



# Individual-based modelling in RangeShiftR

Damaris Zurell, Anne Malchow

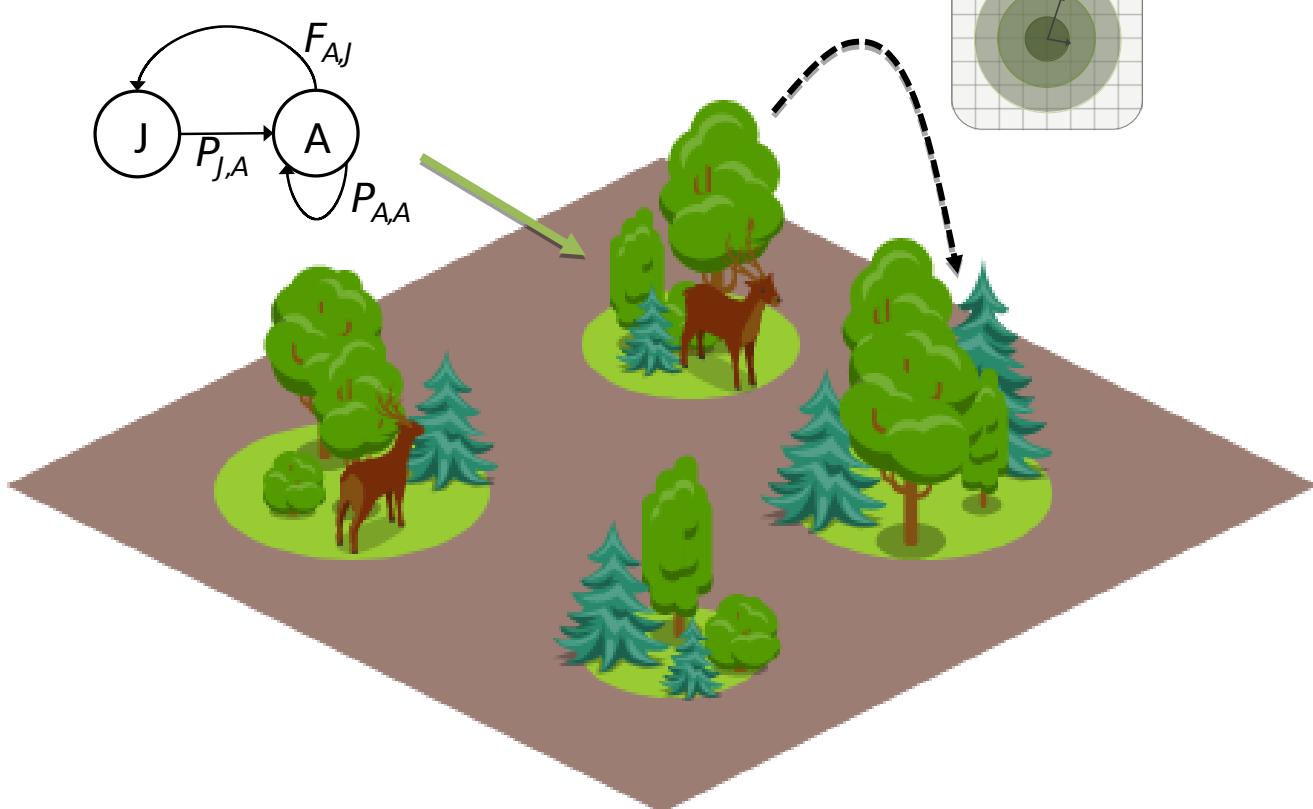
<https://damariszurell.github.io>



# Spatially explicit population models

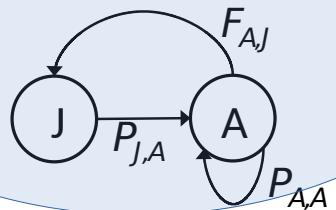
**Local population dynamics**  
described by population  
model, e.g. logistic growth or  
matrix population model

