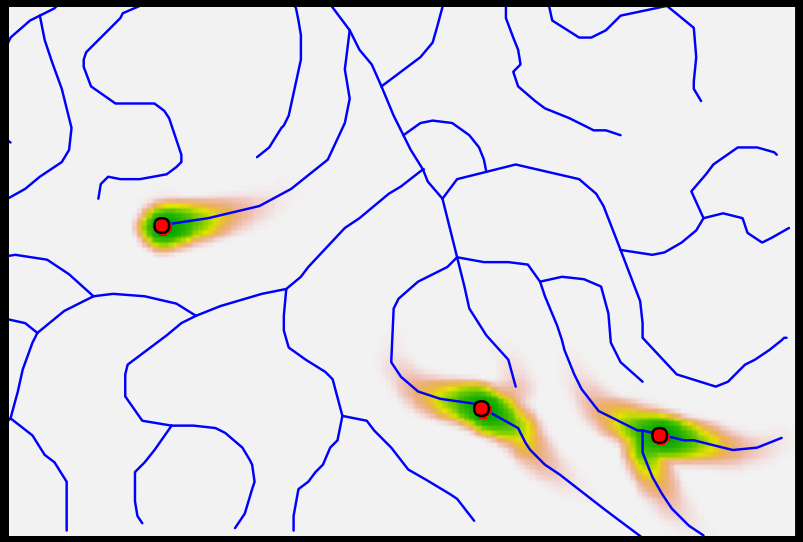
Measuring 'ecological' distance in spatial capture-recapture models

Chris Sutherland, Angela Fuller & Andy Royle

American mink in riparian corridors



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USGS science for a changing world

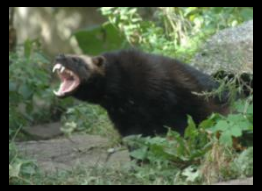
Spatial Capture-Recapture (SCR)

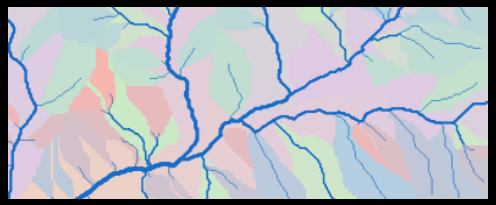
Acknowledges the inherent spatially nature of ecological processes and observation processes:

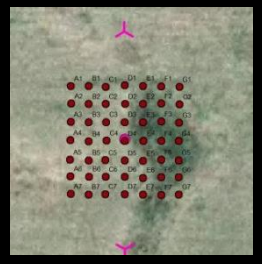
- effective area sampled ~ *absolute* density
- heterogeneous encounter probabilities

but, useful for many other challenges in ecological research:

- movement, space-use, resource selection, survival, recruitment

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Acknowledges the inherent spatially nature of ecological processes and observation processes:

- effective area sampled ~ *absolute* density
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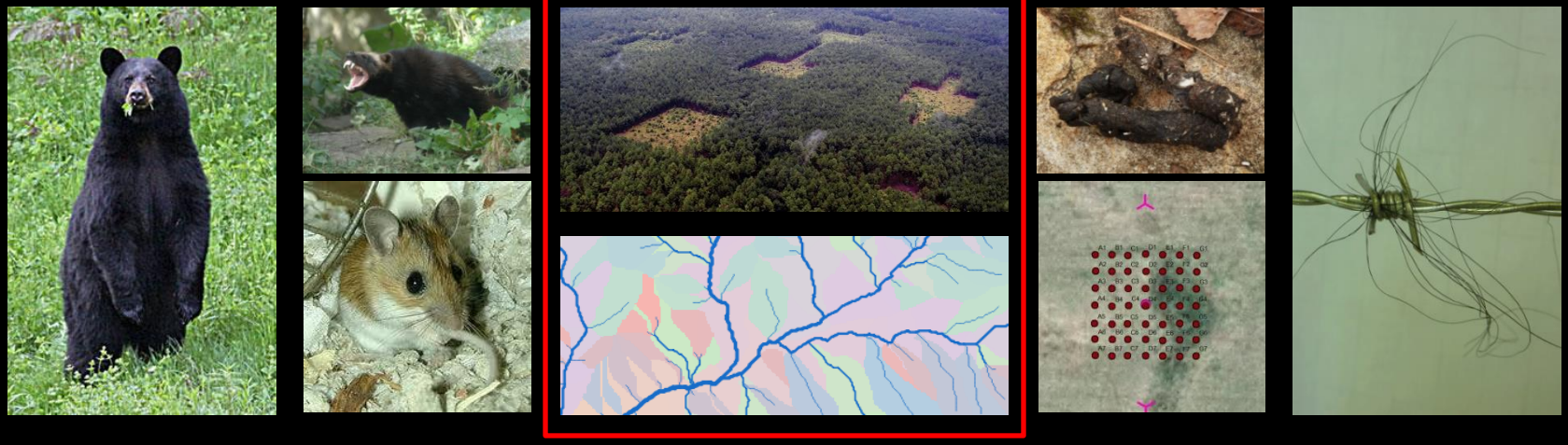
but, useful for many other challenges in ecological research:

- movement, space-use, resource selection, survival, recruitment, *connectivity/landscape resistance* (Royle *et al*., 2013)

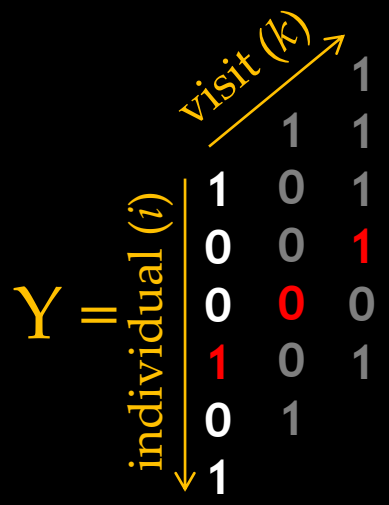


Spatial Capture-Recapture (SCR)

Retaining the spatial information about trap locations and therefore about individual encounter locations:

Non-spatial encounter history

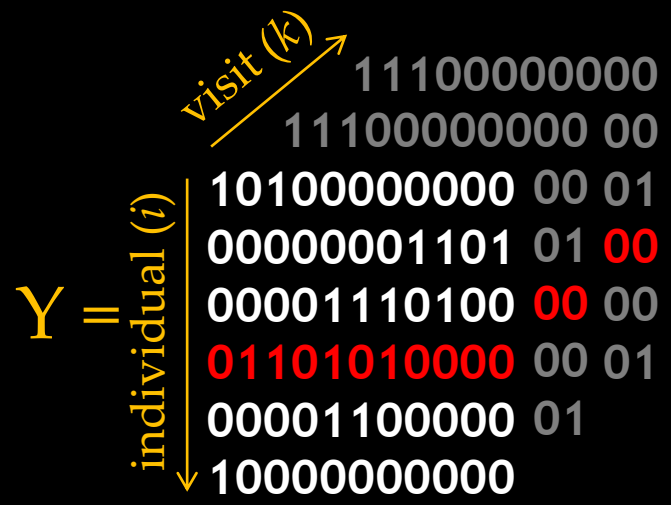
$y_{i,k} = [y_{i,k}\ y_{i,k}\ \cdots,\ y_{i,k}]$



Caught in any trap

Spatial encounter history

$y_{i,k} = [y_{i,1,k}, y_{i,2,k}, \cdots, y_{i,J,k}]$



Spatial Capture-Recapture (SCR)

A typical SCR data set therefore consists of:

- spatial locations of each trap - $\boldsymbol{x}_j$
- individual-by-trap/location spatial encounter histories – $\boldsymbol{y}_{i,j}$

Biologically: Observations $\boldsymbol{y}_{i,j}$ occur as a result of movement around an home range center and frequency of detection decreases with distance between trap and activity center $\boldsymbol{s}_i$

Statistically: Observations $\boldsymbol{y}_{i,j}$ are realizations of a probability distribution whose mean is a latent variable $\boldsymbol{s}_i$ i.e. a random-effects model

Model for encounter probability (many exist):

