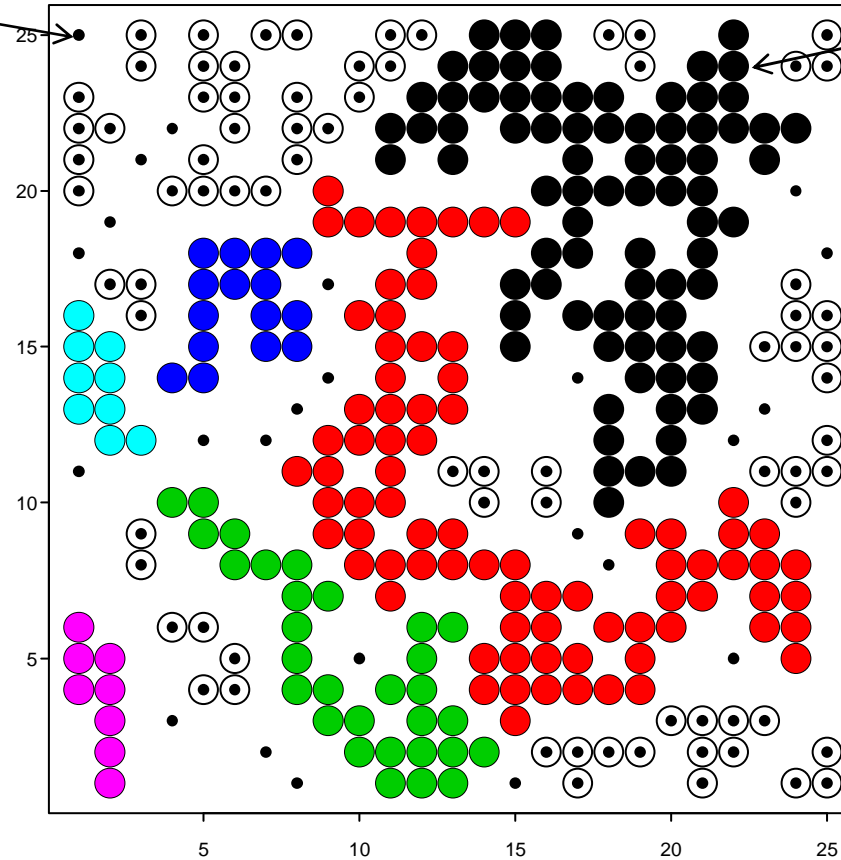
Equivalent to a scheme where we pay $c_1 + c_2$ to every farmer, then deduct c_2 from all farmers who are isolated not part of any cluster:

- Eliminates single farms
- For simplicity assume $c_1 = 0$ and $c_2 > 0$ (payment consists of AB only)