**Dispersal** described by  
dispersal kernel or  
movement simulator

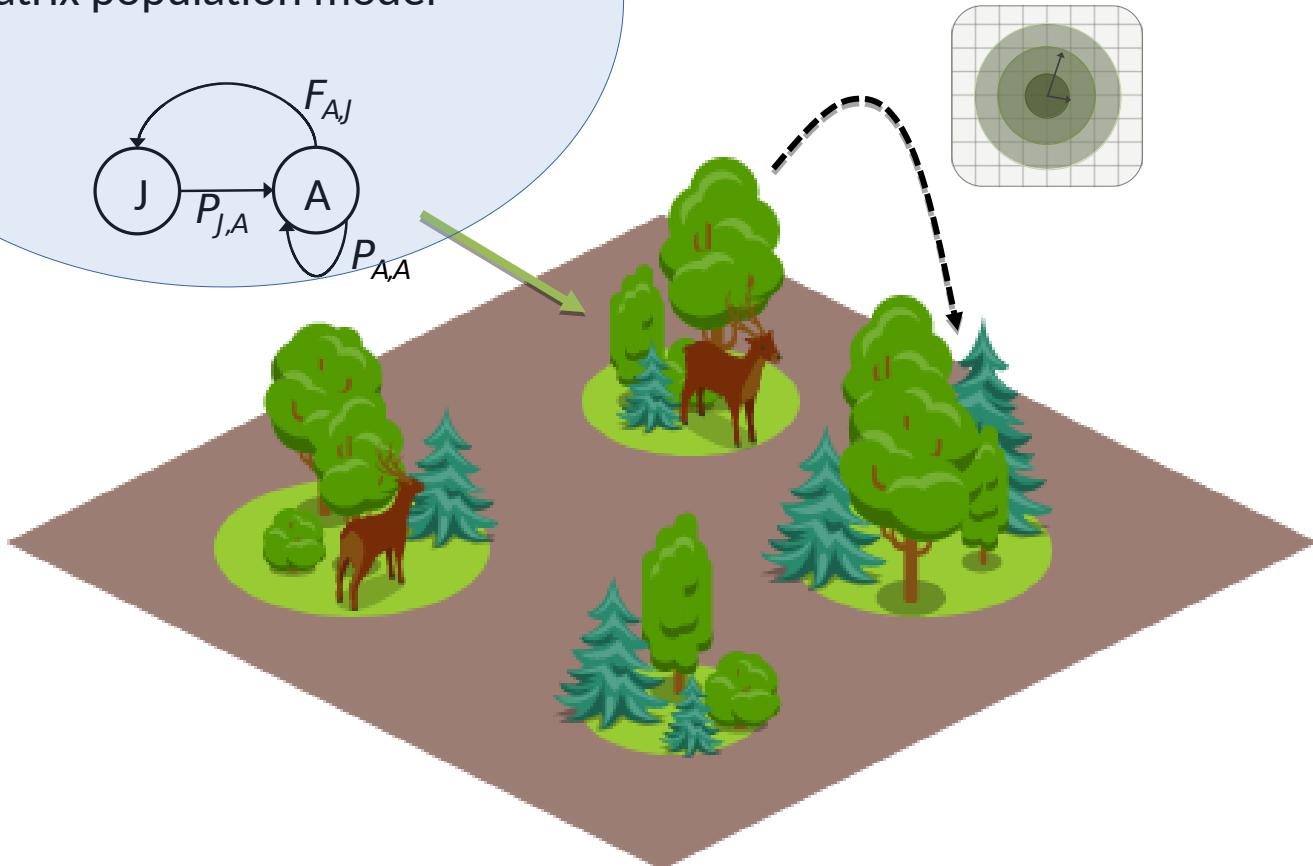


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# RangeShiftR – local population dynamics

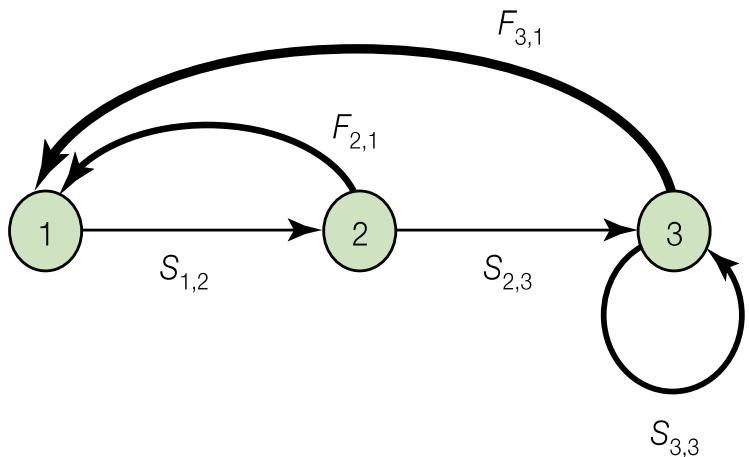
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- Stage-structured population:
  - Life cycle can be described by subsequent developmental stages
  - Rates are defined w.r.t. to a fixed-length time step (usually 1 year)