$$y_{i,j} \sim Binomial(K, p_{i,j})$$

$$p_{i,j} = f(\mathrm{d}[s_i, x_j])$$

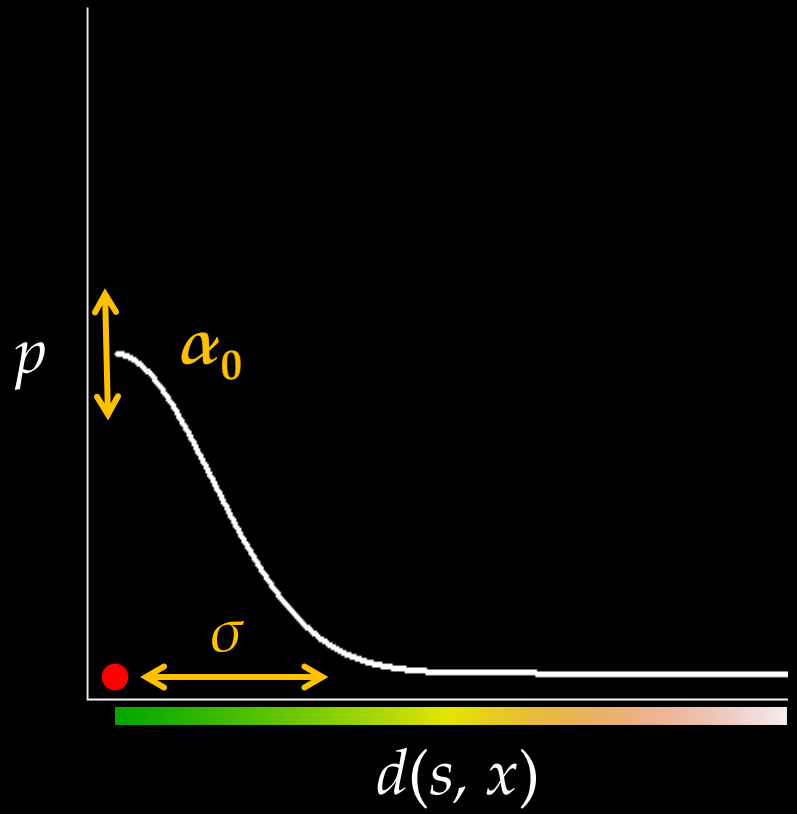
Modeling movement using SCR

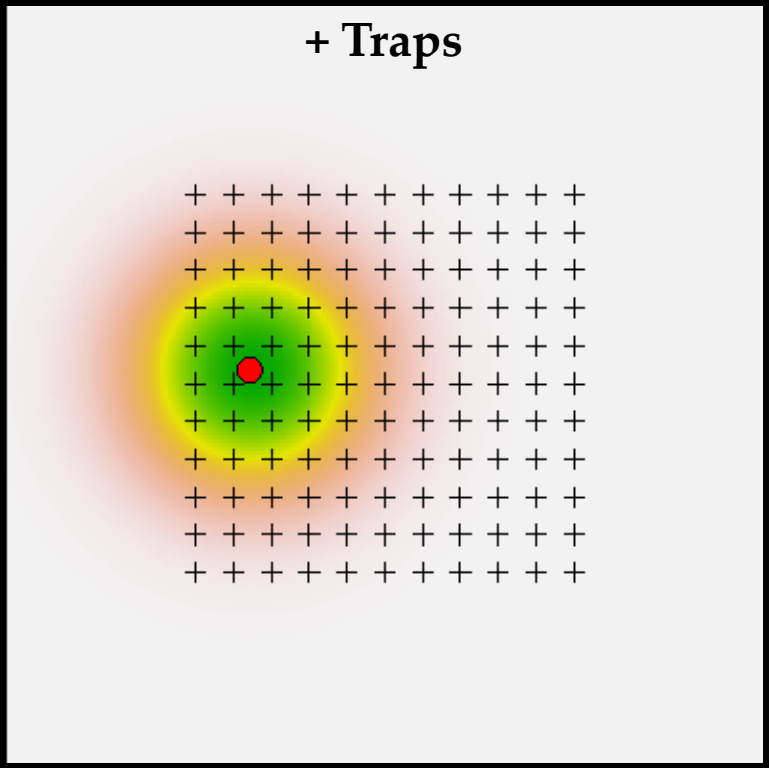
Bivariate normal encounter model:

$$y_{i,j} \sim Binomial(K, p_{i,j})$$

$$p_{i,j} = \alpha_0 \exp(-\alpha_1 \, d[s_i, x_j]^2)$$

$$\alpha_1 = 1/(2\sigma^2)$$





Modeling movement using SCR [*poorly in some cases?*]

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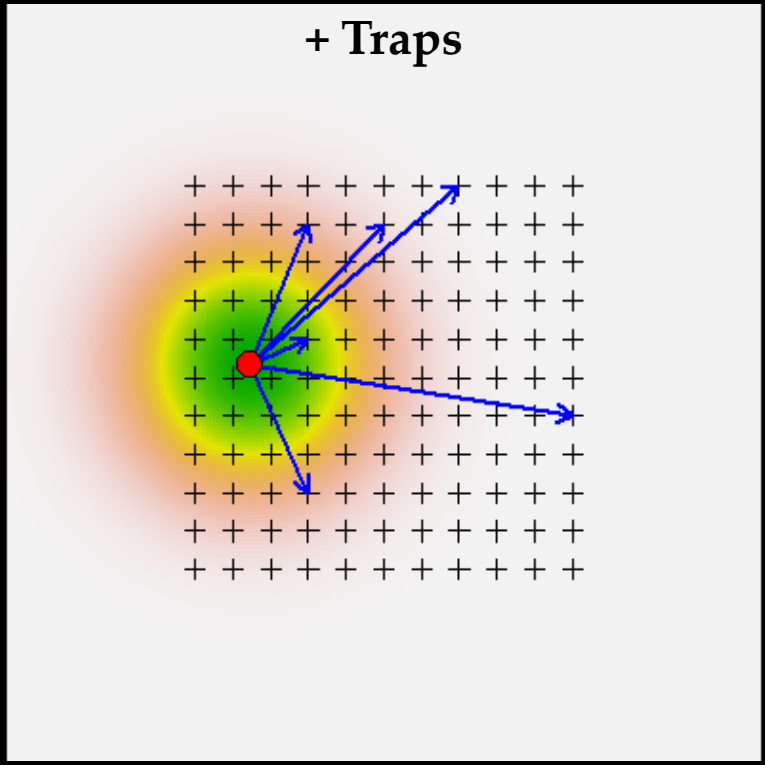
Euclidean distance:

- circular home range
- uniform landscape [use]

⇒Biologically unrealistic



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Euclidean distance:

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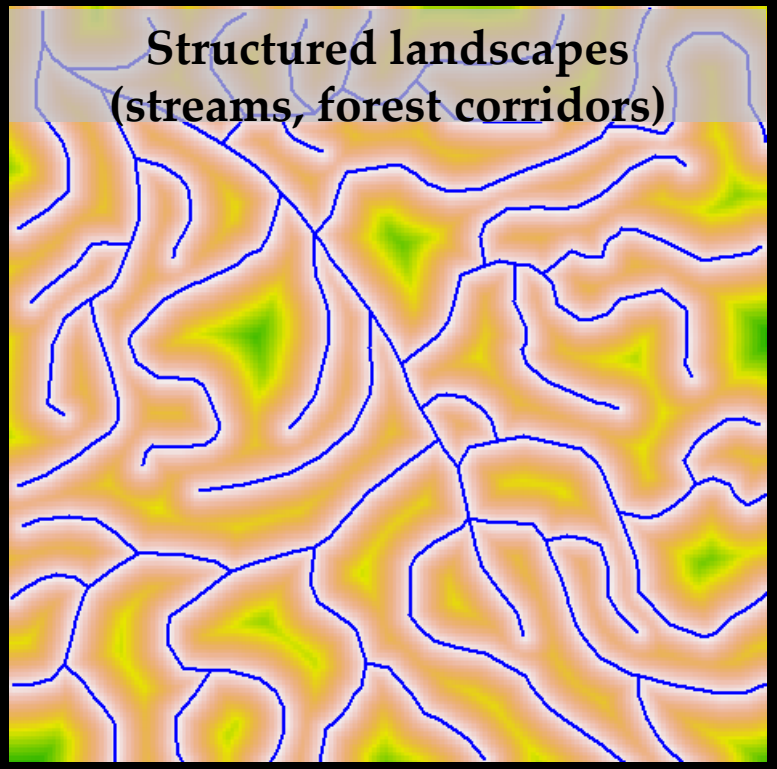
⇒Biologically unrealistic

Movement is not equally likely through all habitats:

- cost/resistance



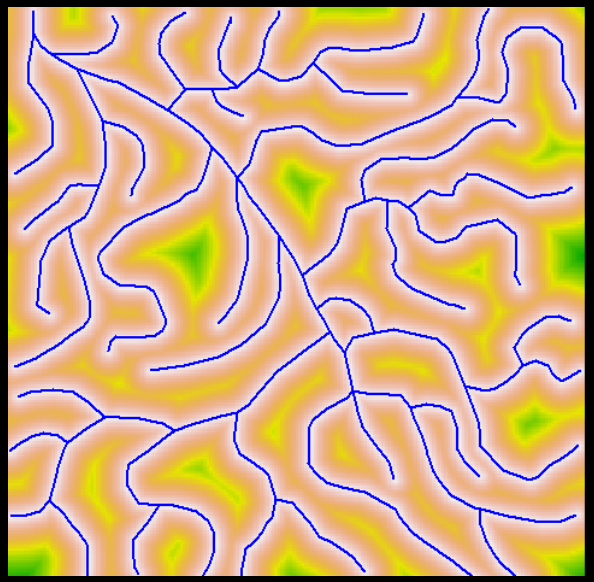
Stream networks & riparian species – my motivation!

The American mink *Neovison vison*:

- economically important
- community regulator
- top predator (aquatic)
- indicators of ecosystem health

A perfect model system:

- semi-aquatic (∴ non-Euclid. movement)
- habitat specialist (∴ non-Euclid. movement)
- landscape (dist. to water) 'easy' to define

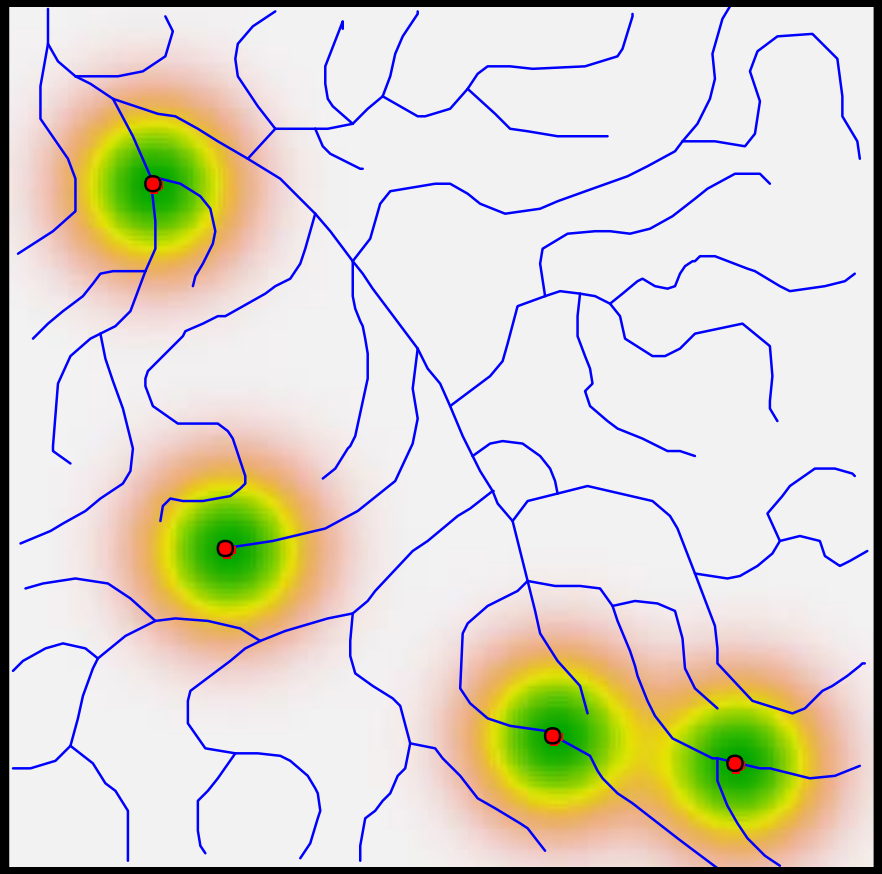


So, how should we measure distance?