Agglomeration bonus

Sites with no neighbour

Sites with neighbours,
large cluster

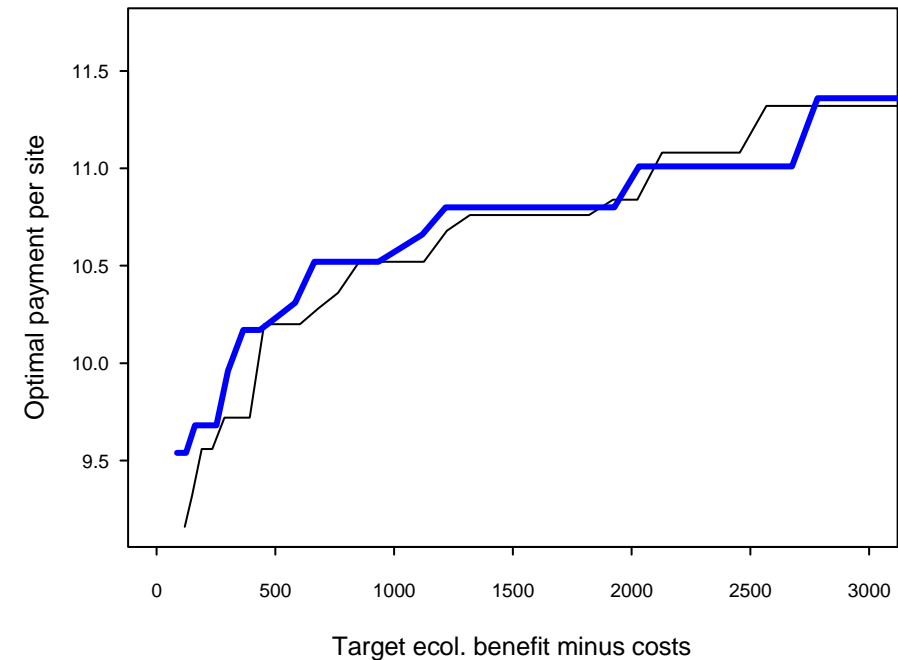


Sites with neighbours,
but small cluster

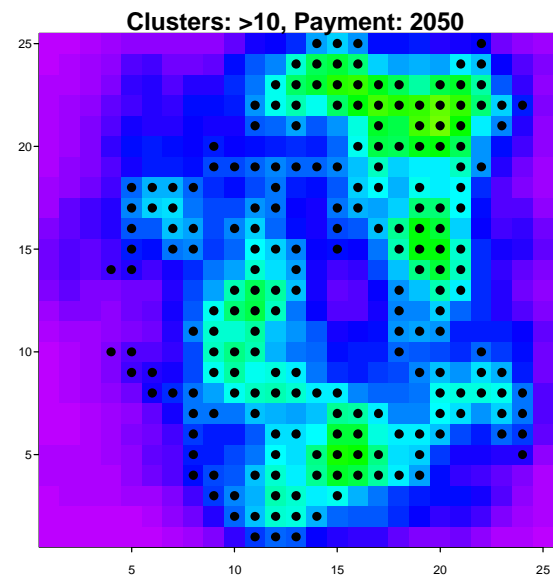
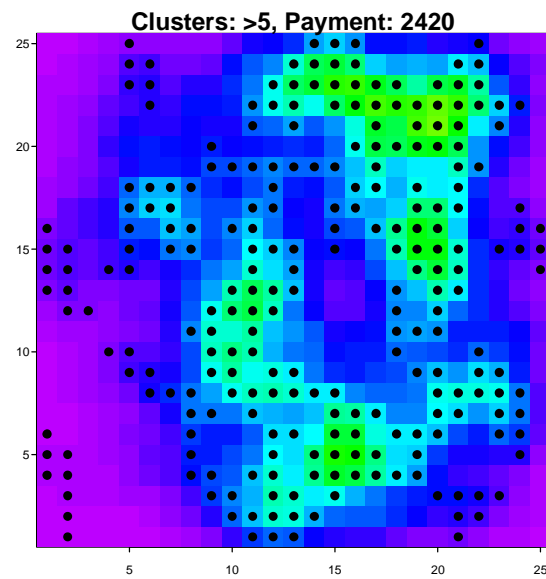
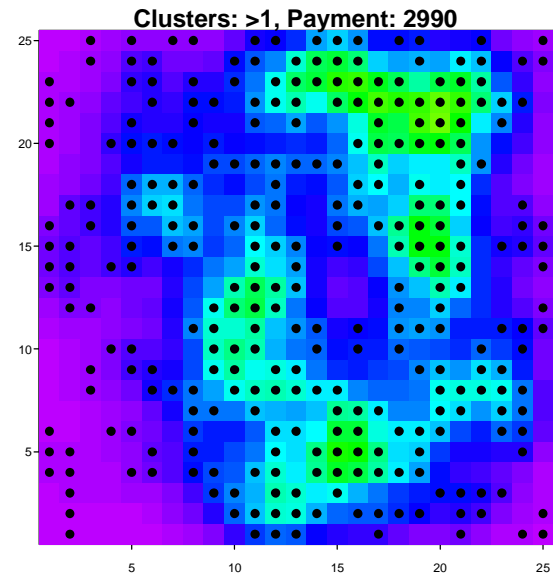
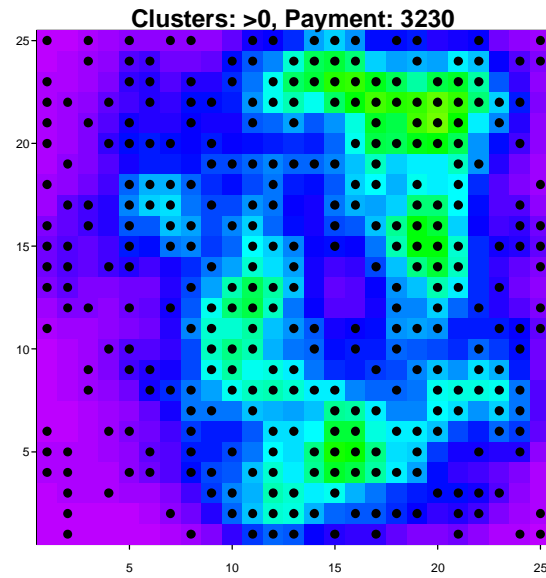
- Even under the uniform payment, there are only very few sites that have no neighbours
- Agglomeration bonus for the nearest neighbour is not going to make much difference!