# RangeShiftR – local population dynamics

- Stage-structured population:
  - Life cycle can be described by subsequent developmental stages
  - Rates are defined w.r.t. to a fixed-length time step (usually 1 year)
- Example:

Life-cycle graph



Stages:

- ① Juveniles - do not reproduce
- ② Sub-adults - inexperienced breeders
- ③ Mature adults - experience breeders

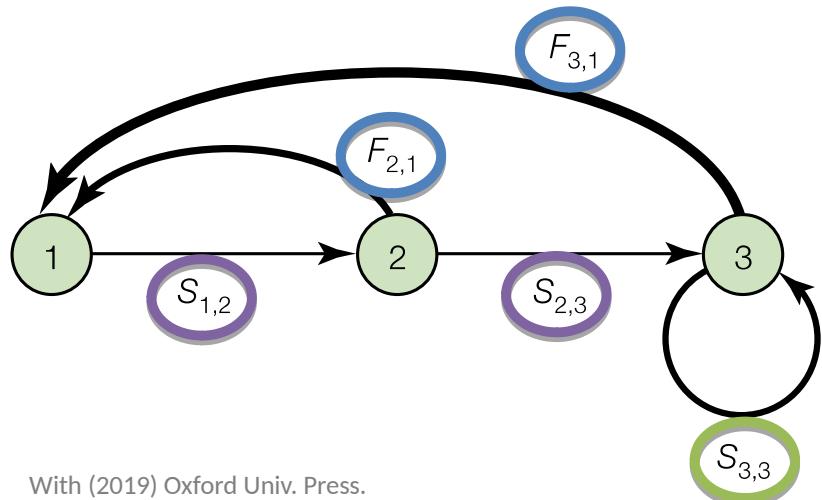
Transition rates:

- |           |  |
|-----------|--|
| $F_{i,1}$ | Fecundity                                      |
| $S_{i,j}$ | Development rate<br>(transition to next stage) |
| $S_{i,i}$ | Survival probability                           |

# RangeShiftR – local population dynamics

- Parameters provided through classical transition matrices (but applied stochastically)
  - Transition matrices can be age-structured (Leslie matrix) or stage-structured (Lefkovitch matrix)

Life-cycle graph:



(Lefkovitch) Transition matrix:

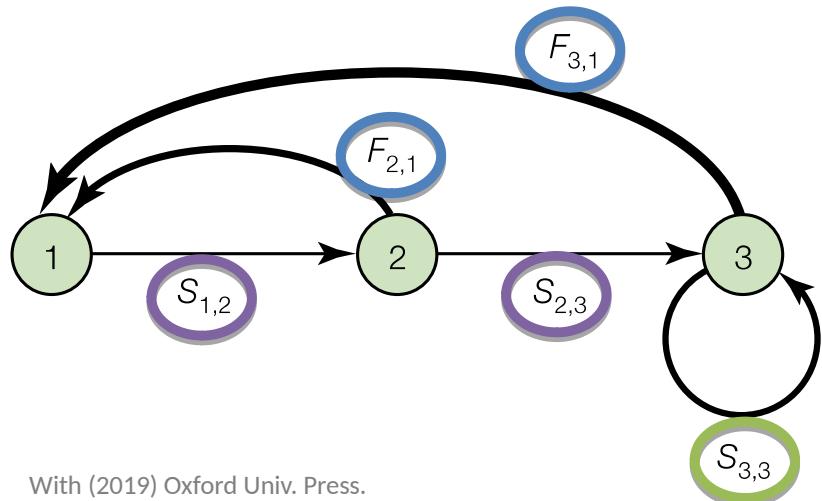
$$A = \begin{pmatrix} S_{1,1} & F_{2,1} & F_{3,1} \\ S_{1,2} & S_{2,2} & 0 \\ 0 & S_{2,3} & S_{3,3} \end{pmatrix}$$

The equation shows the Lefkovitch transition matrix A as a 3x3 matrix. The columns are labeled "Development" (purple) and the rows are labeled "Survival" (green). The matrix elements are:  $S_{1,1}$ ,  $F_{2,1}$ ,  $F_{3,1}$  in the first column;  $S_{1,2}$ ,  $S_{2,2}$ , 0 in the second column; and 0,  $S_{2,3}$ ,  $S_{3,3}$  in the third column. The label "Fecundity" is positioned above the first two columns.

# RangeShiftR – local population dynamics

- Parameters provided through classical transition matrices (but applied stochastically)
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Life-cycle graph:



With (2019) Oxford Univ. Press.