Distance as the *what?* moves…

Three ways to measure distance:

- Euclidean distance - distance as the 'crow flies'

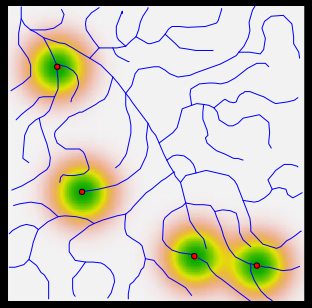


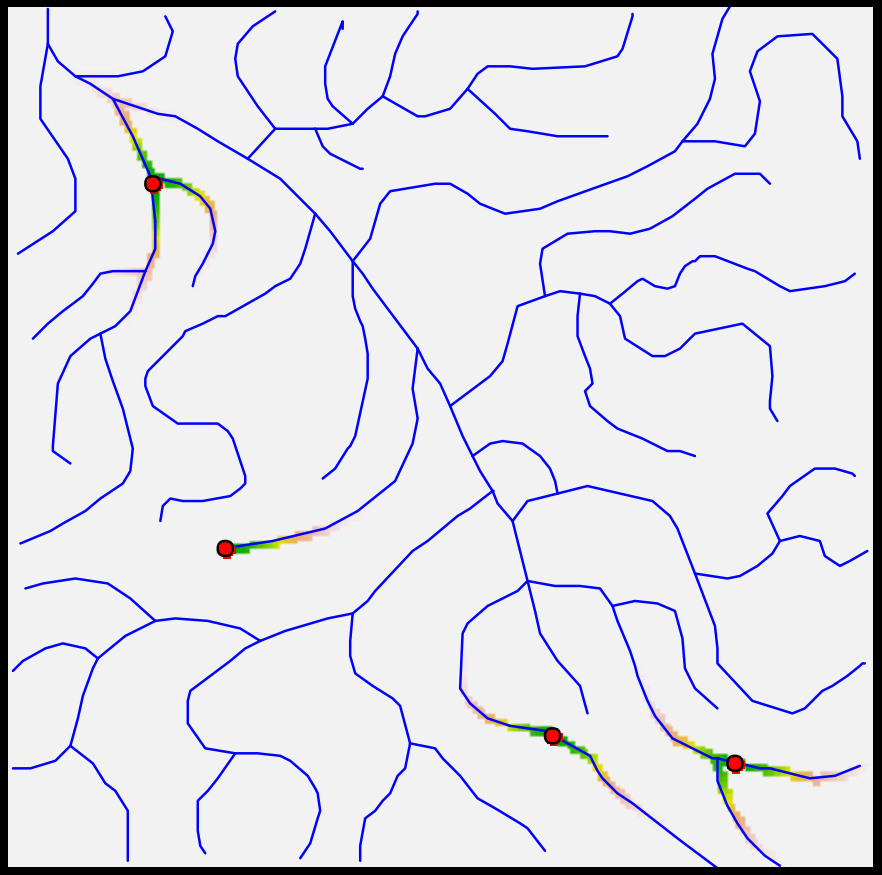
Distance as the *what?* moves…

Three ways to measure distance:

- River/stream distance - distance as the 'fish swims'

Distance as the 'crow flies'



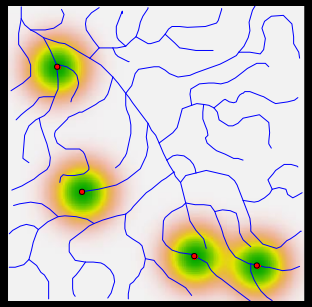


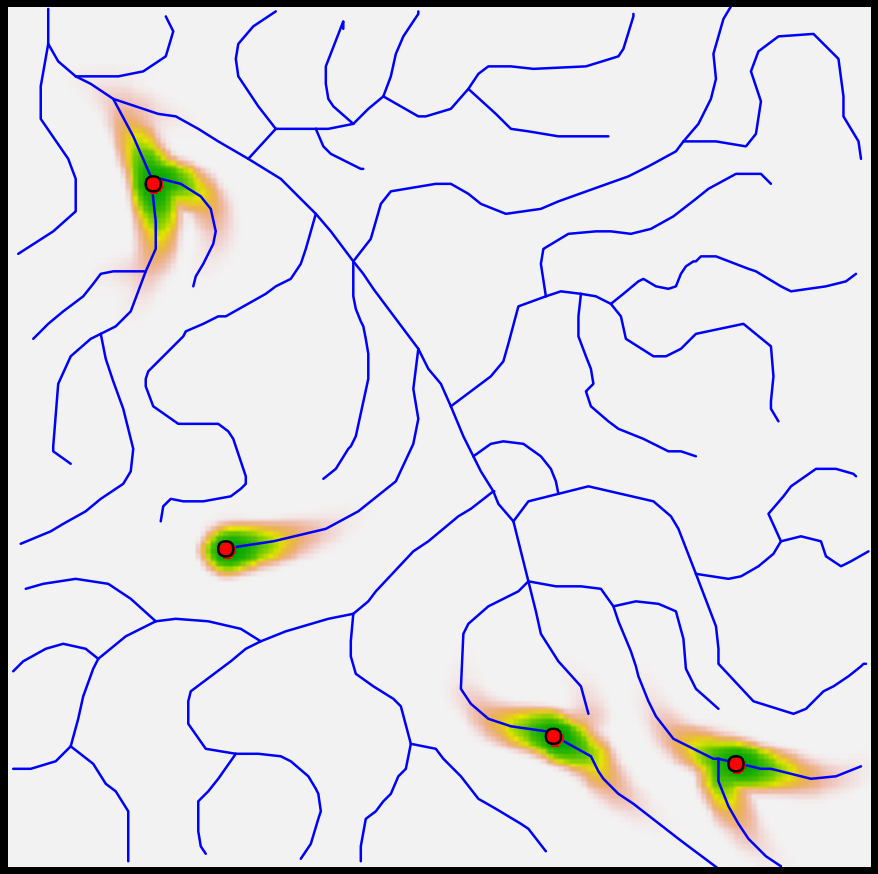
Distance as the *what?* moves…

Three ways to measure distance:

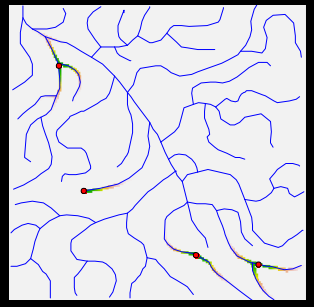
- ‘Cost weighted’ distance - distance as the ‘mink moves’

Distance as the ‘crow flies’



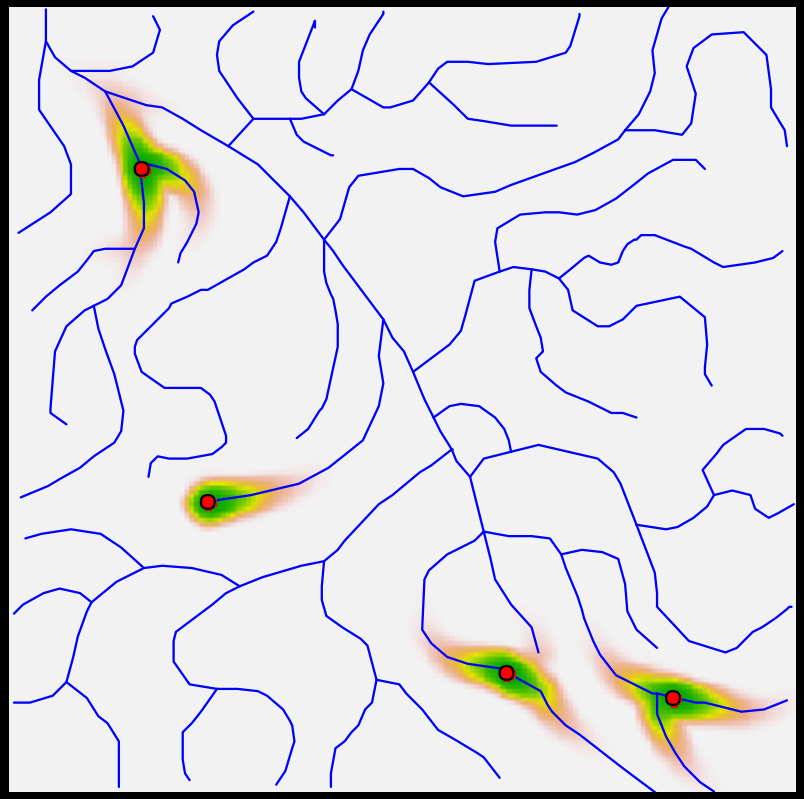


Distance as the ‘fish swims’



Distance as the *MINK* moves…

Cost weighted '*mink moves*' distance:



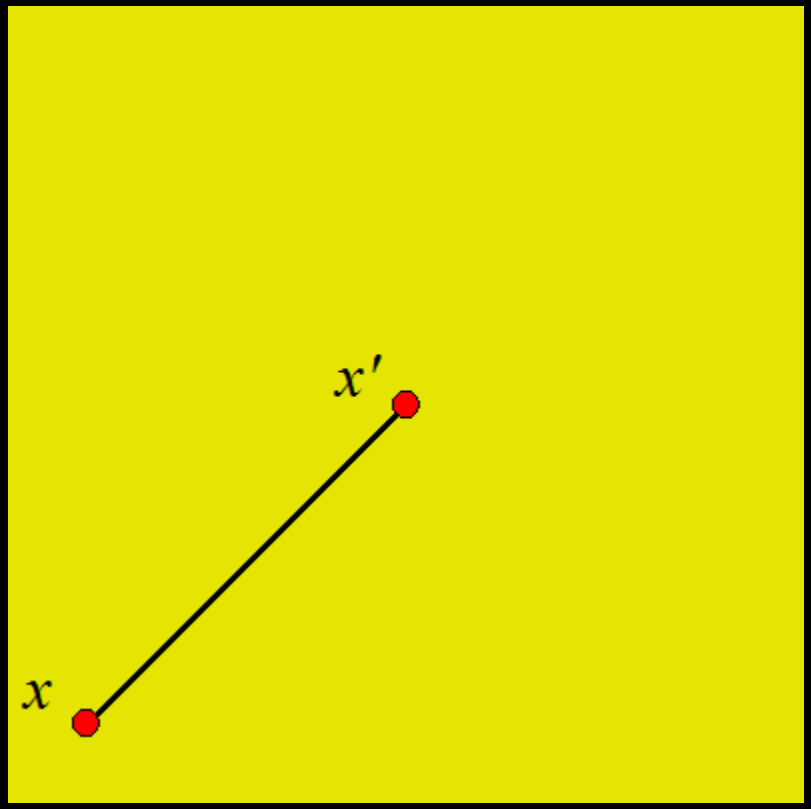
- Spatially varying landscape resistance (*distance to water*)
- Usually arbitrarily defined
- Use observations of movements to *estimate* resistance, ***r*** [*within SCR framework!*]