Agglomeration bonus

- Payment is made only if a farmer has at least one converted farm in the neighbourhood
- Ecological benefit: **proportion of converted sites that have at least one neighbour converted**
- Similar payment structure and total budget as for the uniform payment
 - Single farms do not play a major role

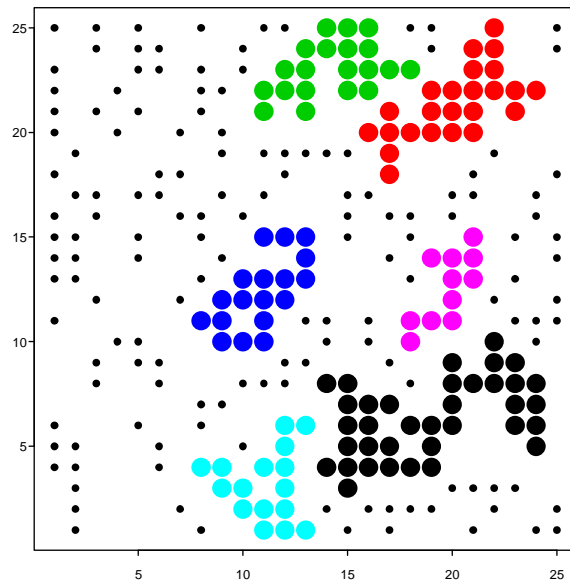


Agglomeration bonus



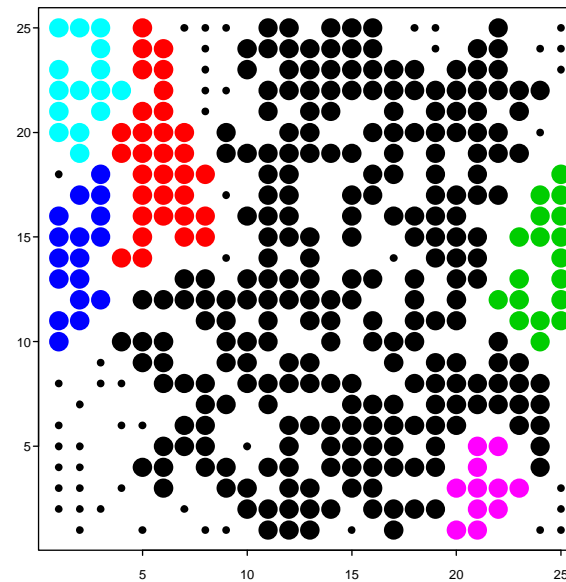
Agglomeration bonus – why it does not work and when it could work