Lynx transition matrix:

$$A_{\text{Lynx}} = \begin{pmatrix} & \text{Fecundity} & \\ & 0 & 0 & 5.0 \\ & 0.53 & 0 & 0 \\ & 0 & 0.63 & 0.8 \\ & \text{Development} & & \text{Survival} \end{pmatrix}$$

# RangeShiftR – local population dynamics

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- In RangeShifter, the processes of reproduction and survival / development happen subsequently

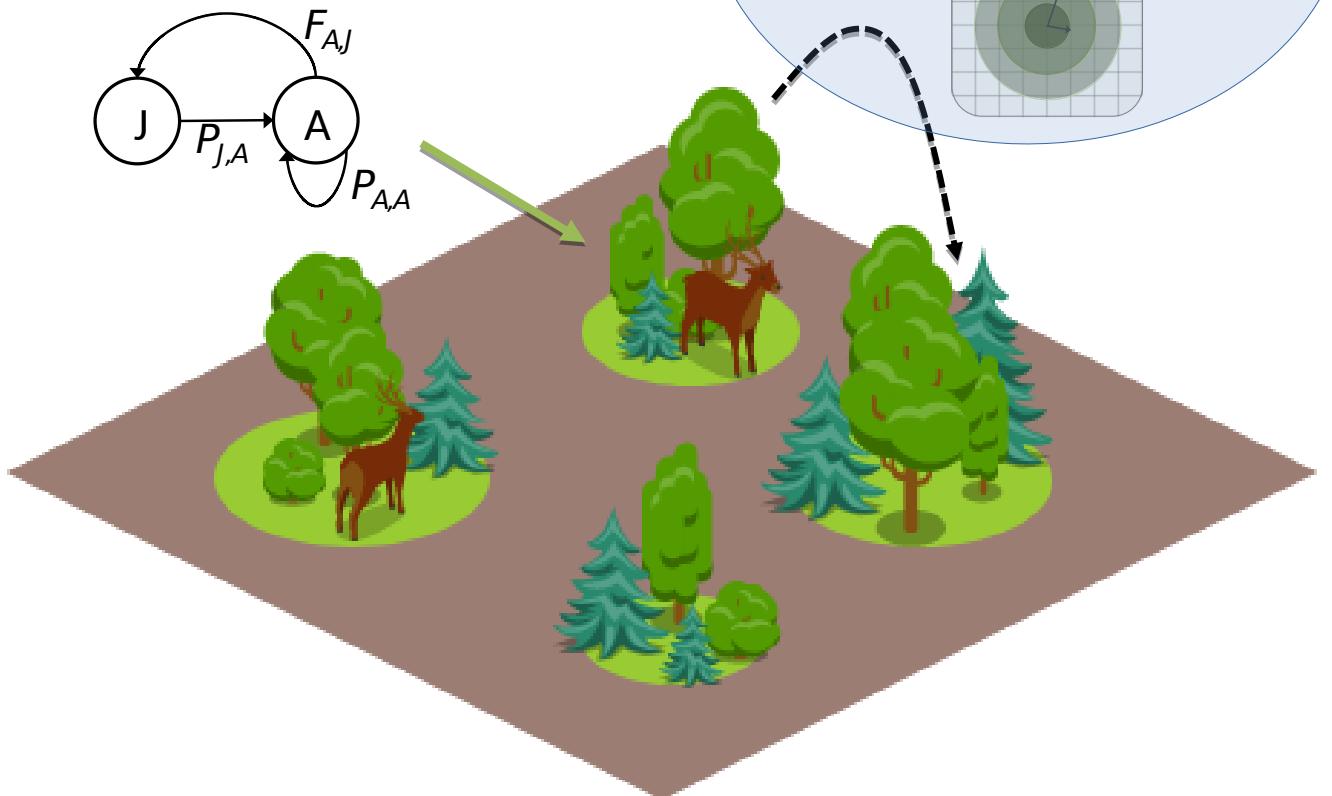
# RangeShiftR – local population dynamics

- In RangeShifter, the processes of reproduction and survival / development happen subsequently
  - introduce “**stage 0**”  
(for individuals that develop to stage 1 in the same year they are born)

$$A_{\text{Lynx, RS}} = \begin{pmatrix} 0 & 0 & 0 & 5.0 \\ 1 & 0 & 0 & 0 \\ 0 & 0.53 & 0 & 0 \\ 0 & 0 & 0.63 & 0.8 \end{pmatrix}$$