Estimating landscape resistance using SCR

Gaussian encounter model:

$$y_{x,x'} \sim Binomial(K, p_{x,x'})$$

$$p_{x,x'} = \alpha_0 \exp(-\alpha_1 \, d[x, x']^2)$$



Royle *et al.*, 2013

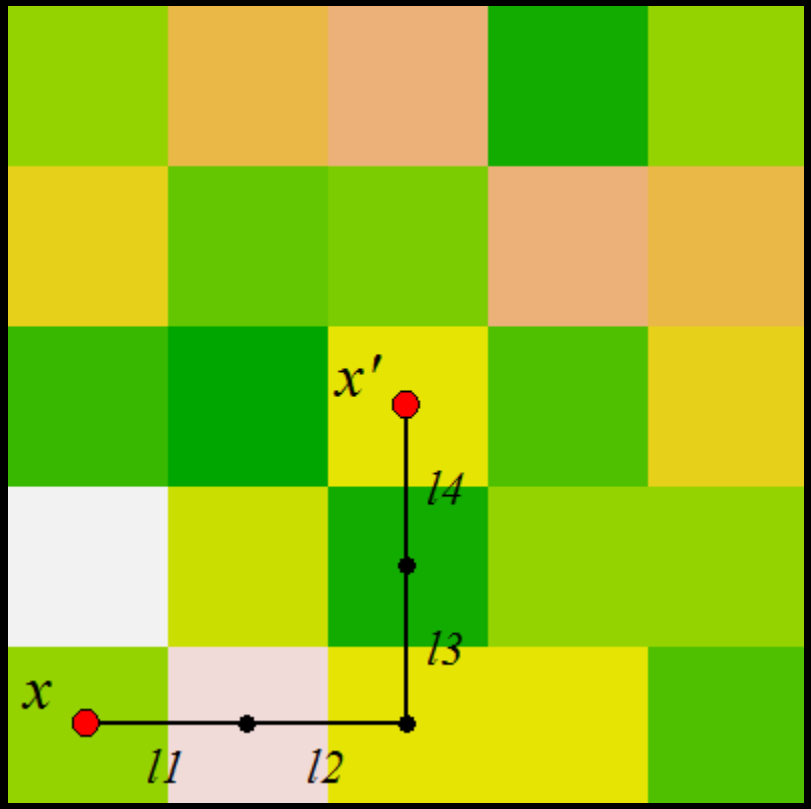
Estimating landscape resistance using SCR

Gaussian encounter model:

$$y_{x,x'} \sim Binomial(K, p_{x,x'})$$

$$p_{x,x'} = \alpha_0 \exp(-\alpha_1 \, d_{lcp}[x, x']^2)$$

$$d(x, x') = \sum_{i=1}^{m-1} \text{cost}(\mathbf{l}_i, \mathbf{l}_{i+1}) \|\mathbf{l}_i - \mathbf{l}_{i+1}\|$$



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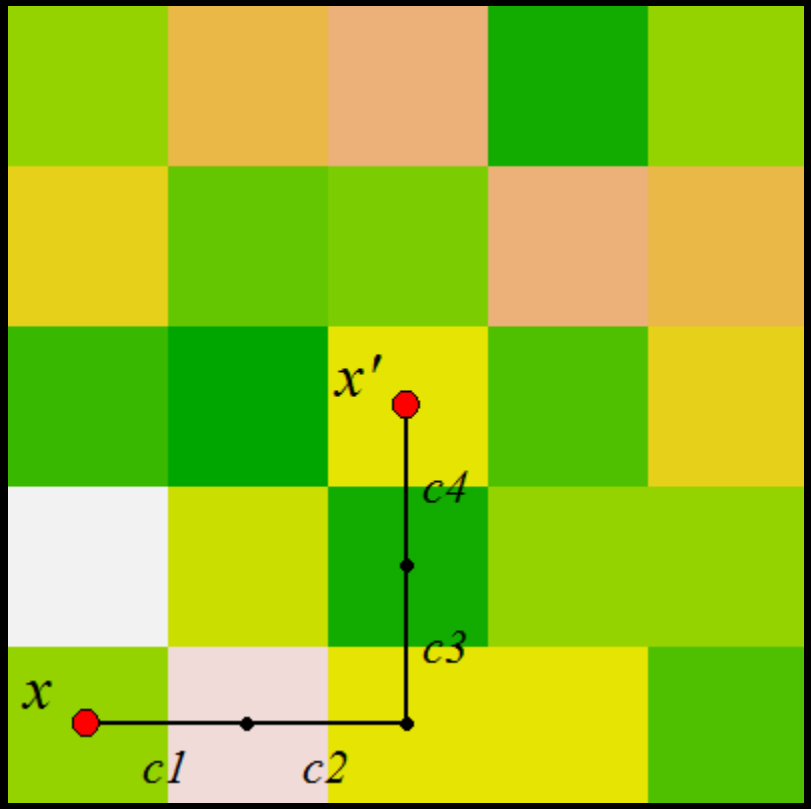
$$\text{cost}(l_i, l_{i+1}) = f[\boldsymbol{r}, z(l_i) - z(\mathbf{l}_{i+1})]$$



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$$\mathrm{d}_{lcp}(x, x') = min\left[\sum_{i=1}^{m-1} \mathrm{cost}\,(\mathbf{l}_i, \mathbf{l}_{i+1}) \|\mathbf{l}_i - \mathbf{l}_{i+1}\|\right]$$

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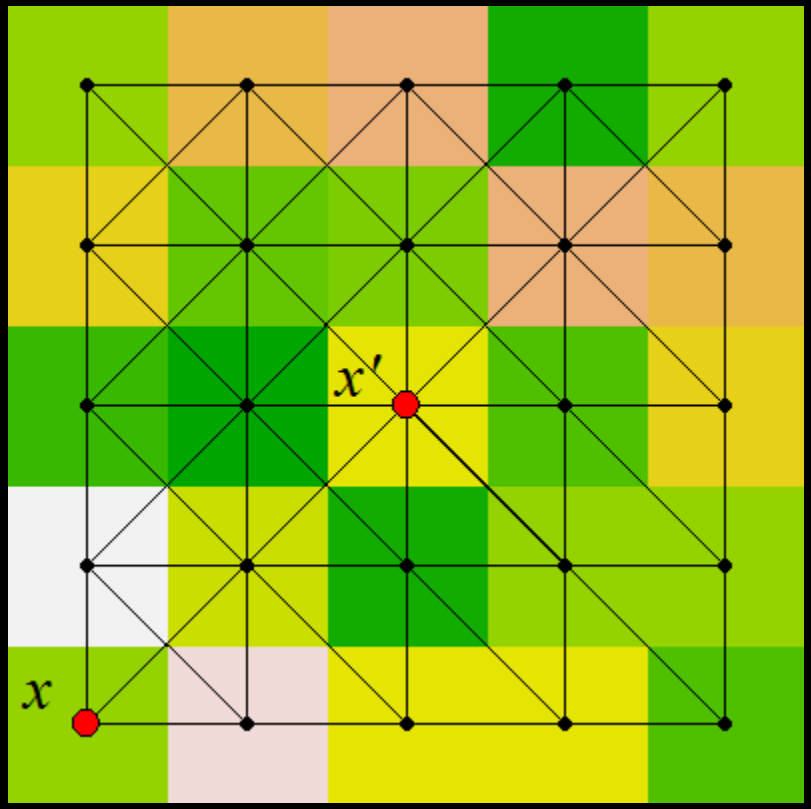


Royle *et al.*, 2013

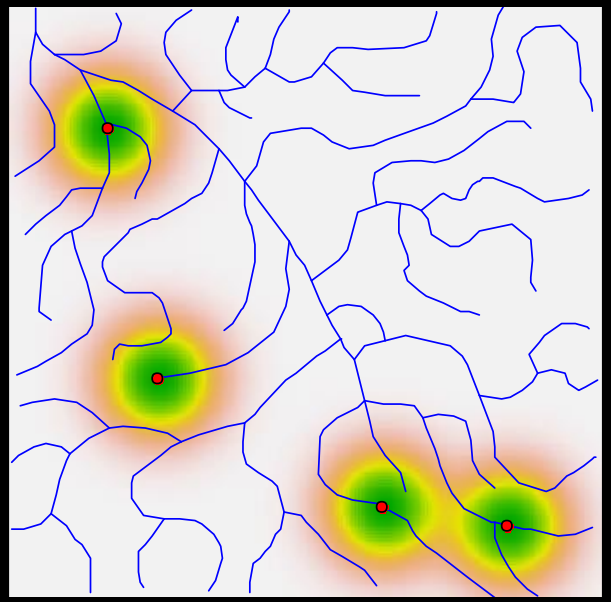
The cost function - learning about the space-use

$$\log[\text{cost}(x, x')] = r\frac{z(x) + z(x')}{2}$$

r provides information about space use patterns and behavior

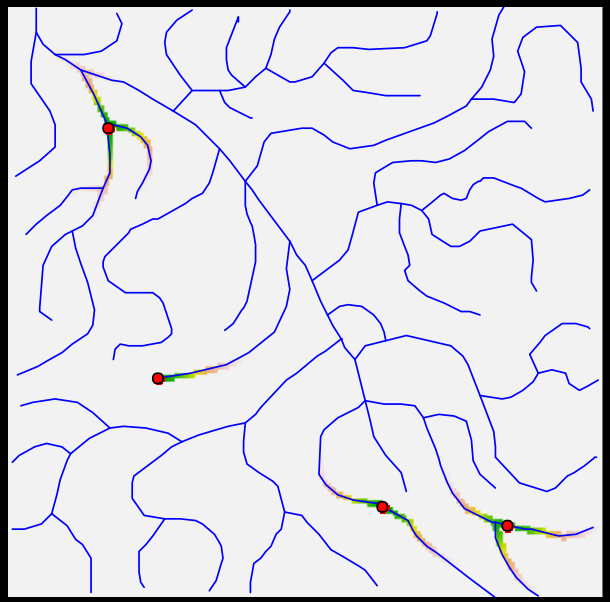
Euclidean distance
('crow flies')

$r = 0$



Stream distance
('fish swims')