$a = 10.0$



- not enough ‘big’ clusters to which individual farms can be connected

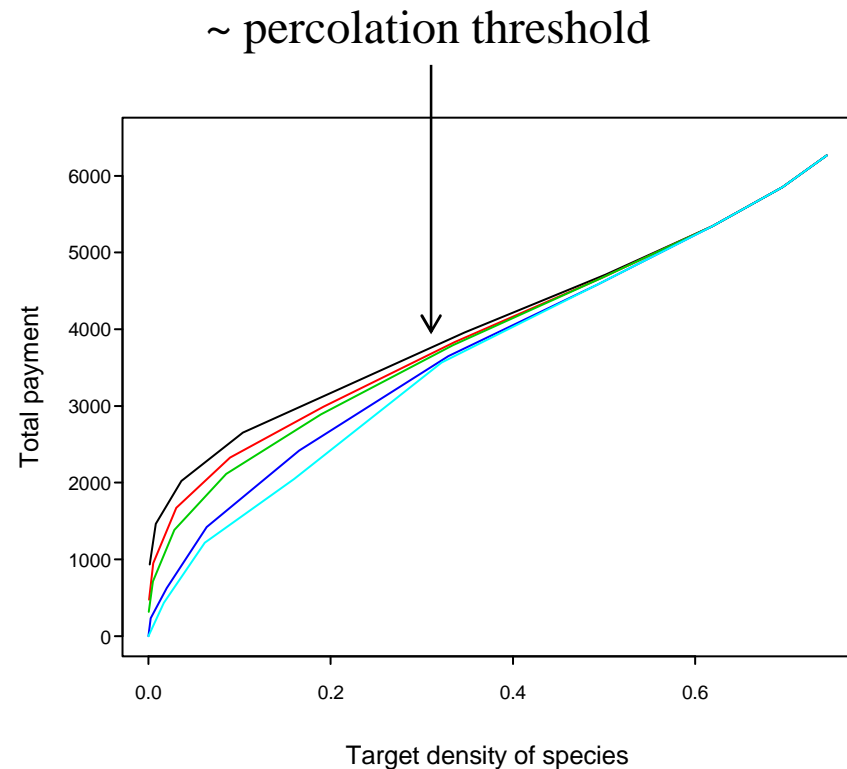
$a = 10.5$



- not enough individual farms to be connected to

Agglomeration bonus

- Payment is only made if a site belongs to a cluster of a certain size
 - Agglomeration bonus paid to groups of farmers of a certain size or larger
 - Sizes: 1+, 2+, 3+, 6+ and 11+
- Directing payments at larger groups makes the scheme more effective at lower environmental benefits, but does not make much difference above the percolation threshold
- Alternatively, pay only to farmers in the largest cluster(s)



Conclusions



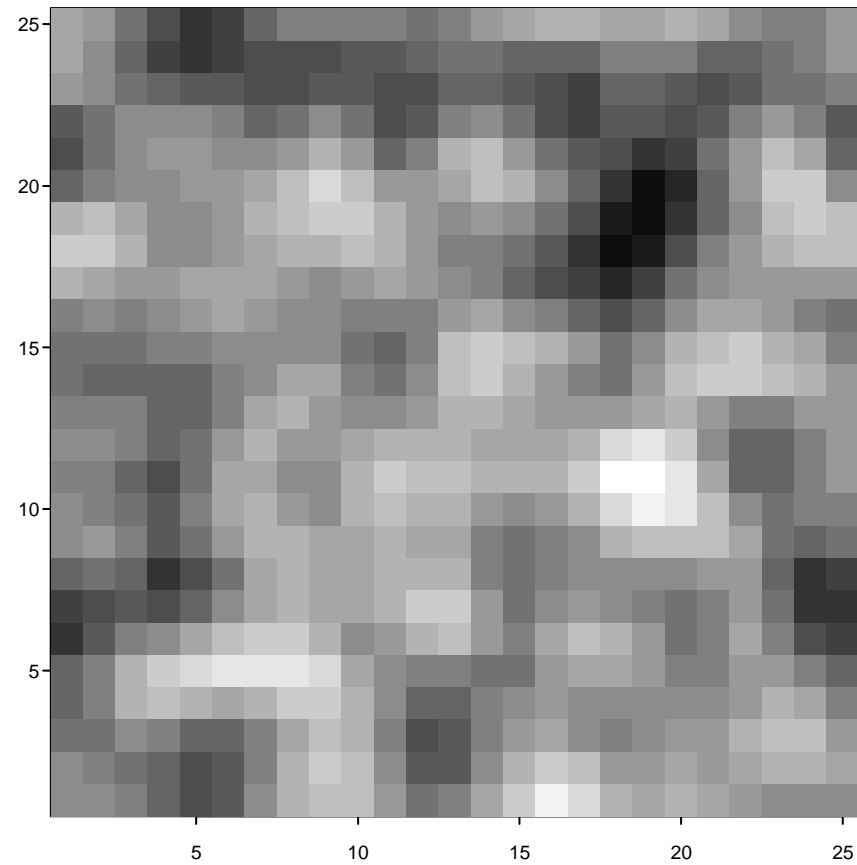
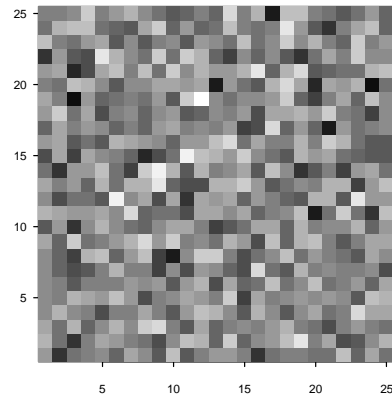
Summary:

1. Framework for studying conservation subsidies in the light of ecological dynamics
2. Results:
 - Uniform payment is wasteful
 - Simple agglomeration bonus does not improve the results significantly
 - Need to extend AB to groups
3. Spatially correlated environmental costs:
 - Matching spatial scales

Assumptions:

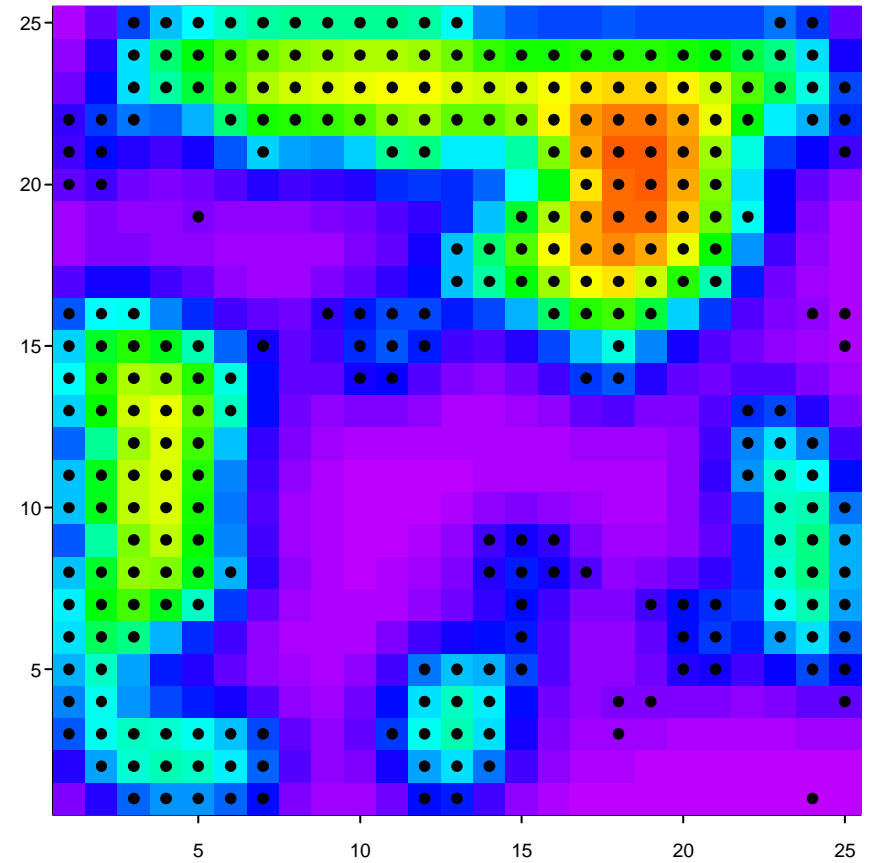
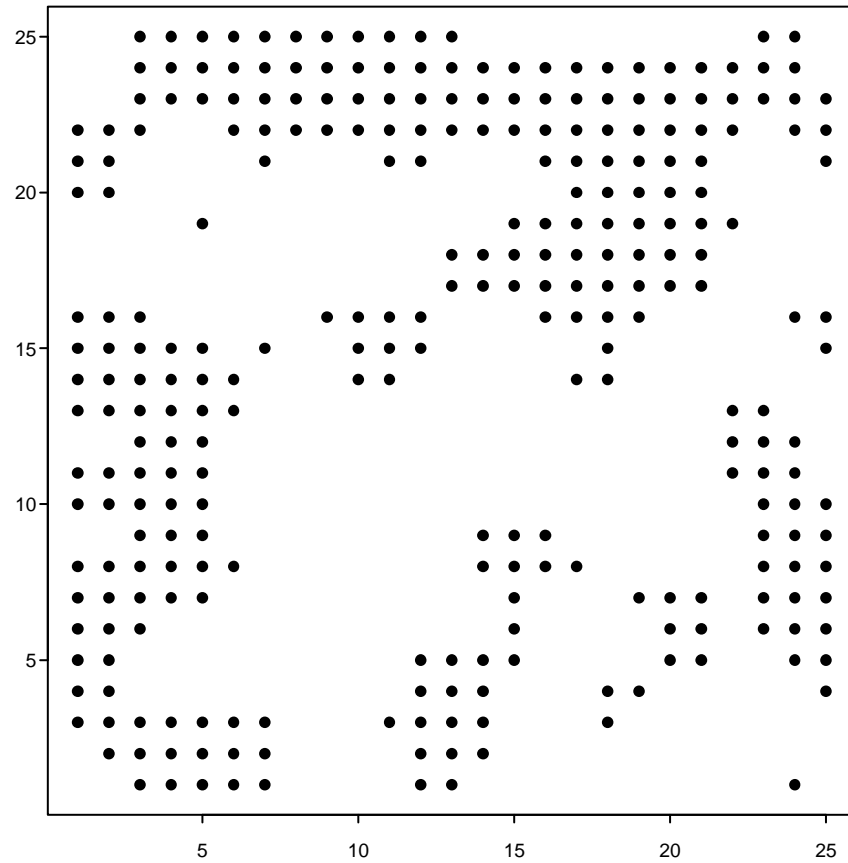
