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

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Plan

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3. Ecological model
4. Uniform payment
5. Simplification – percolation theory
6. Aggregation bonus
7. Correlated environmental costs
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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:

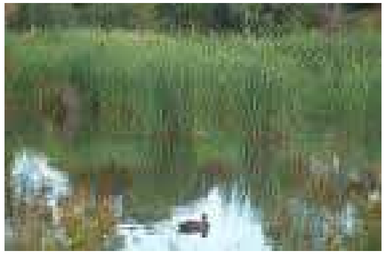
1. Land-use approach by planning conservation at the landscape level
2. Incentive design to reach the social target:
    - Interconnected conserved habitat
    - Maximum size of connected habitat
    - Lowest cost of conversion
3. Agglomeration bonus
    - Additional premium paid depending on neighbour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

Introduction

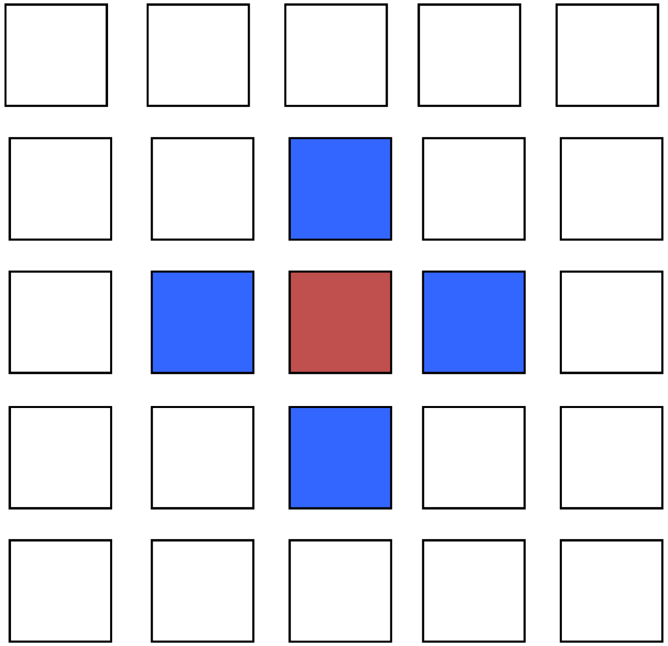
1. Two characteristic scales:
    - Landscape level (wetlands): conservation outcome
    - Individual level (farmer, field): stimulus
2. Two approaches:
    - Simulation of an ecological model
    - Simple model based on percolation
3. Goal is to create connected cluster of conserved patches
    - Need 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
- 25x25=625 sites for illustration
- von Neumann neighbourhood with 4 nearest neighbours



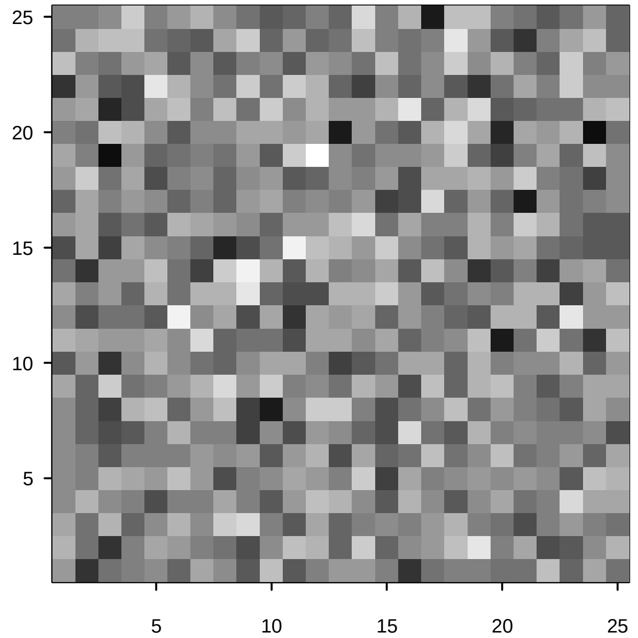
- Each site can be occupied by individuals
  - insects
  - birds
  - animals
- Population dynamics
  - births, deaths and competition
  - migration

Spatial model

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

Cost-benefit analysis:

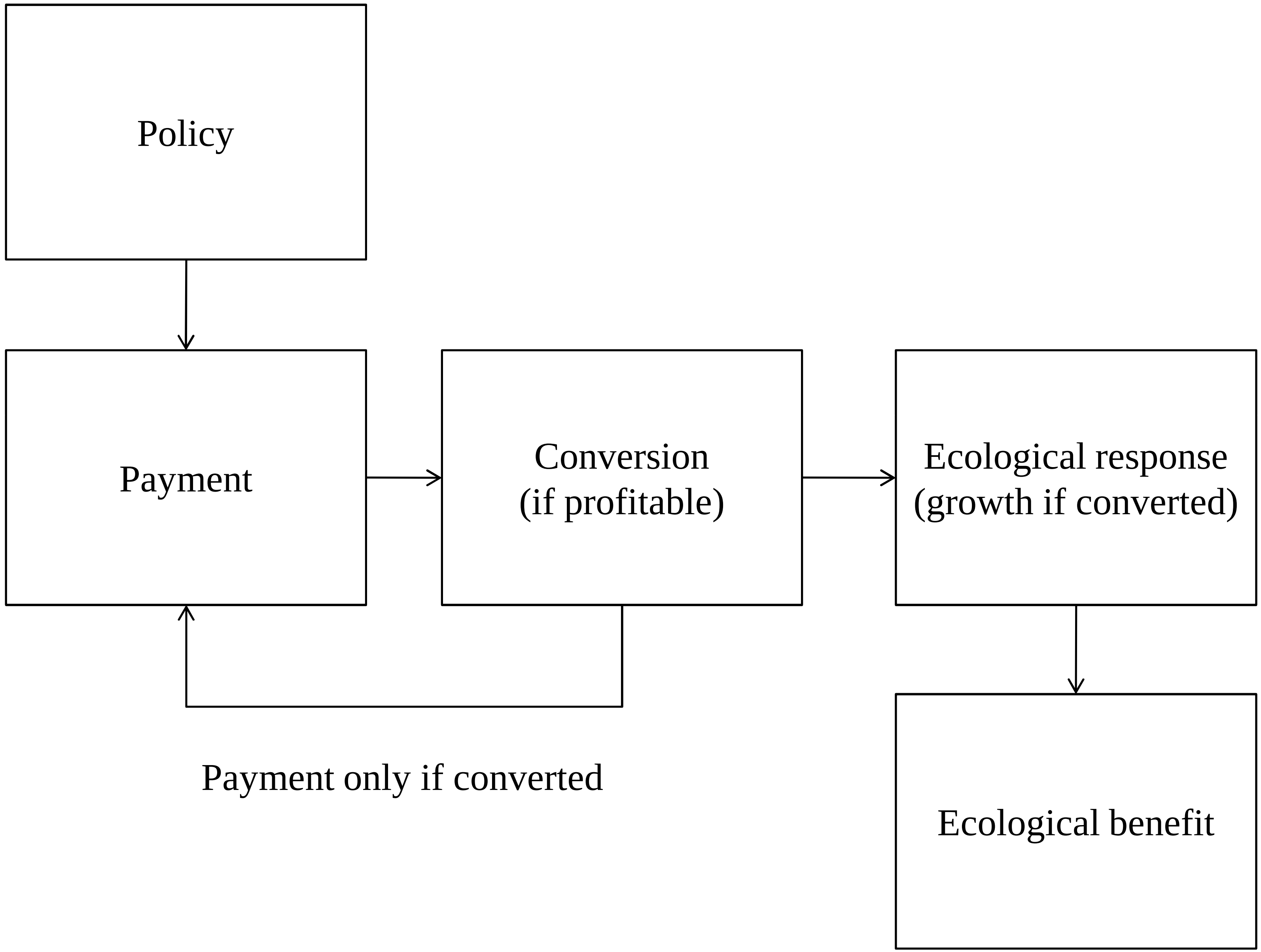
1. Each conversion costs *a*
    - *Foregone profits* forms main part of this cost
2. Conversion costs are distributed randomly
    - independently
    - with spatial correlation



$$a \sim \mathrm{N}(\mu, \sigma)$$

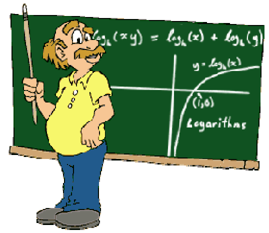
Grey scale corresponds to varying costs of conversion