$r \to \infty$



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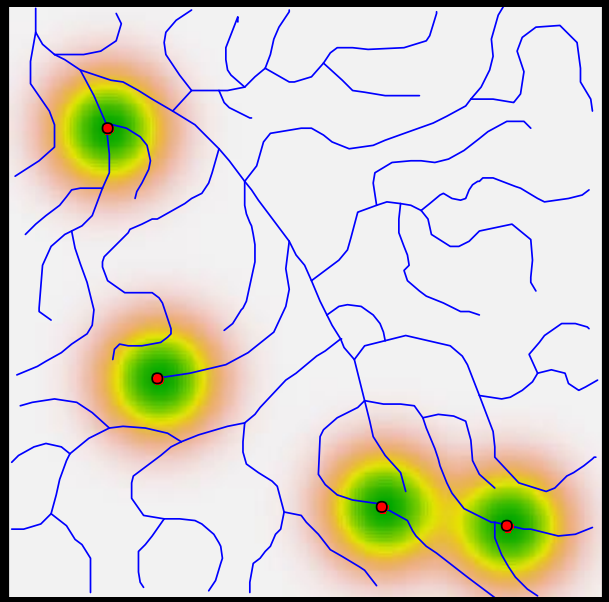
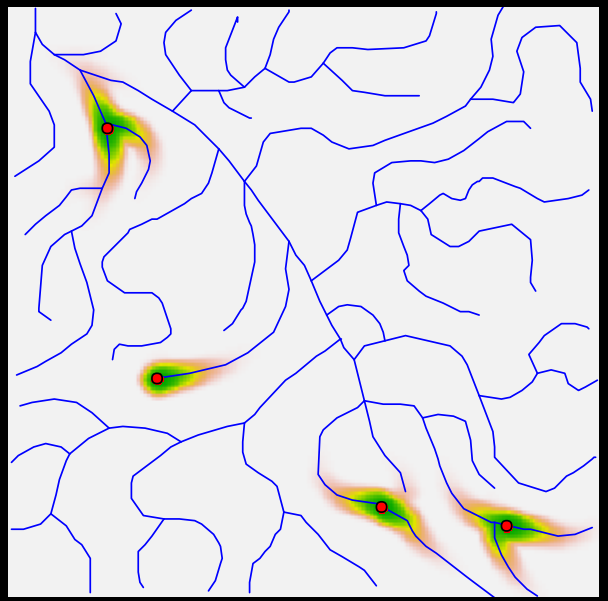
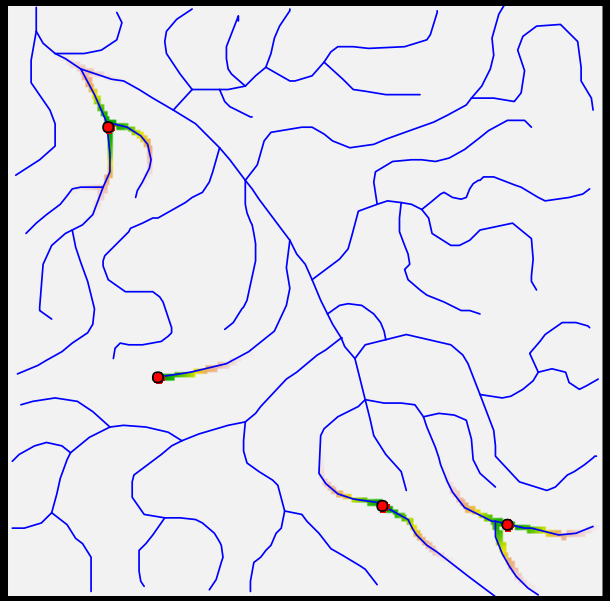
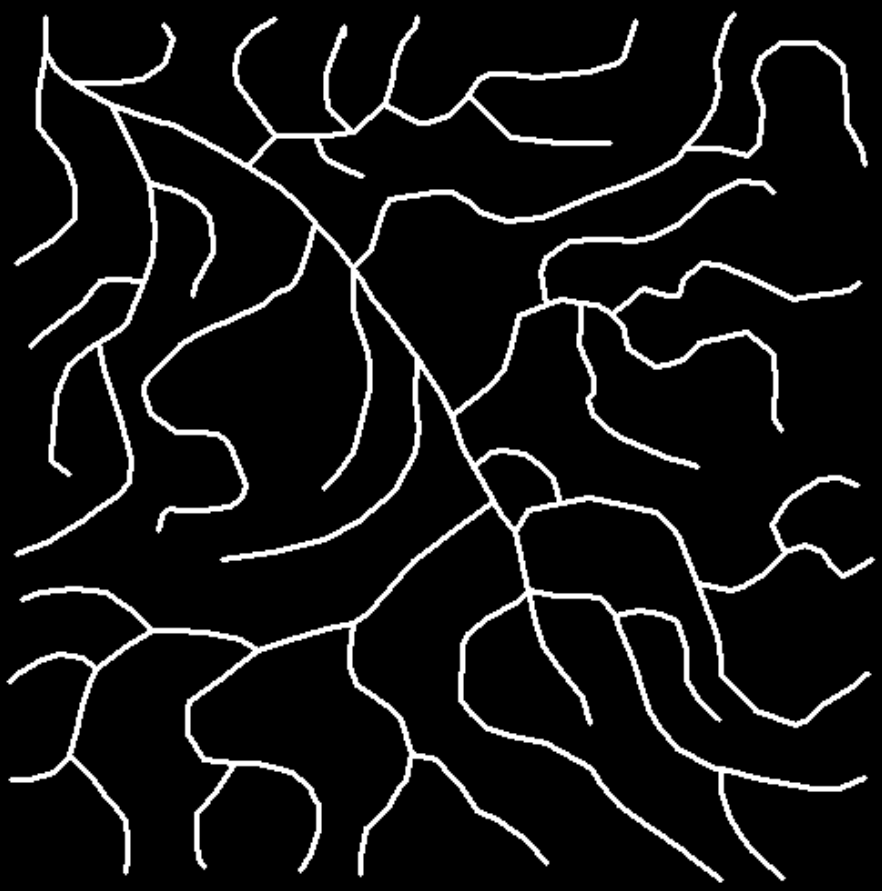
Euclidean distance ('crow flies')	Ecological distance ('mink moves')	Stream distance ('fish swims')
$r = 0$	$0 < r < \infty$	$r \to \infty$

Testing the theory:
Mink-*like* simulation study

Mink-*like* simulation study - Data

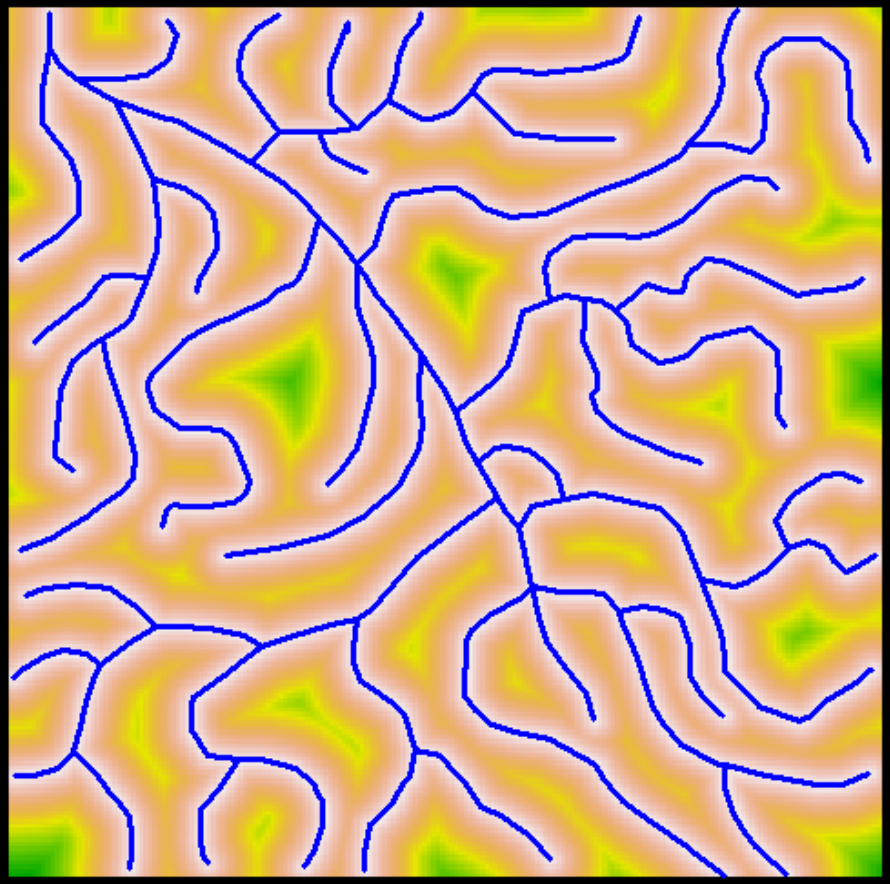
- water layer



Mink-*like* simulation study - Data

- water layer
- distance to water covariate

  (200m x 200m grid cells)