1. Full knowledge of costs and benefits
2. Full knowledge of where the farm is and whether it is connected or not

Spatially correlated conversion cost



- Correlation built in by a multi-pass kernel smoothing
- Range of conversion cost same
- Similar spatial scale to species dispersal

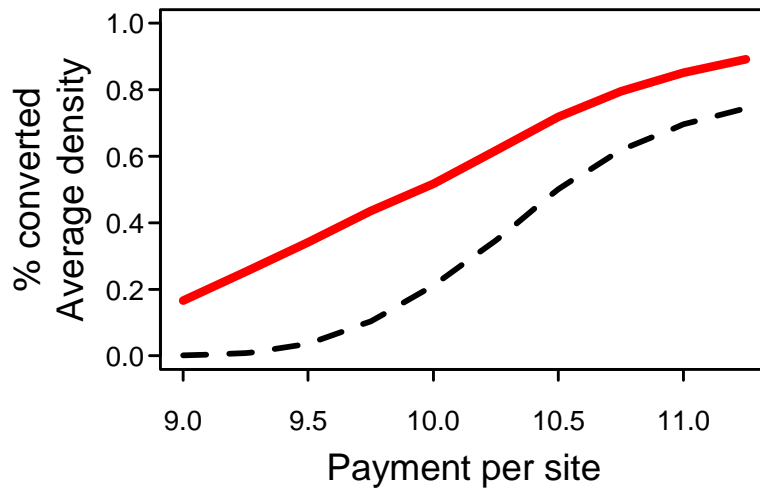
Correlated environmental cost



Very few conversions are 'lost'