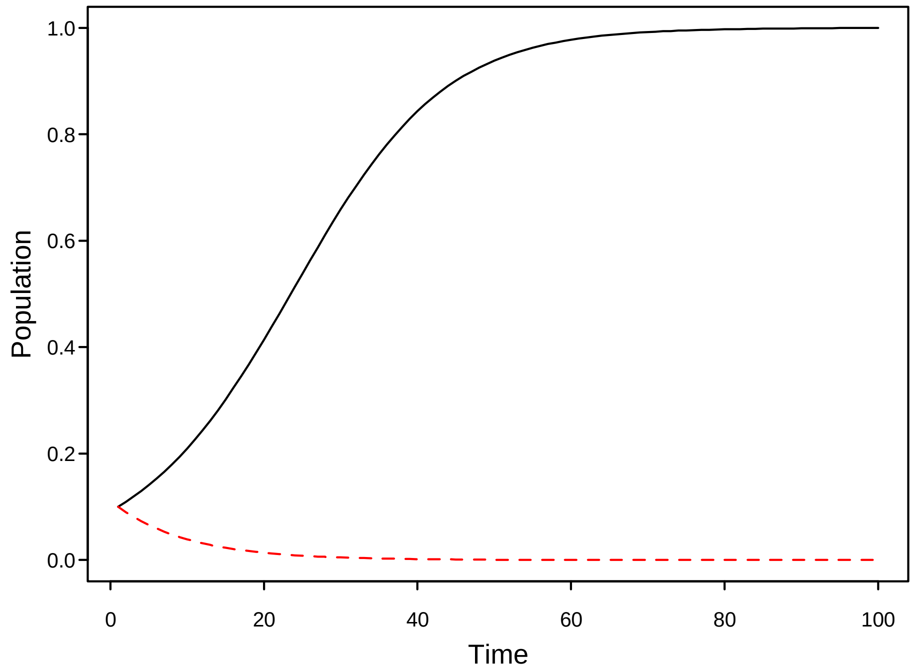
Linking economics with ecology



Ecological model: Within-patch dynamics

Converted site = Conducive patch





$$y_{n+1} = \begin{cases} y_n + \beta y_n \left(1 - \dfrac{y_n}{\kappa}\right) & \text{; conducive patch} \\ y_n - \beta y_n & \text{; suppresive patch} \end{cases}$$

Logistic growth

Exponential decline

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

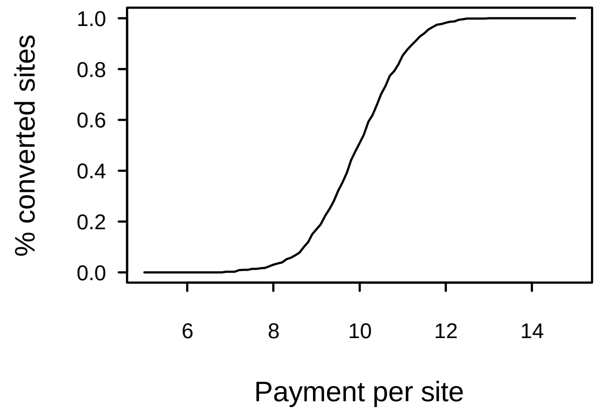
Uniform payment, no migration

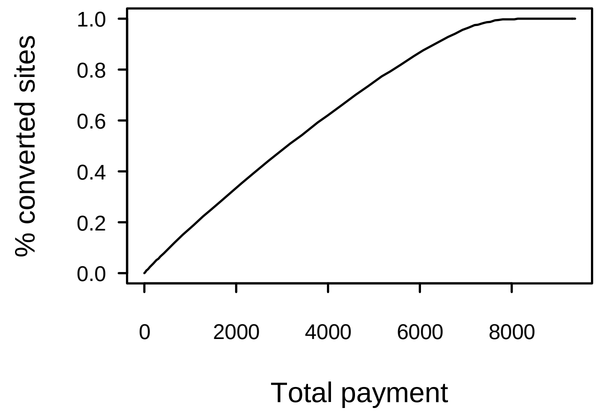
- Payment c_1 made to all farmers who decide to switch to wetland
- No *explicit* spatial correlation
- All farmers for whom $c_1 > a$ will switch

Objective: Maximise the area converted

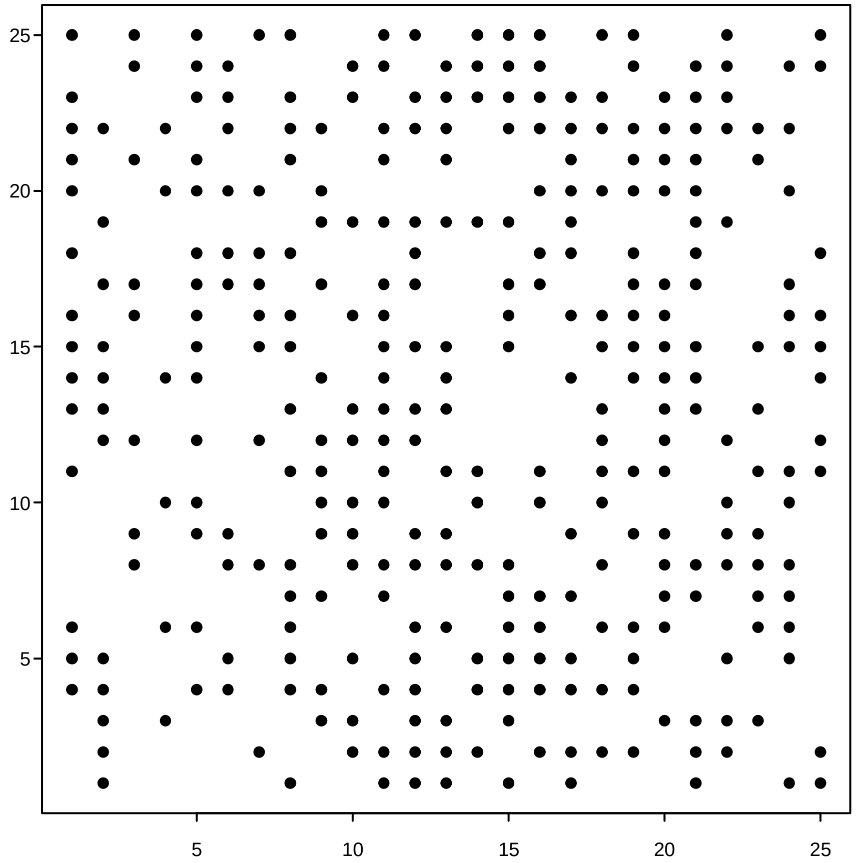
$$P\left(a < c_1\right) = \Phi\left(c_1\right)$$

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





Uniform payment, no migration



Payment *a*=10

$$a \sim \mathrm{N}(\mu, \sigma)$$

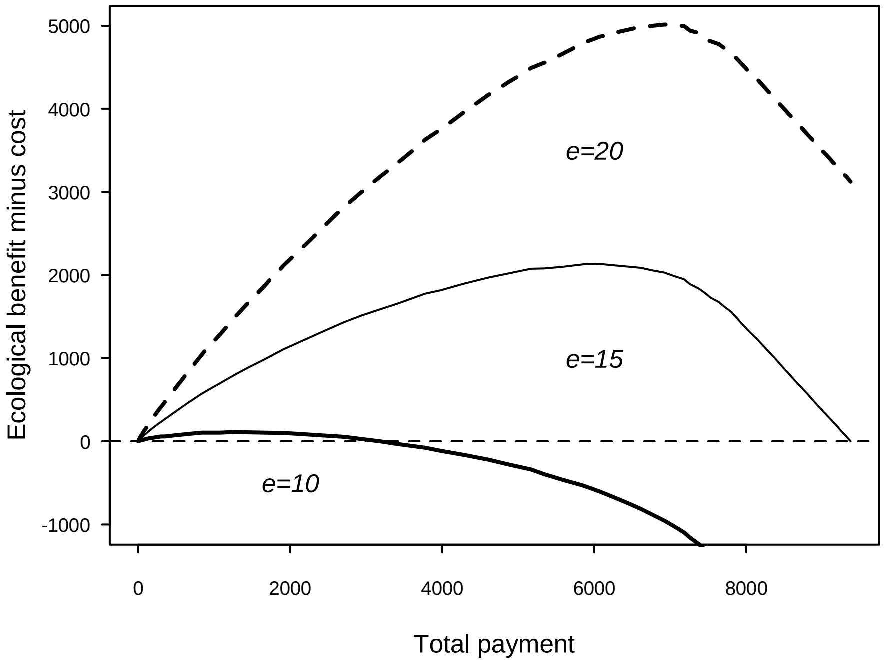
$$\mu = 10.0$$

$$\sigma = 1.0$$

Points represent sites converted (50%)