Mink-*like* simulation study - Data

- water layer
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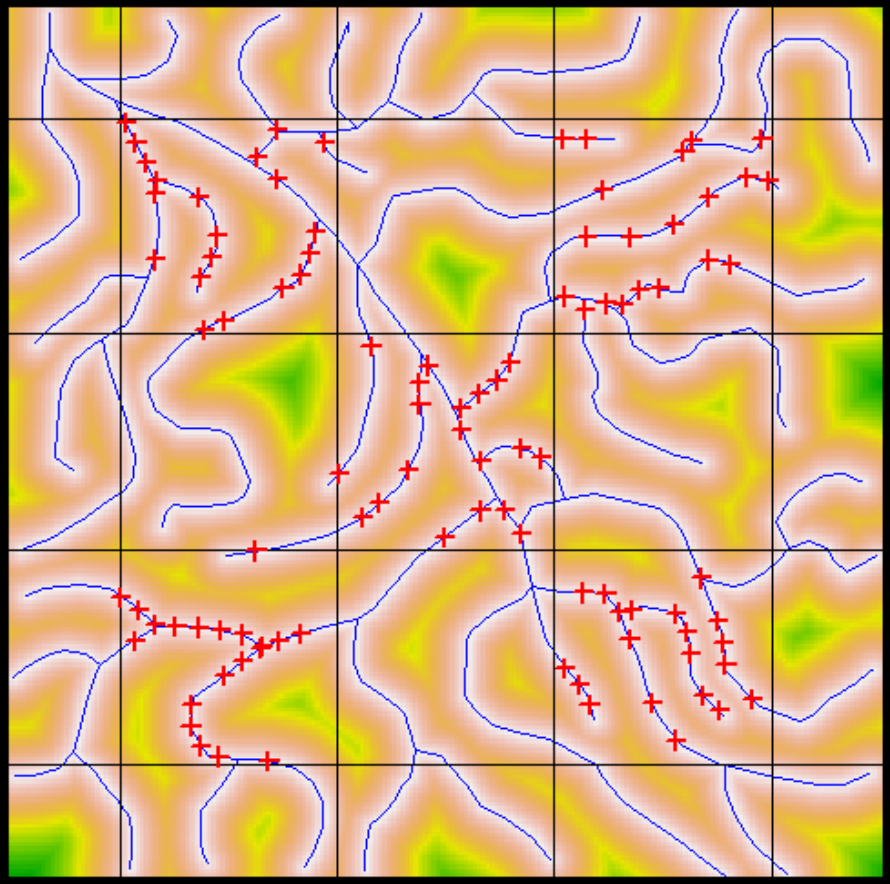
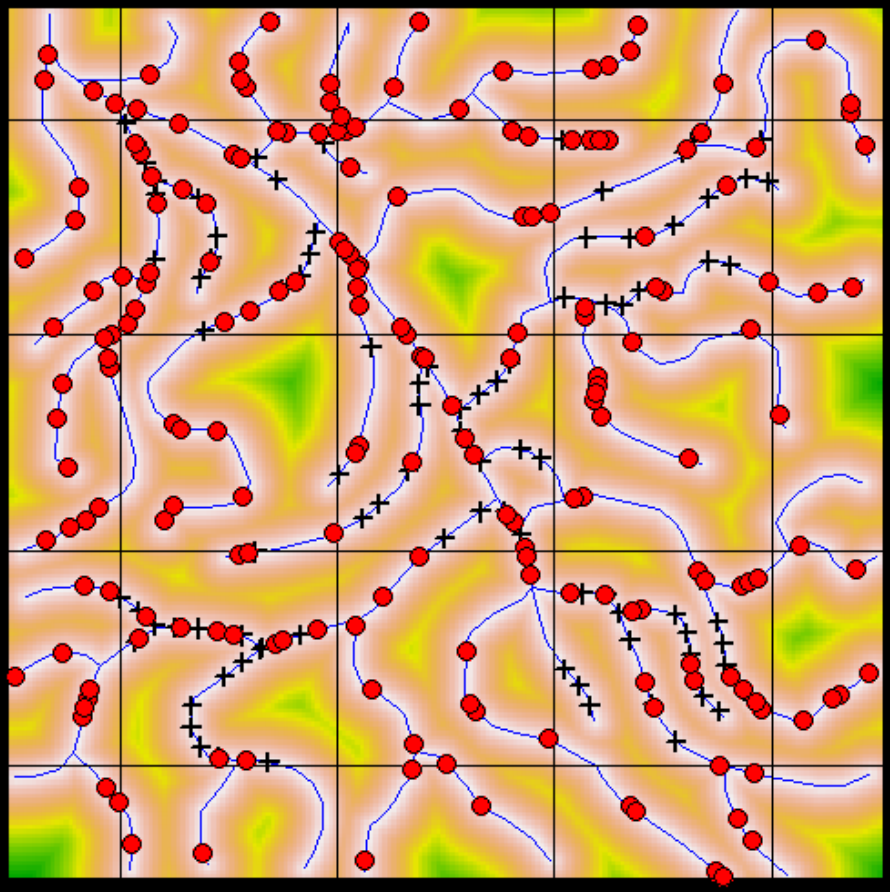
- 100 traps (5 clusters of 20)



Mink-*like* simulation study - Data

- water layer
- distance to water covariate (200m x 200m grid cells)
- 100 traps (5 clusters of 20)
- $N = 200$ mink located along the water way



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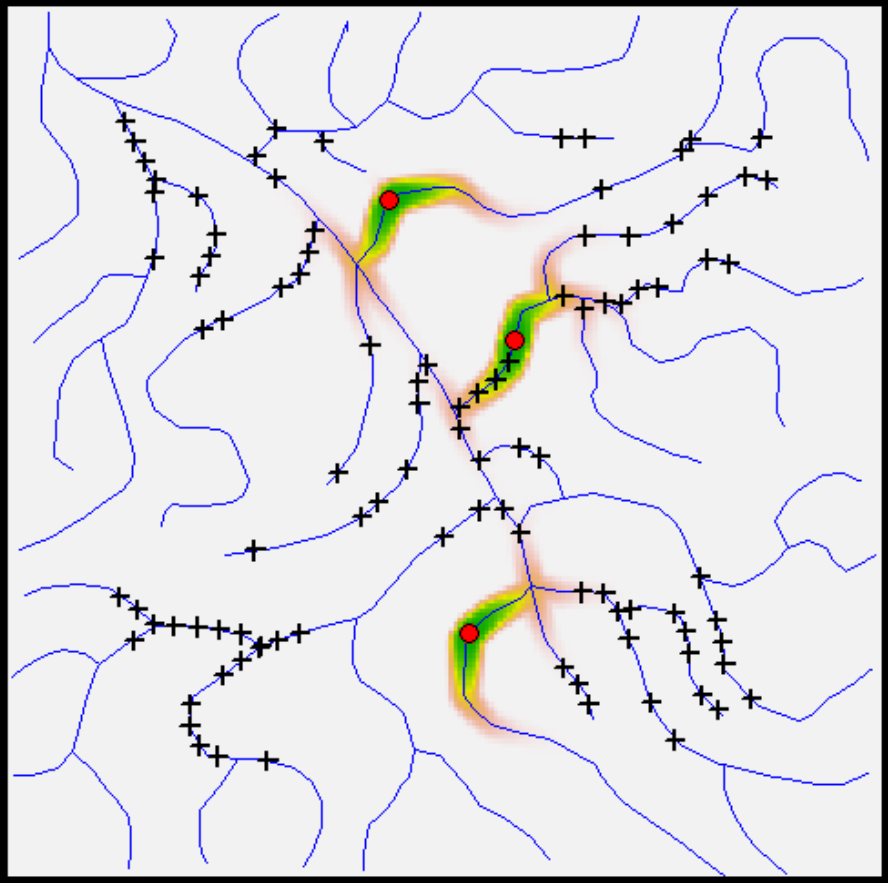
- generate spatial encounter histories using:

$$\alpha_0 = 0.38;\ \sigma = 0.05; r = 2.5$$



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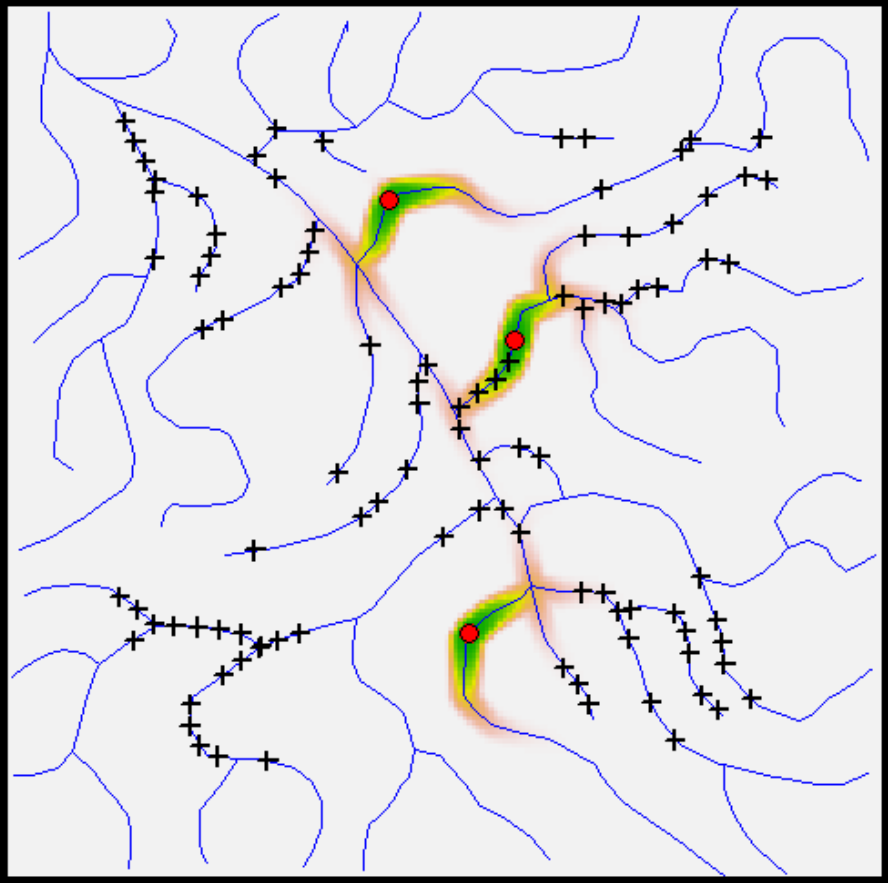
- Fit the model (repeat 253 times)



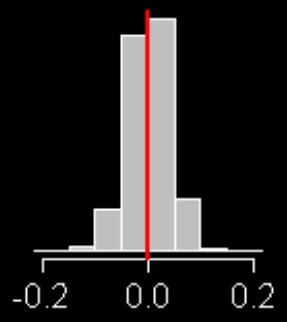
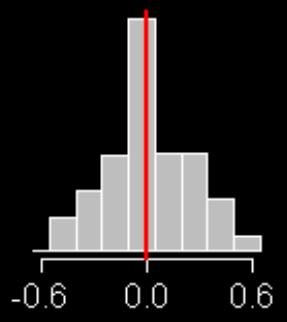
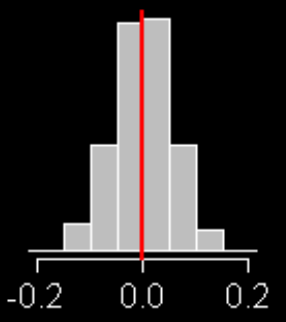
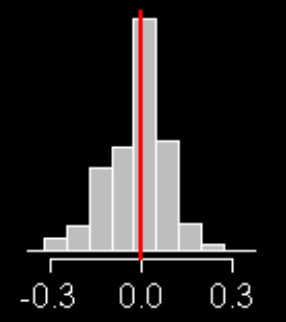
Mink-*like* simulation study - Results

1. Retrieving known parameter values using the *'mink moves'* ecological distance model:

   Statistical properties of $\hat{\theta} = [\alpha_0, \sigma, \bar{N}, r]$

Mink-*like* simulation study - Results

Estimating parameters of known values $\theta = [\alpha_0, \sigma, \overline{N}, r]$

	α_0	σ	$\overline{N}$	r
Known	*-0.50*	*0.050*	*200.00*	*2.50*
Mean	*-0.50*	*0.049*	*200.32*	*2.55*
RMSE	*0.06*	*0.012*	*10.77*	*0.24*
% Bias	*0.1*	*-2*	*0.2*	*1.9*
				

$$(\hat{\theta} - \theta)/\theta$$

Mink-*like* simulation study - Results

1. Retrieving known parameter values using the *'mink moves'* ecological distance model:

✓ $\hat{\theta} = [\alpha_0, \sigma, \bar{N}, r]$ recovered with little bias

2. Compare the 'performance' of two competing models:

$M_{ecological}$ – *'mink moves'* model estimating landscape resistance

vs.