Correlated environmental cost

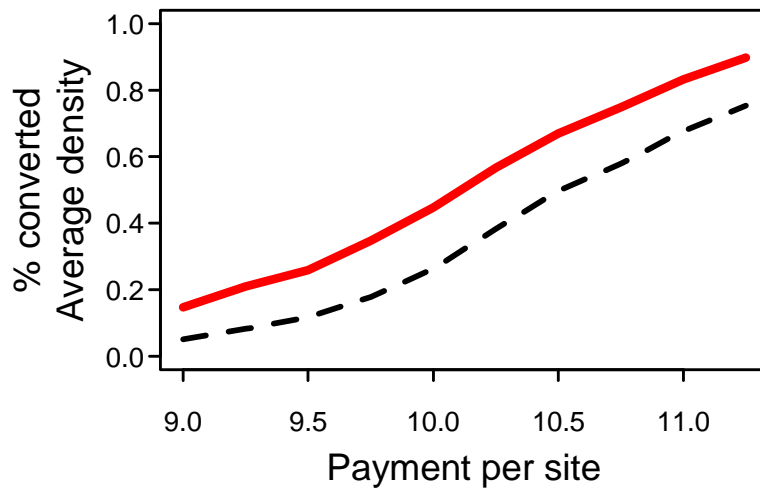
Uncorrelated cost



% converted

$d=0.1$: moving species

Correlated cost

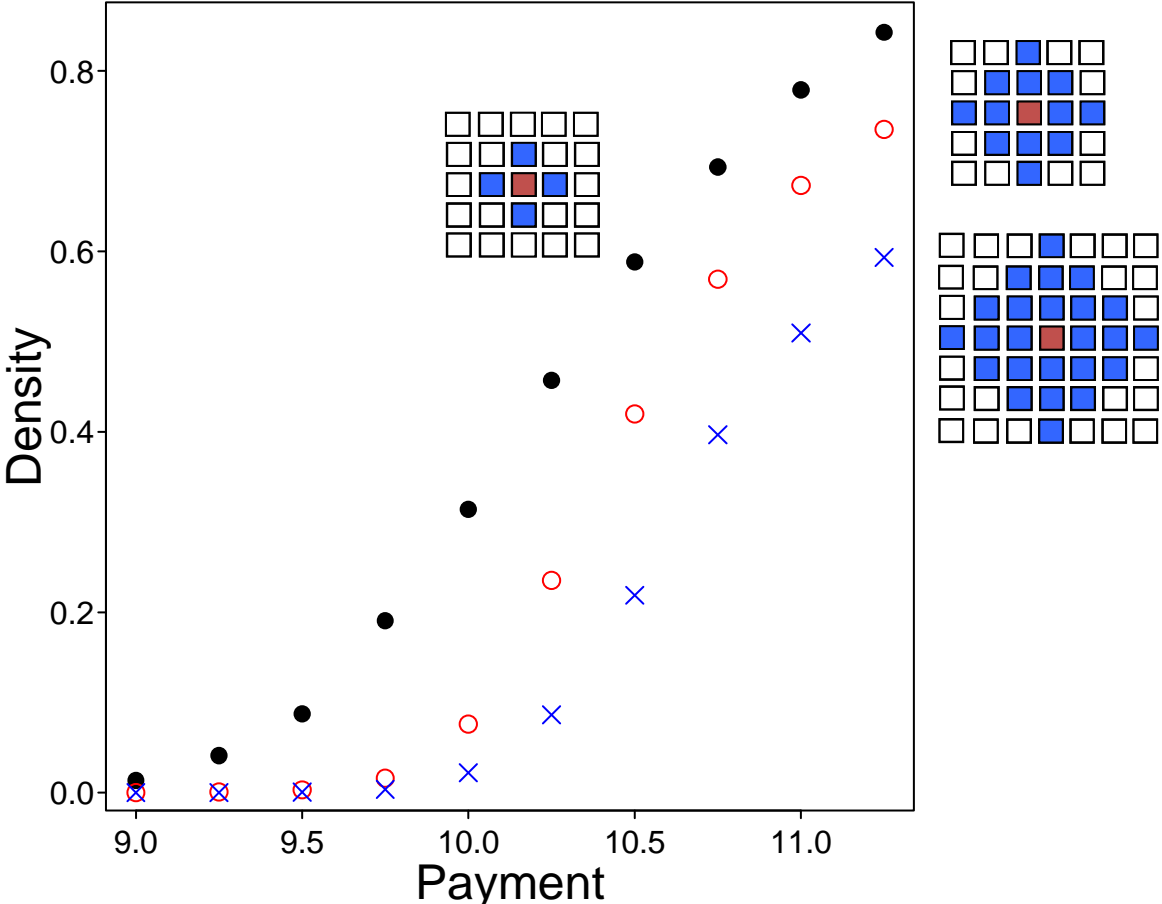


% converted

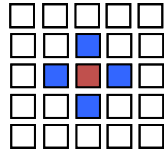
$d=0.1$: moving species

- Closer match for conversion and species density
- Conversion more effective
- Similar spatial scales