Uniform payment, no migration

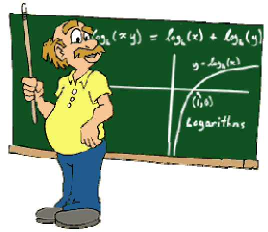
1. Ecological benefit: proportion of sites converted
2. As the ecological benefit per site, *e*, increases, so does the total benefit minus costs;
3. There is an optimal total payment that leads to maximum ecological benefit

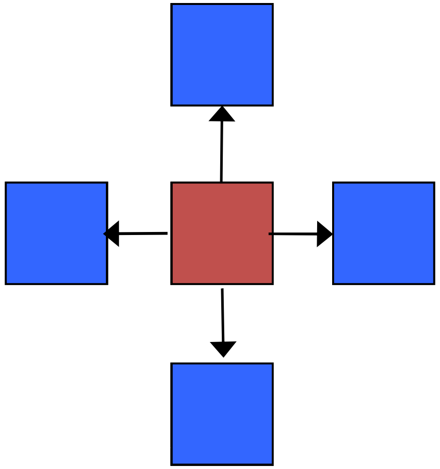


$$\text{Total payment} = c_1 \times \text{number of converted farms}$$

$$\text{Environmental benefit} = e \times \text{number of converted farms}$$

Between-patch dynamics



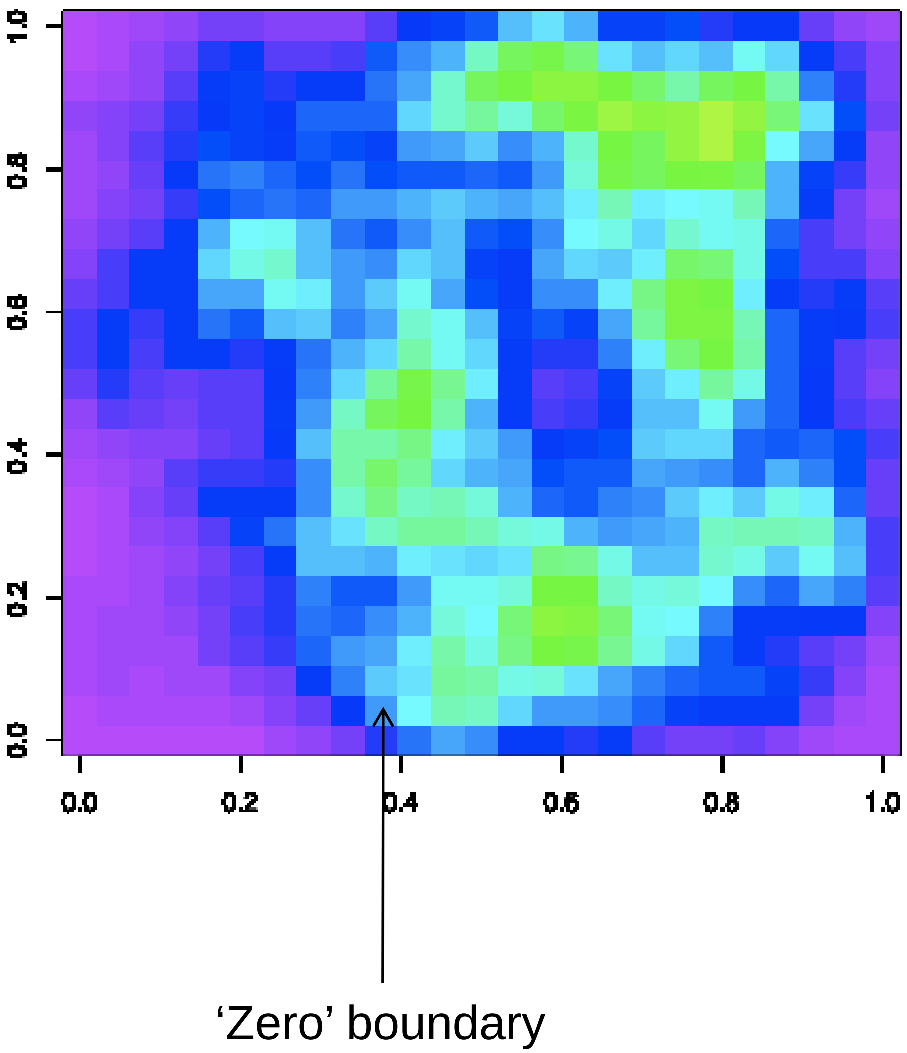


$$y_{n+1}(i) = \begin{cases} y_n(i) + \beta y_n(i)\left(1 - \dfrac{y_n(i)}{\kappa}\right) & \text{; conducive patch} \\ y_n(i) - \beta y_n(i) & \text{; suppresive patch} \end{cases}$$

$$+D \sum_{j \in \mathrm{Nb}(i)} \left(y_n(j) - y_n(i)\right) \qquad \text{; movement}$$