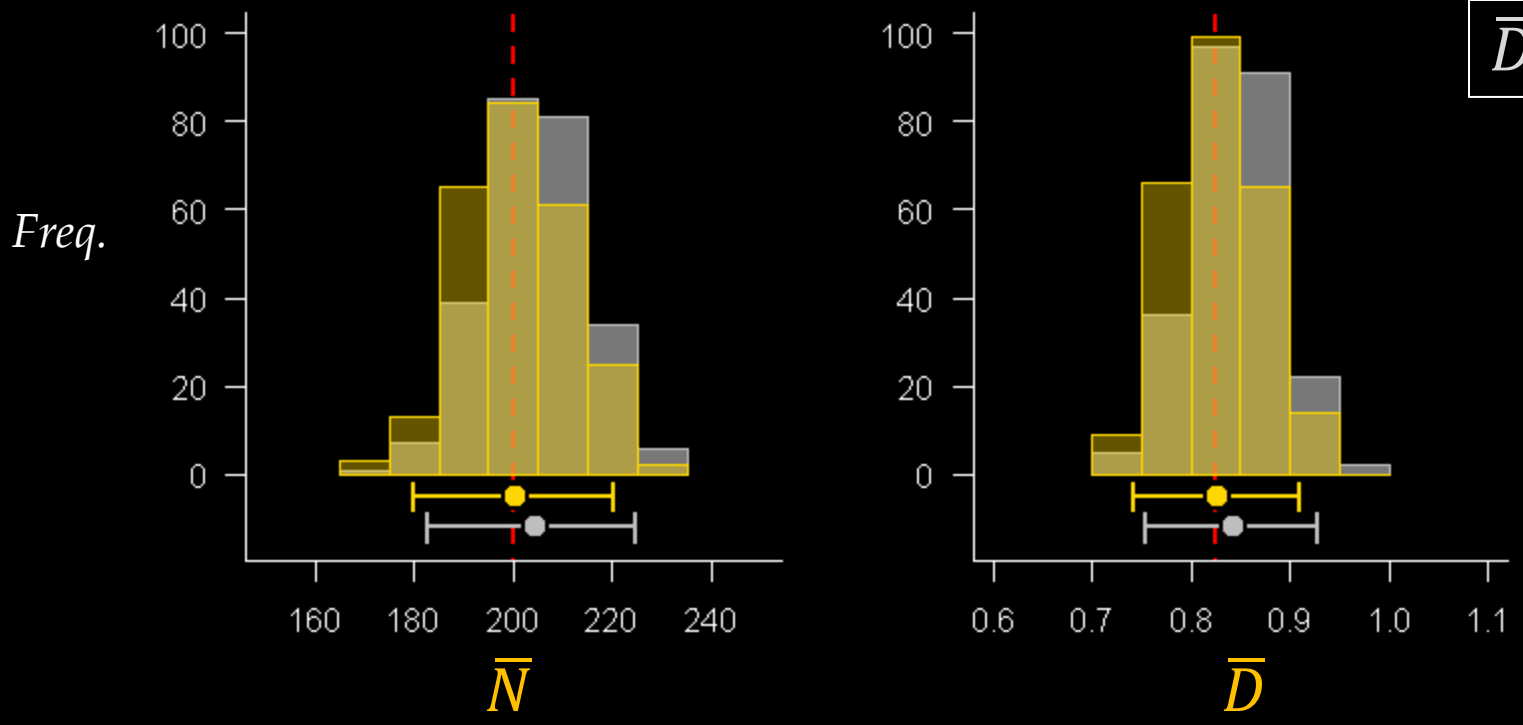
$M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

Mink-*like* simulation study - Results

Comparing estimates of $\overline{N}$ (and $\overline{D}$) using Euclidean *vs.* ecological distance:

% bias in *N (D)*	
Euclidean	2.2
Ecological	0.2

$$\overline{D} = \overline{N}/A$$

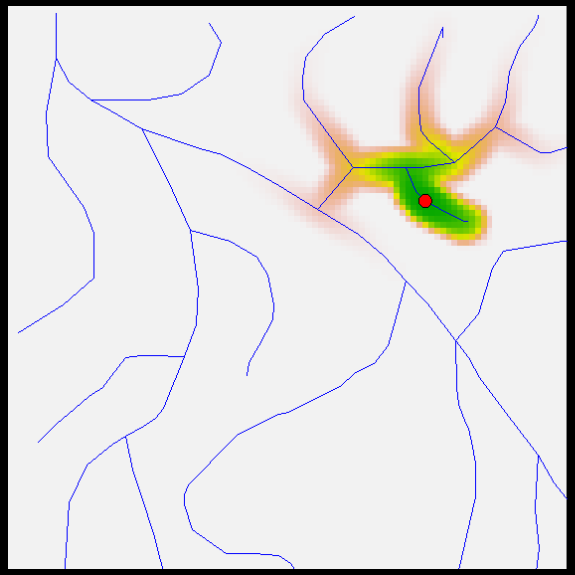


Mink-*like* simulation study - Results

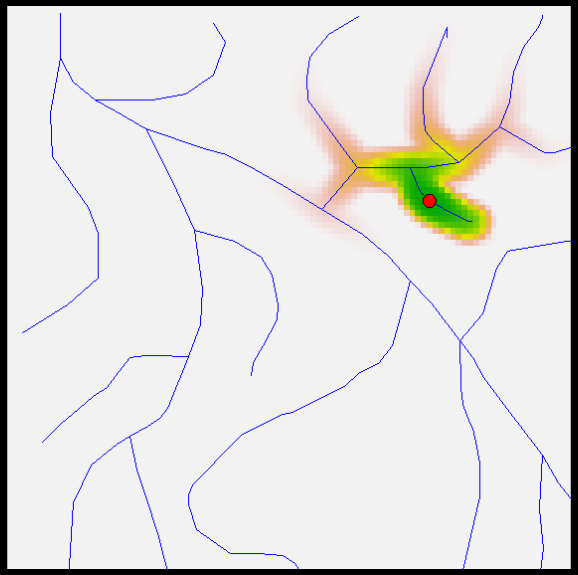
Comparing space-use patterns (home range *shapes*) assuming

Euclidean *vs.* ecological distance:

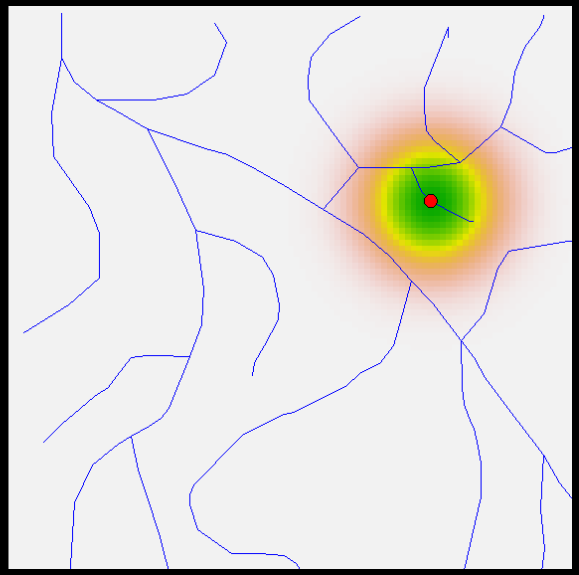
Simulated space-use data ('truth')



Estimated using 'ecological distance'



Estimated using 'Euclidean distance'



Mink-*like* simulation study - Models

1. Retrieving known parameter values using the *'mink moves'* ecological distance model:

✓ Unbiased estimators of $\hat{\theta} = [\alpha_0, \sigma, \bar{N}, r]$

2. Compare the 'performance' of two competing models:

✓ $M_{ecological}$ – *'mink moves'* model estimating landscape resistance

vs.

$M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

Testing the theory:

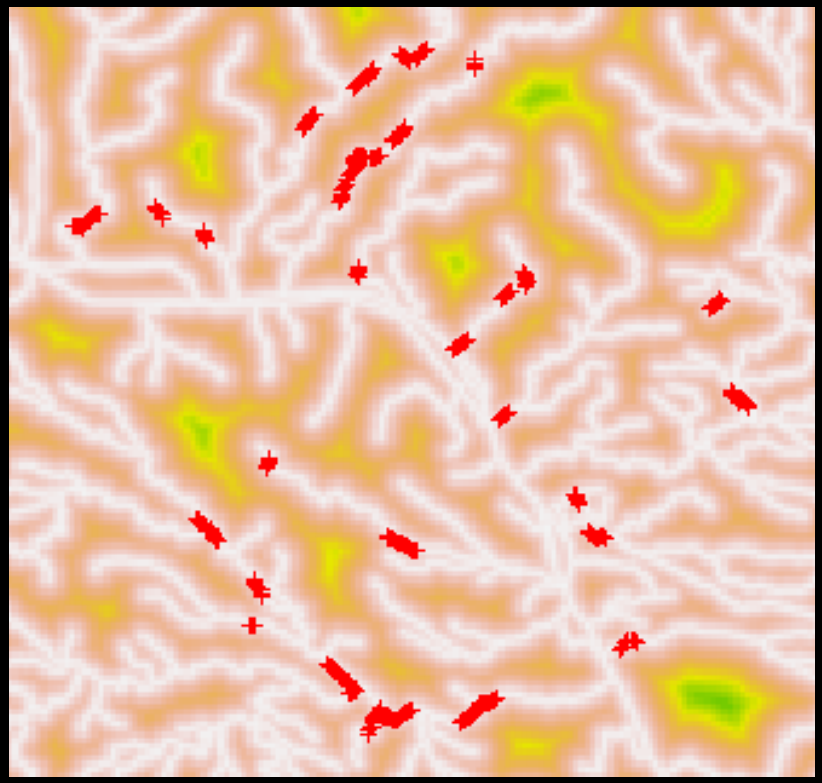
~~Mink-*like* simulation study~~

Application to a population of American mink

Mink study - Data

- Study area = 293.04 km^2 (515km of stream)
- Scat detection dogs
- Genetic identification of individuals
- 25 transects = 255 'effective traps'
- 37 unique individuals

Frequency	1	2	3	4	5	6	7
# individuals (in *n* traps)	24	8	3	1	-	-	1



Mink study - Results

1. Compare the two competing models:

   $M_{ecological}$ – *'mink moves'* model estimating landscape resistance

   vs.

   $M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

Mink study - Results

1. Compare the two competing models:

$M_{ecological}$ – *'mink moves'* model estimating landscape resistance

vs.