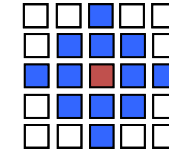
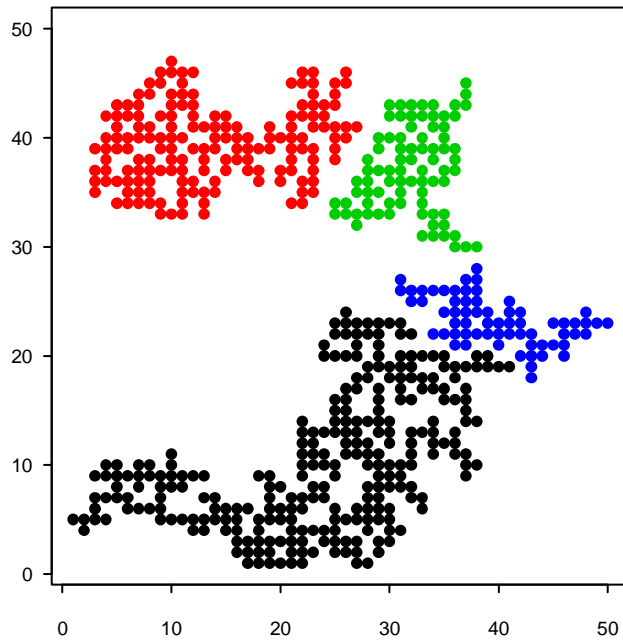
Changing neighbourhood structure



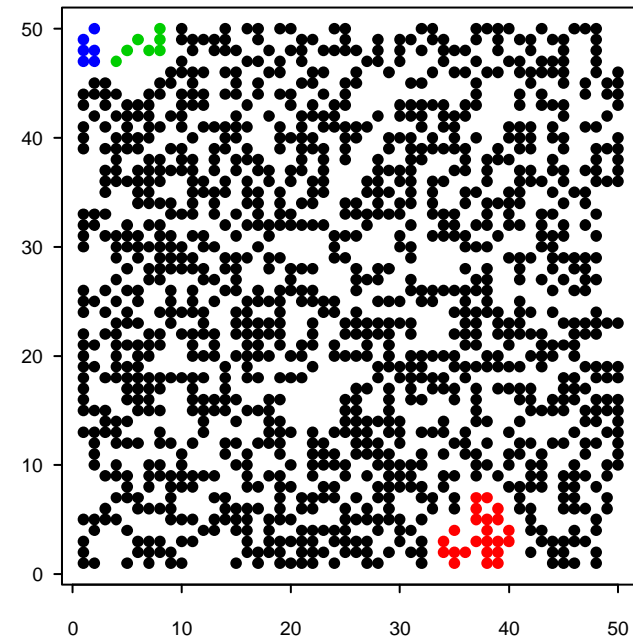
Uniform payment, link to percolation



at least one among 4 neighbours



at least one among 12 neighbours



- but, there could be situations when we might require >1 converted neighbour
- need to know the biology!