Uniform payment, migration

Payment a=10



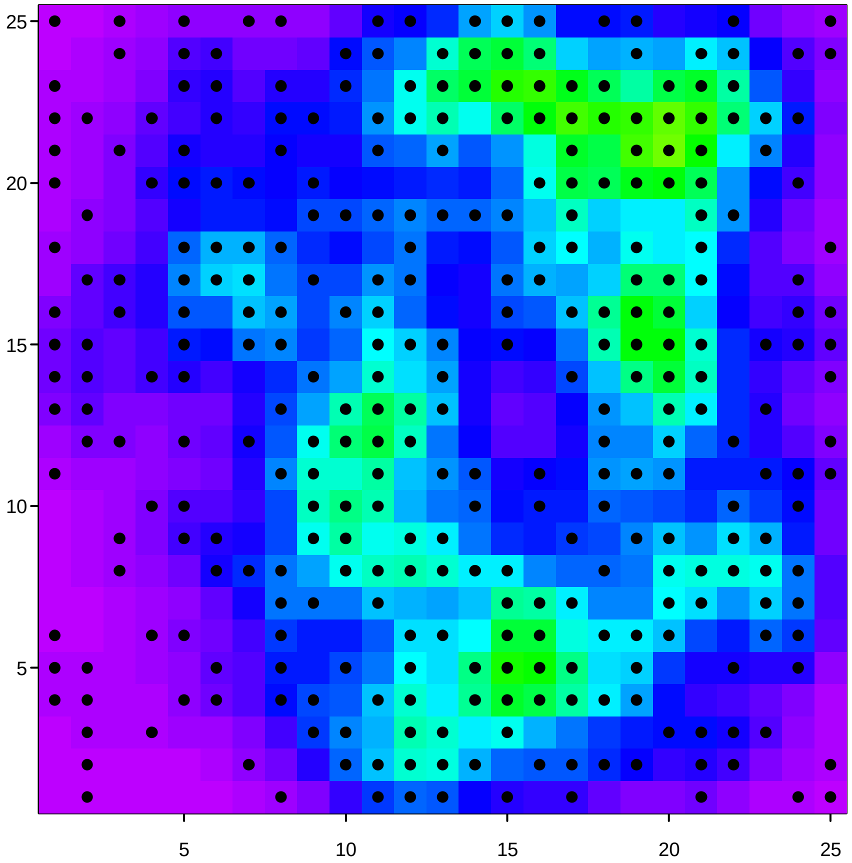
$$d = 0.1$$

$$\beta = 0.1$$

$$\kappa = 1$$

Colour represents density of species

Uniform payment, migration



Payment *a*=10

$$d = 0.1$$

$$\beta = 0.1$$

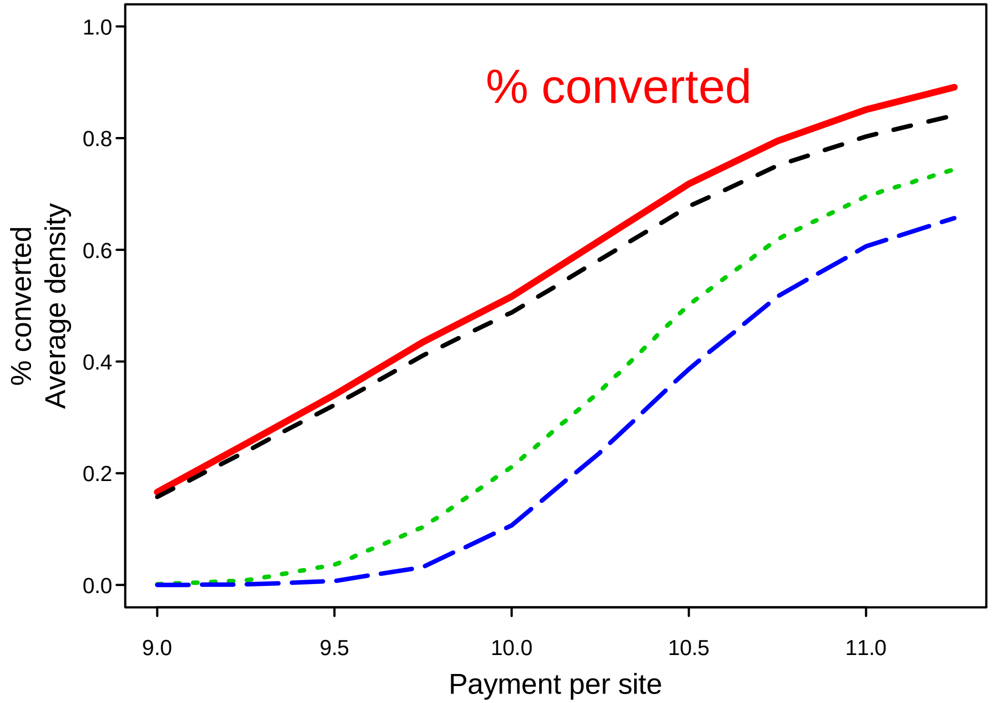
$$\kappa = 1$$

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

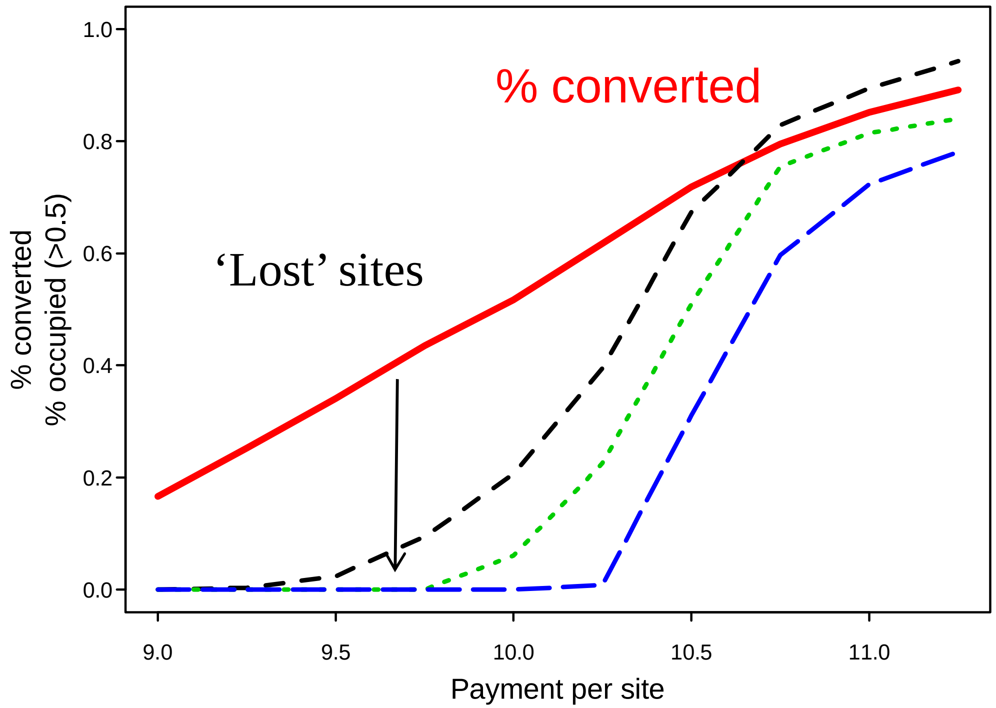
d=0.1: slow movement

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



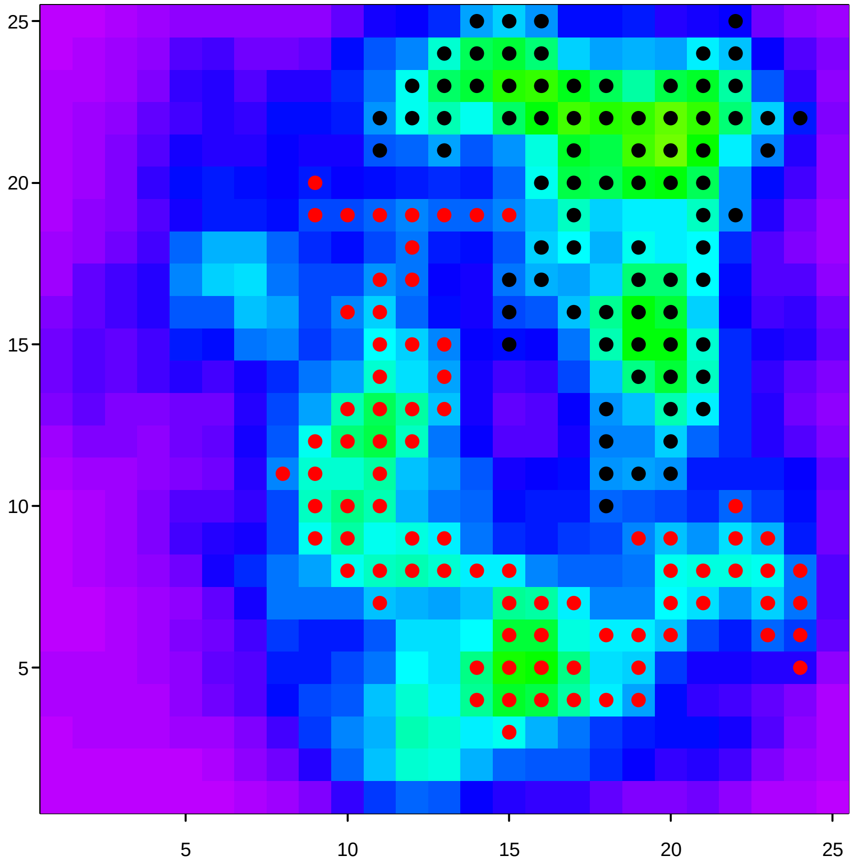
d=0.05: very slow movement

d=0.1: slow movement

d=0.2: fast movement

- 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

$$d = 0.1$$

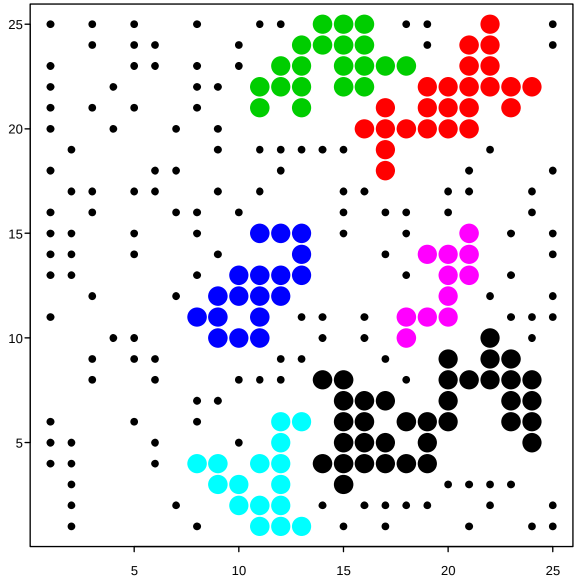
$$\beta = 0.1$$

$$\kappa = 1$$

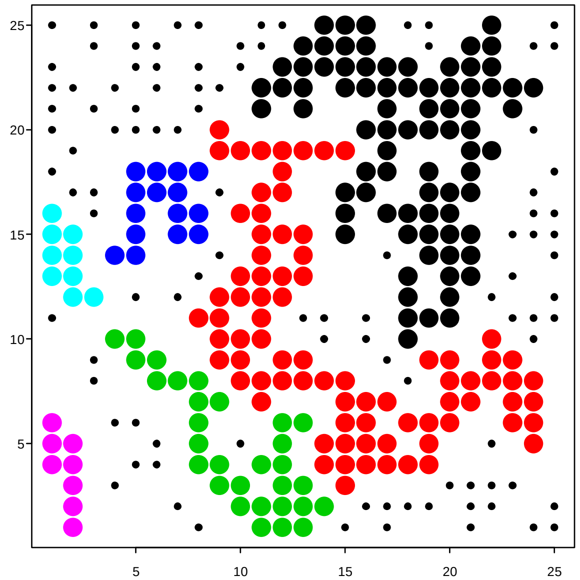
- Link to percolation:
  - Species concentrating on a set of *connected* sites
- Sites are *connected* via von Neumann neighbourhood
- Points represent two largest clusters of connected sites