$M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

Model fit (AIC)

	N_{params}	AIC	Δ AIC	*Density (se)*
$M_{ecological}$	4	366.59	-	1.06 (0.50)
$M_{euclidean}$	3	372.70	6.11	1.08 (0.54)

Mink study - Results

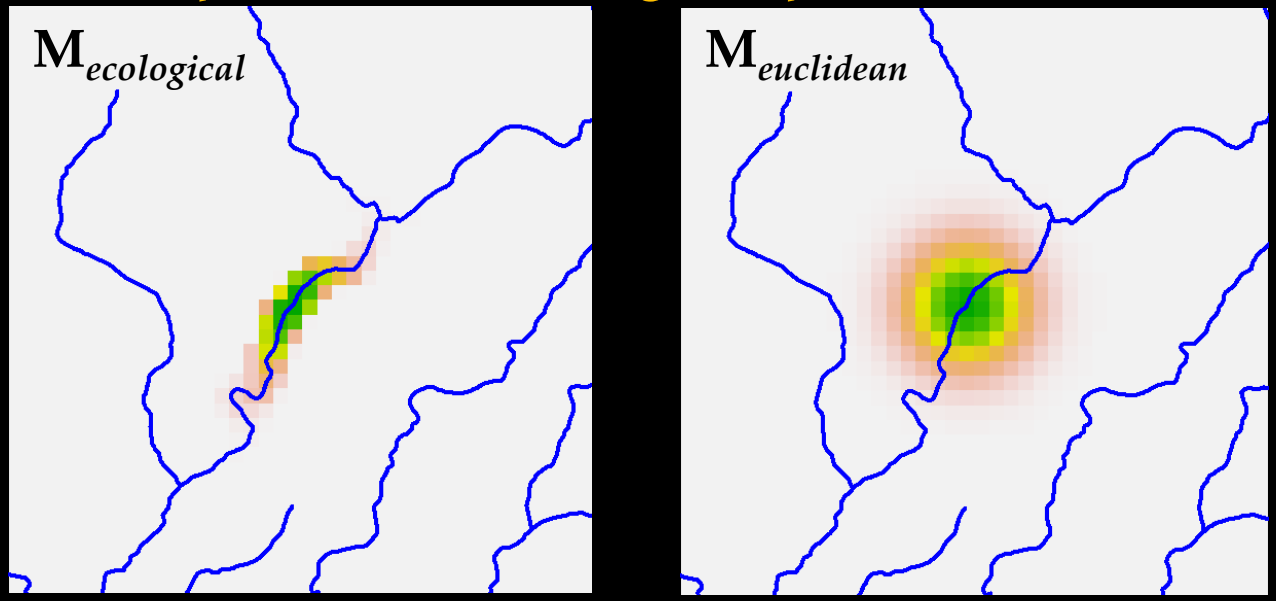
1. Compare the two competing models:

$M_{ecological}$ – *'mink moves'* model estimating landscape resistance

vs.

$M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

Space-use/home range shape: r = 20.35



Mink study - Results

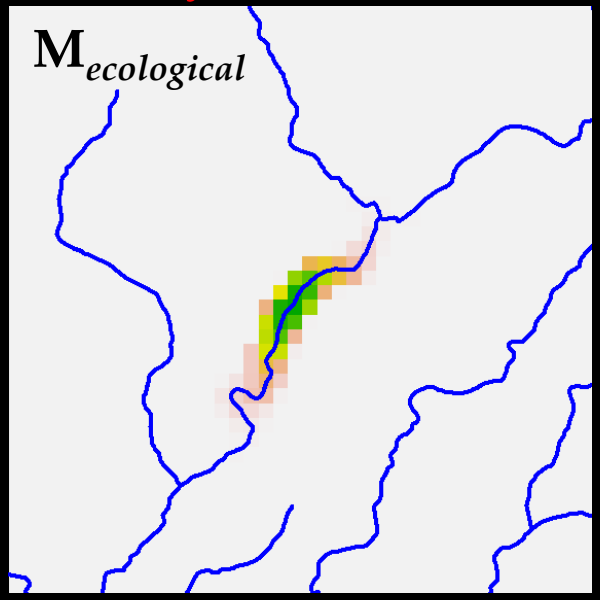
1. Compare the two competing models:

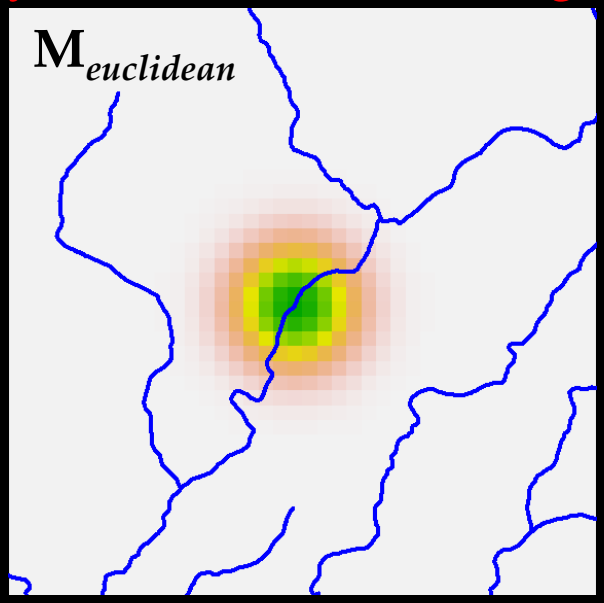
$M_{ecological}$ – *'mink moves'* model estimating landscape resistance

vs.

$M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

7 x more 'costly' to move 100m away from water than along water





Mink study - Results

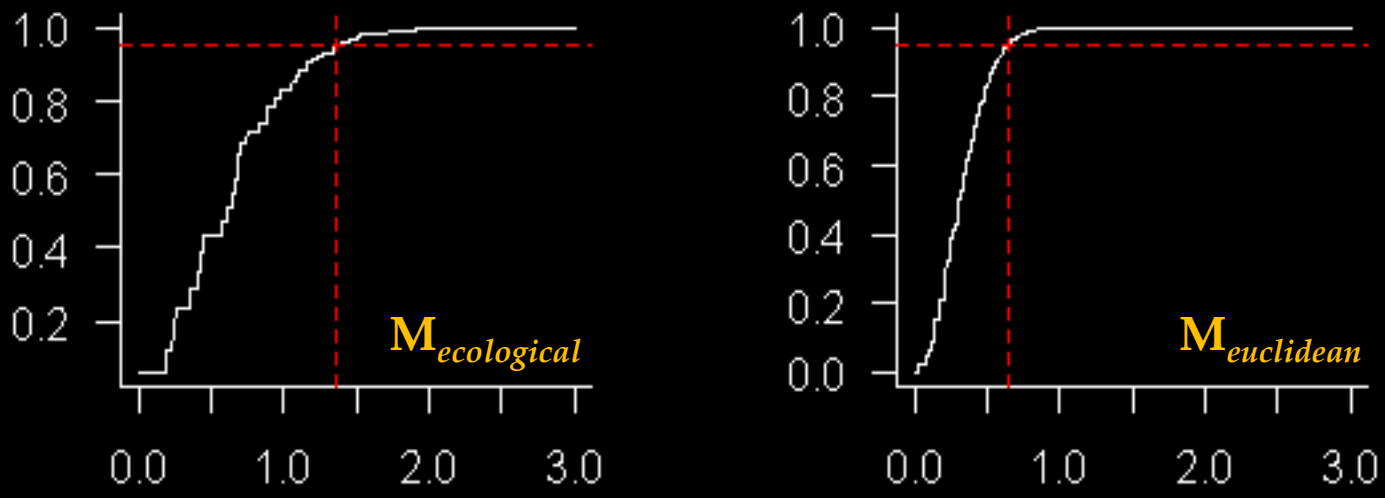
1. Compare the Compare the two competing models:

   $M_{ecological}$ – *'mink moves'* model estimating landscape resistance

   vs.

   $M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

95% Home range size



Mink study - Results

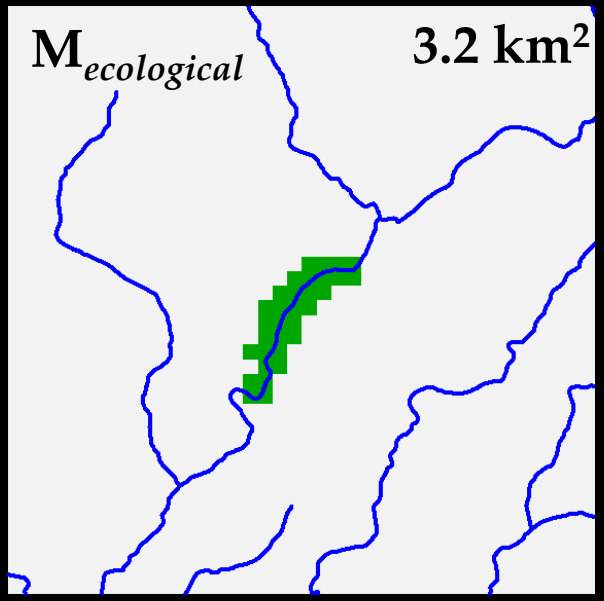
1. Compare the 'performance' of two competing models:

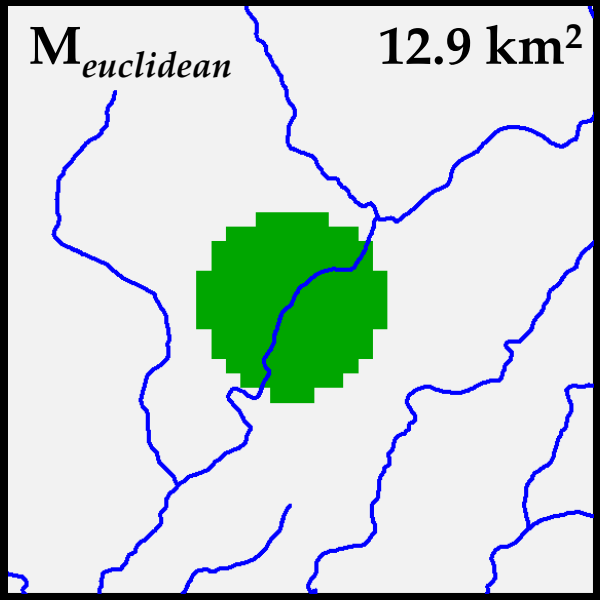
$M_{ecological}$ – *'mink moves'* model estimating landscape resistance

vs.

$M_{euclidean}$ – *'crow flies'* model assuming stationary home ranges

95% Home range size





Alternative distance measures and SCR…

Advantages of measuring *ecological distance*:

- relax the Euclidean assumptions of SCR methods
- no bias in estimators of abundance/density BUT
  - estimation of landscape resistance parameter
  - shape/size of irregular home-ranges/space-use

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