Uniform payment, link to percolation

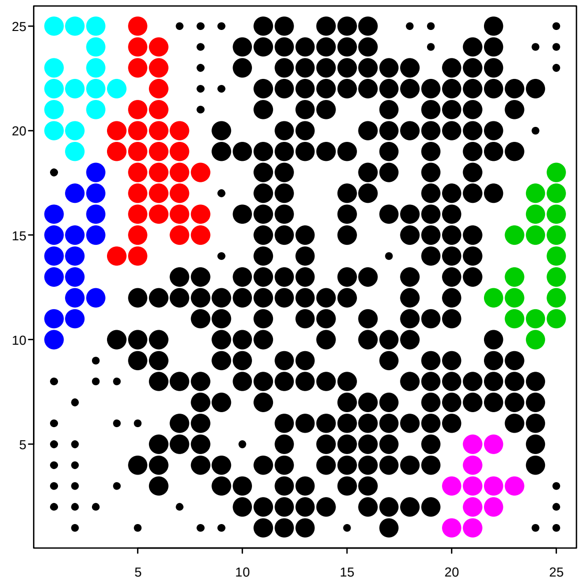
a = 10.0



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 μ=10 and σ=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
    (≈ 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

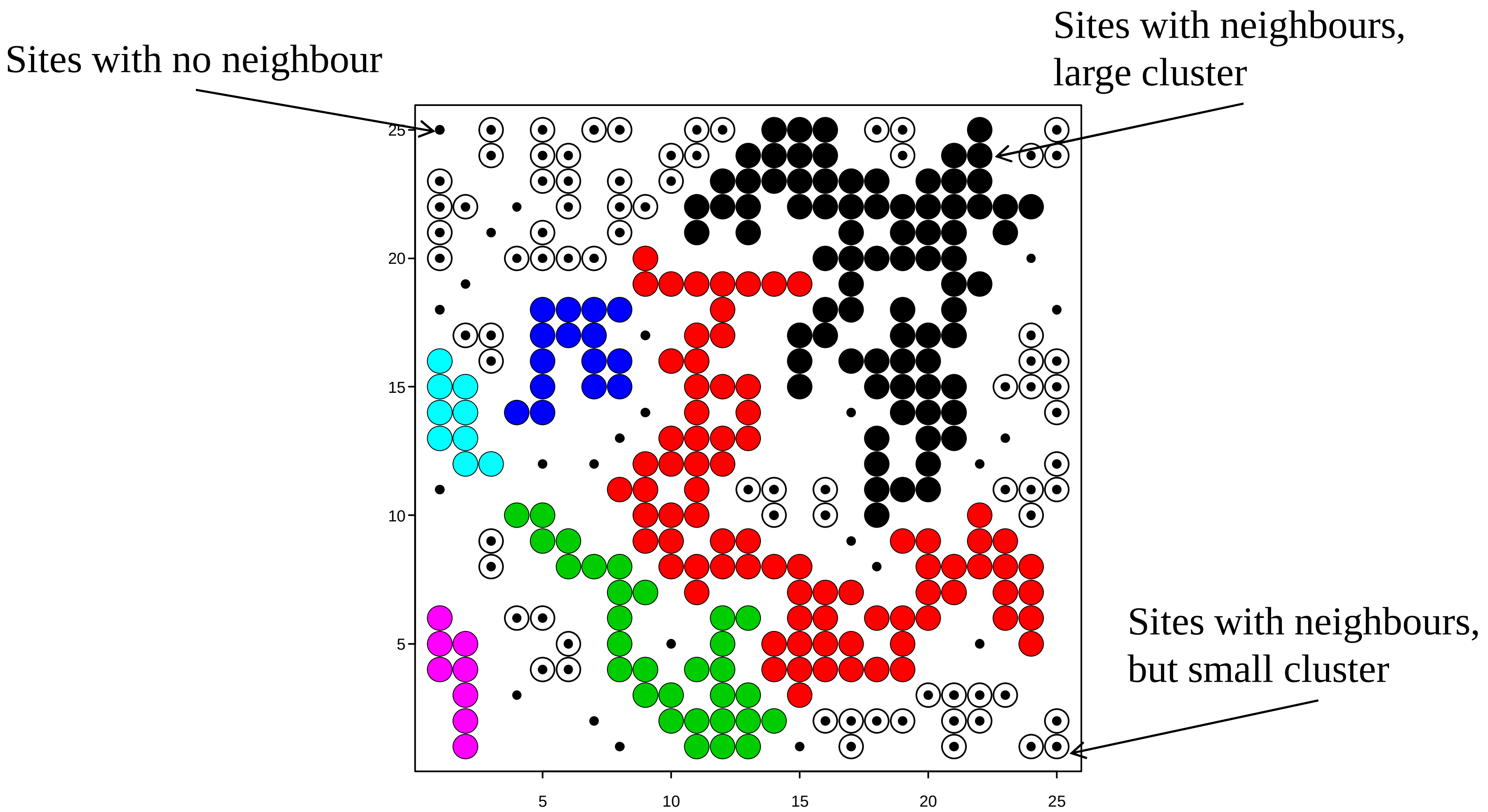
Agglomeration bonus

- 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)

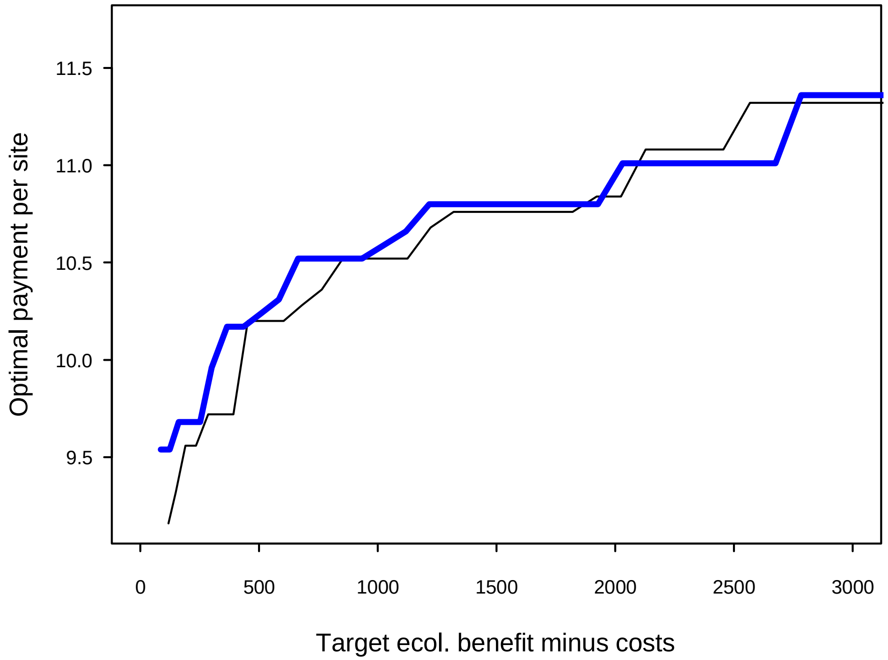
Agglomeration bonus



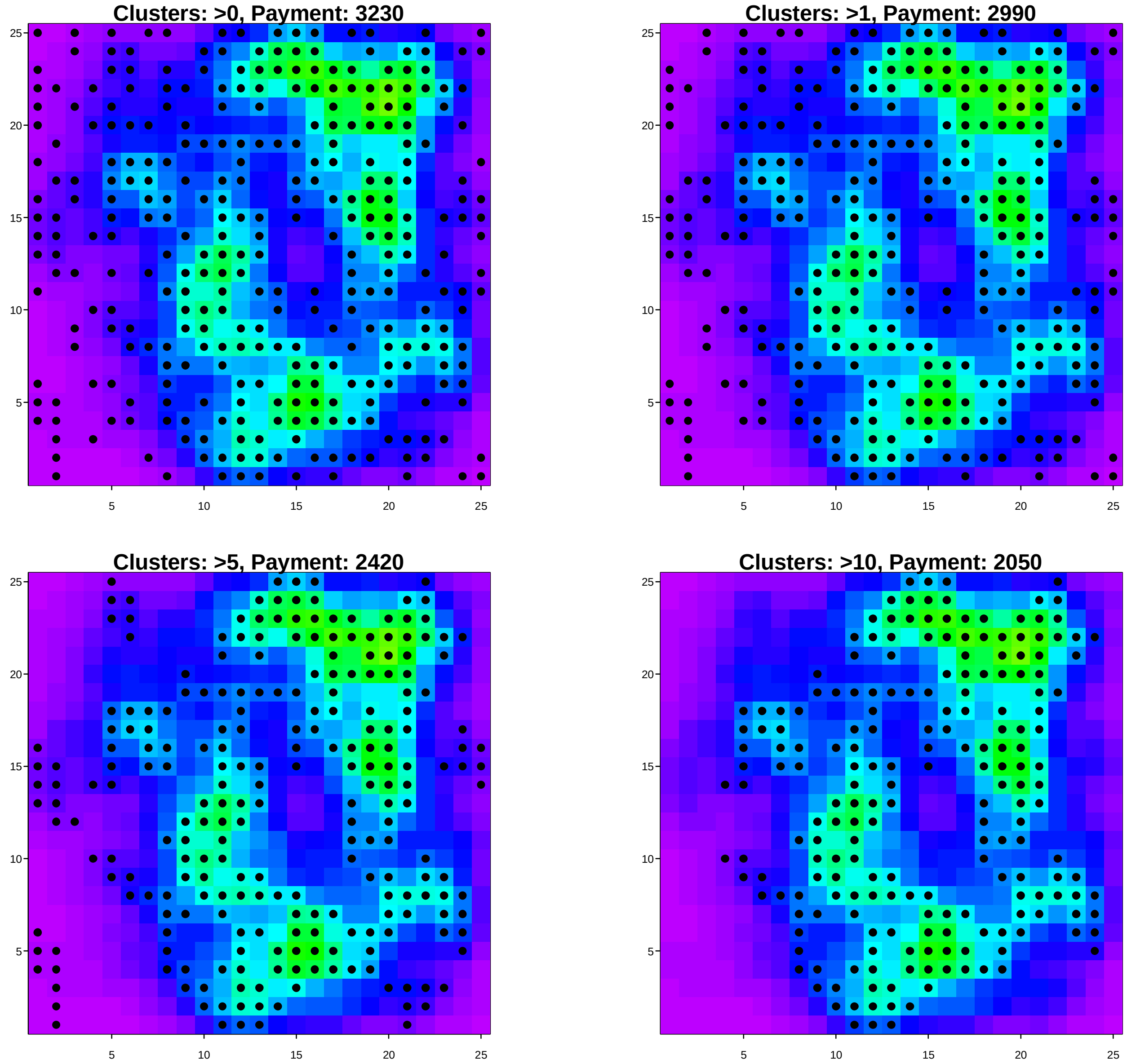
- Even under the uniform payment, there are only very few sites that have no neighbours
- Agglomeration bonus for the nearest neighbour is not going to make much difference!

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

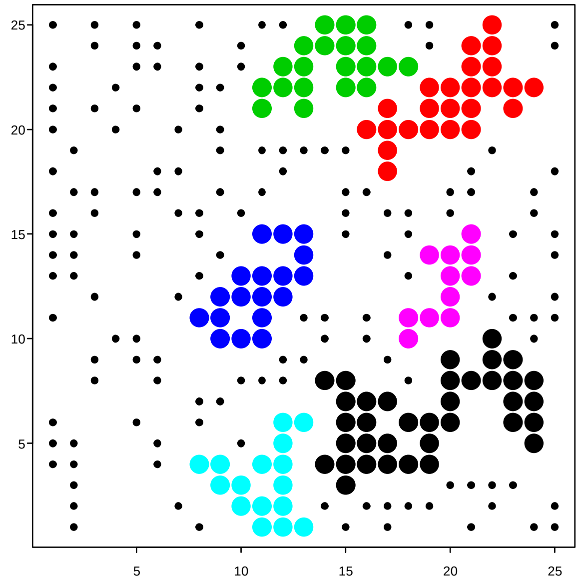


Agglomeration bonus



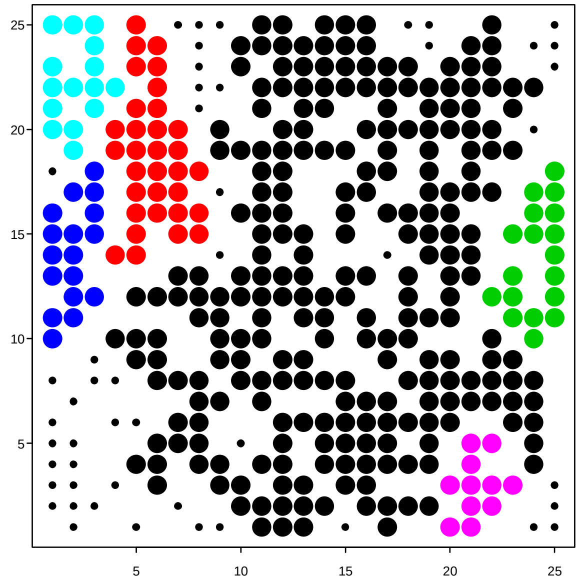
Agglomeration bonus – why it does not work and when it could work

a = 10.0



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

a = 10.5



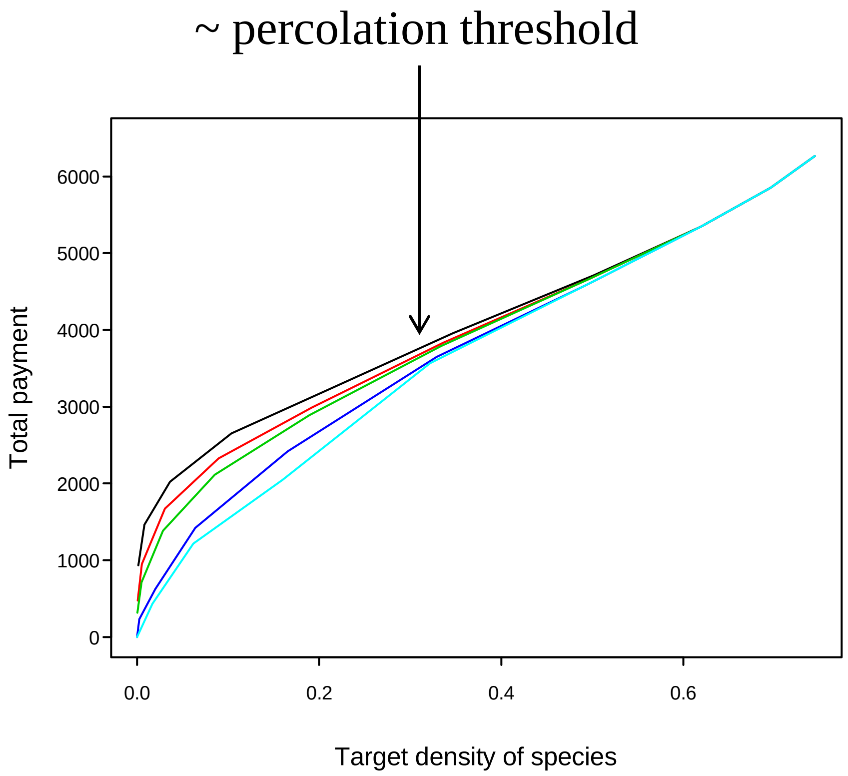
• not enough individual farms to be connected to

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

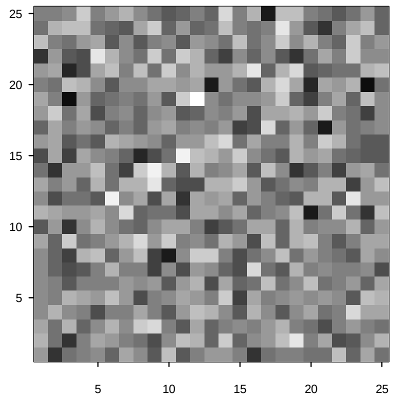
Summary:

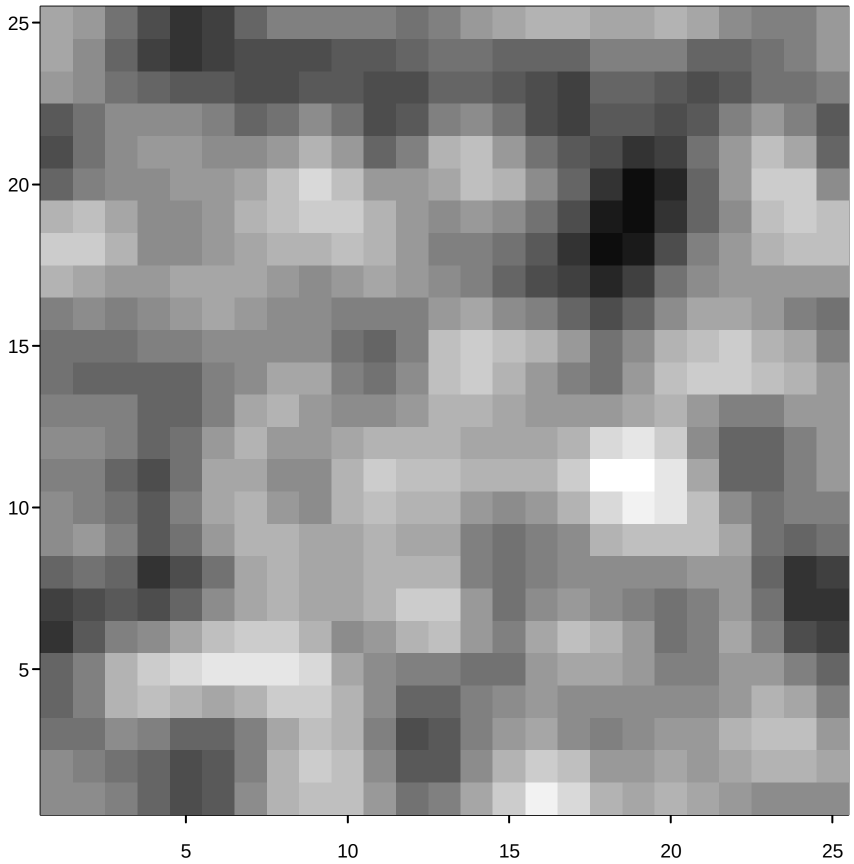
1. Framework for studying conservation subsidies in the light of ecological dynamics
2. Results:
   - Uniform payment is wasteful
   - Simple agglomeration bonus does not improve the results significantly
   - Need to extend AB to groups
3. Spatially correlated environmental costs:
   - Matching spatial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

Assumptions:

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

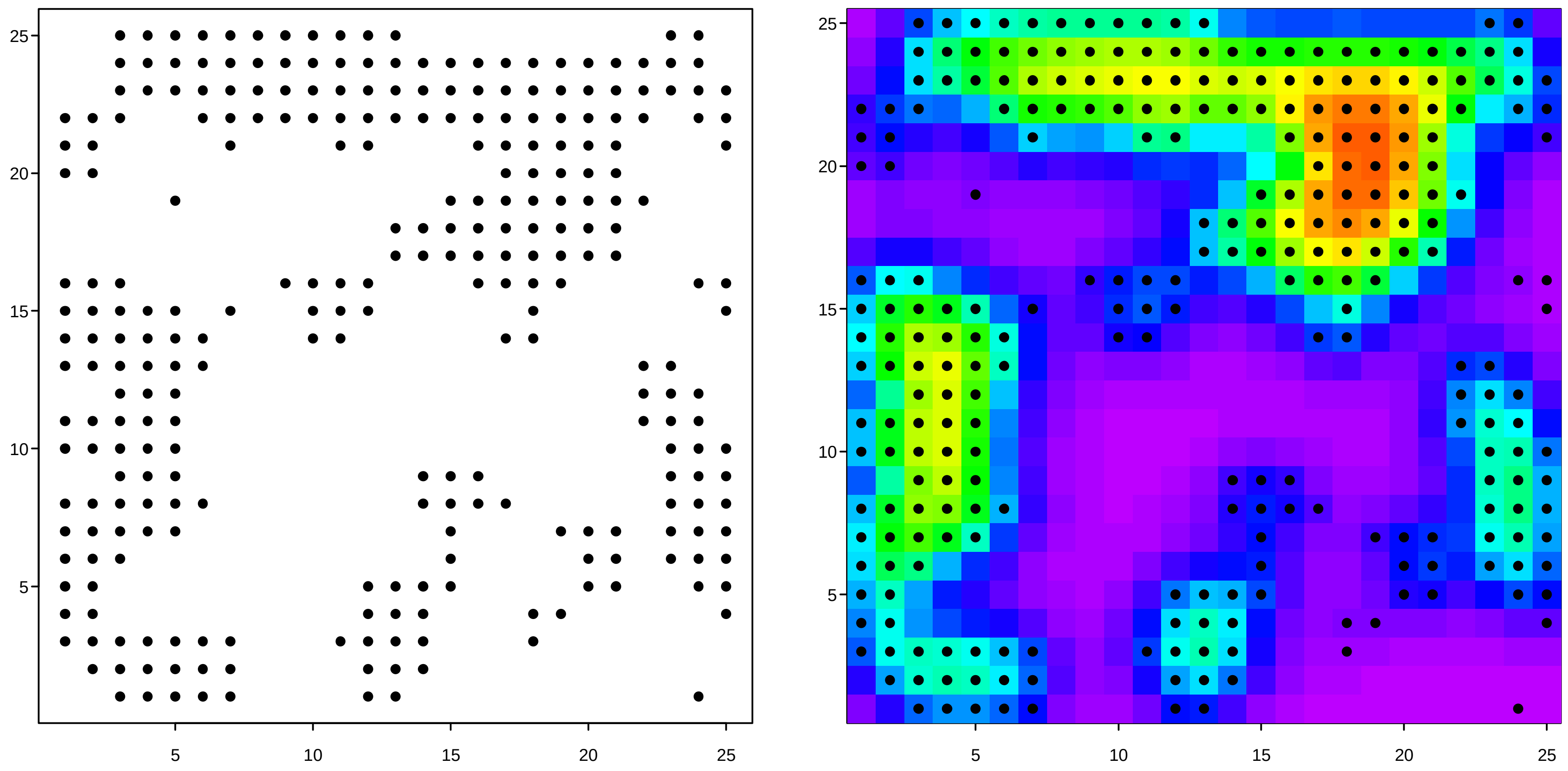
Spatially correlated conversion cost





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

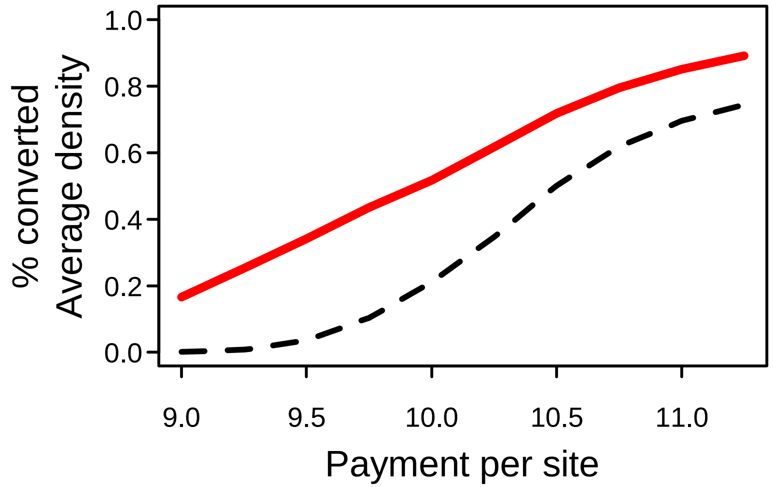
Correlated environmental cost



Very few conversions are ‘lost’

Correlated environmental cost

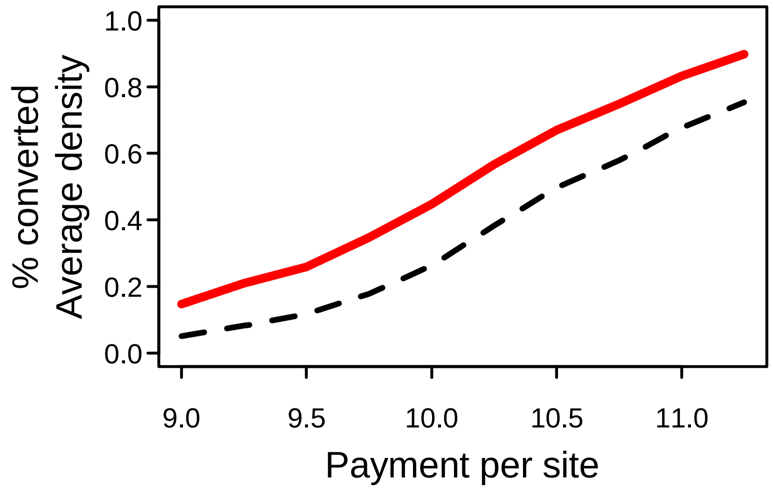
Uncorrelated cost



% converted

d=0.1:moving species

Correlated cost

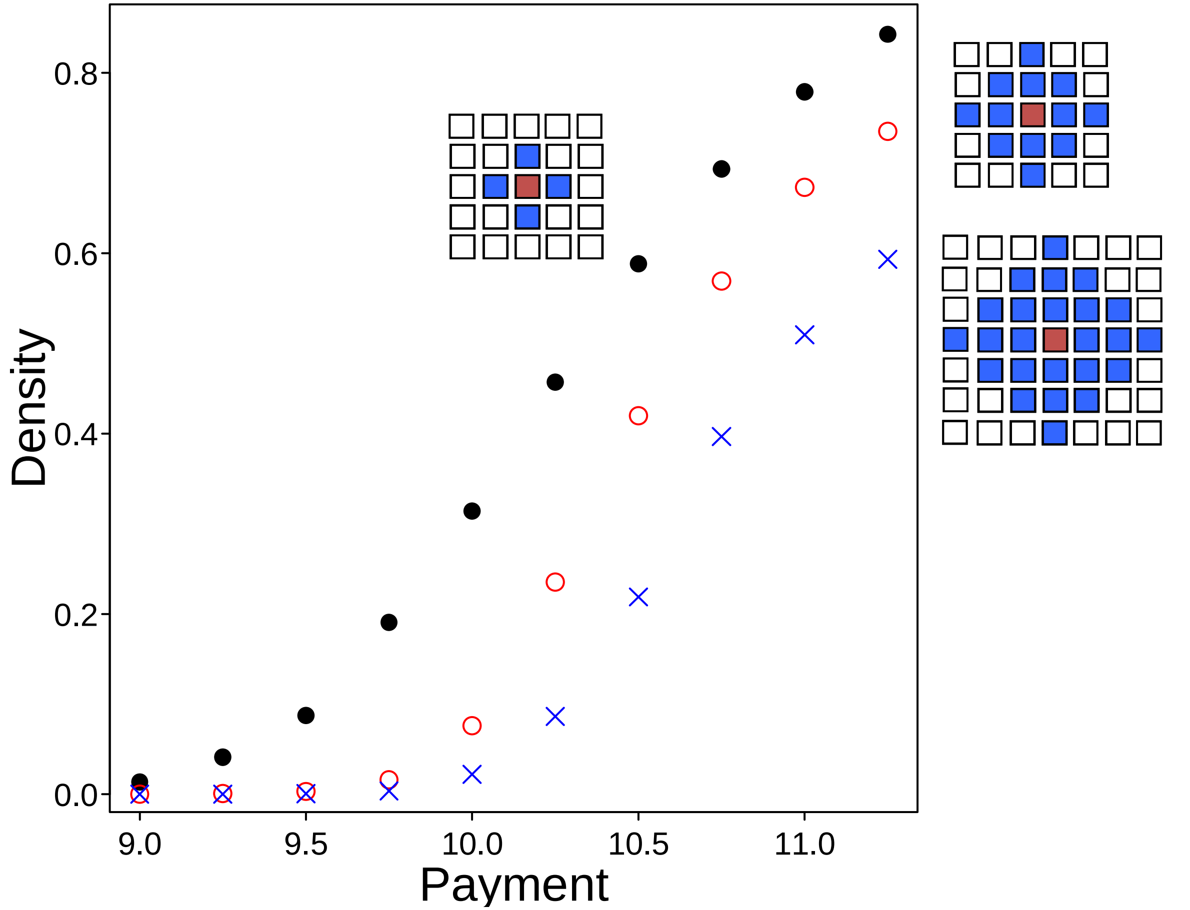


% converted

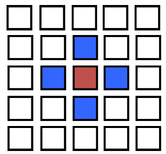
d=0.1:moving species

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

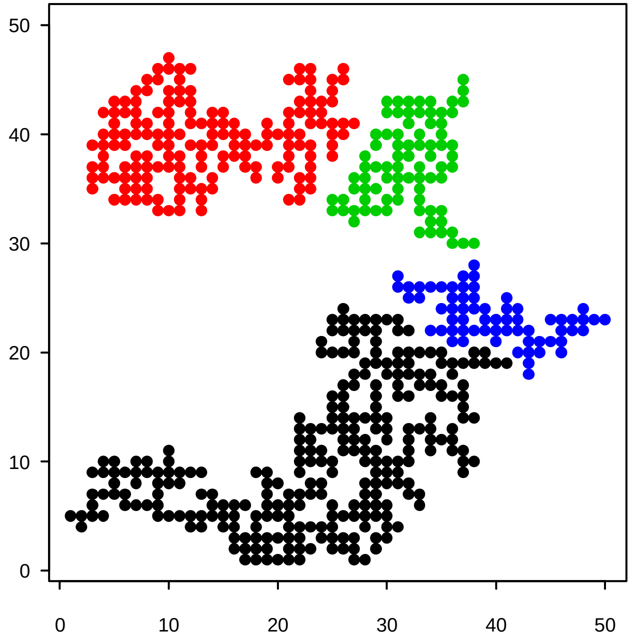
Changing neighbourhood structure

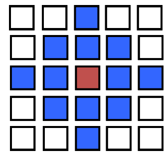


Uniform payment, link to percolation

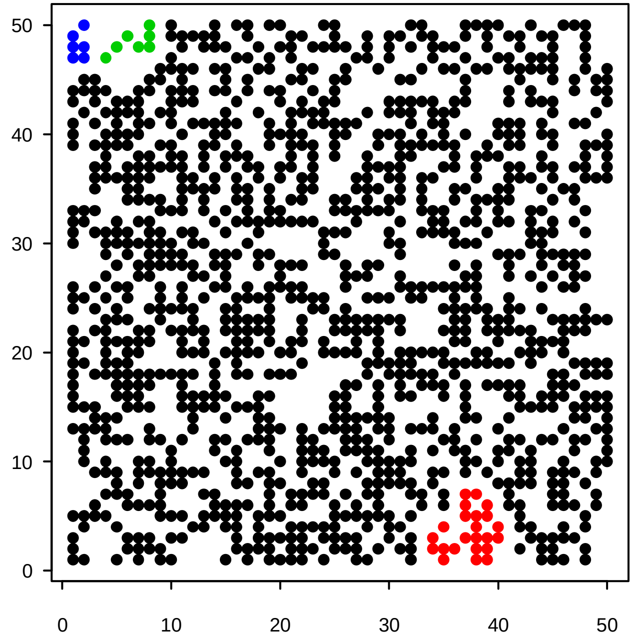


at least one among 4 neighbours





at least one among 12 neighbours



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