# Spatially explicit population models

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# Dispersal

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- Natal/juvenile dispersal: spatial process by which individuals move away from birth location
  - avoid kin competition, exploit new resources
- Critical for range expansion and spatial gene flow
- Associated with various costs and trade-offs that determine the eventual displacement distance
  - has impacts on both population dynamics and genetics

# Dispersing individuals are a special subset of the population

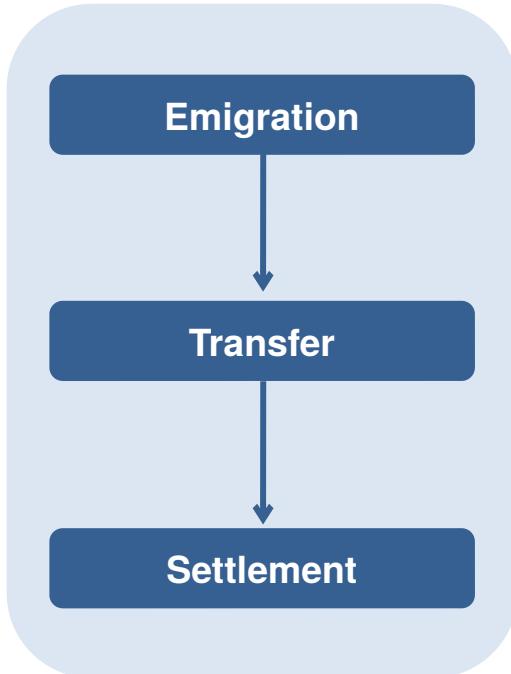
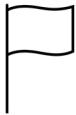
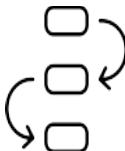


**Fig. 1.** Dispersing individuals are a nonrandom subset of the population.

**(Left)** Dispersing females of the Glanville fritillary, *Melitaea cinxia*, have a higher flight metabolic rate and are more fecund than sedentary ones.

**(Right)** In Siberian jays, *Perisoreus infaustus*, the subordinate individuals disperse, whereas the heavier and more dominant remain in their natal territories.

# RangeShiftR: three phases of dispersal

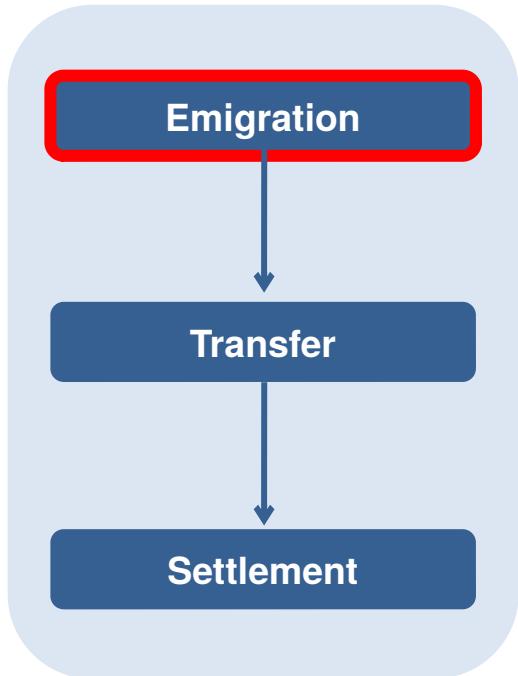


Leaving the natal site (area where born)

Movement through the landscape

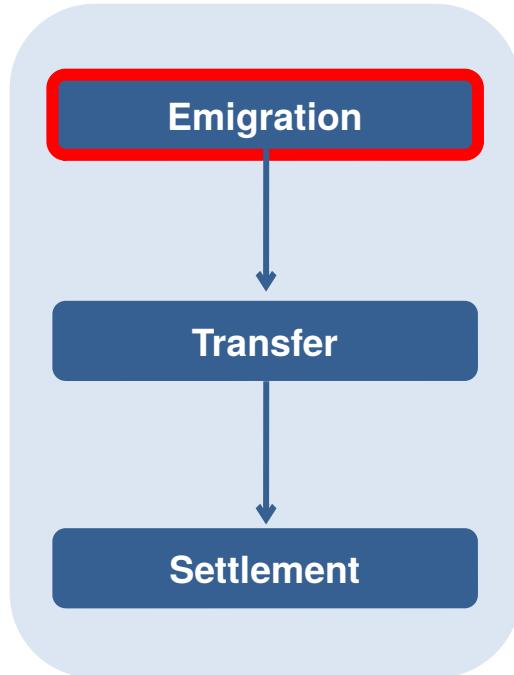
Establish in a new habitat site /area

# RangeShiftR: three phases of dispersal



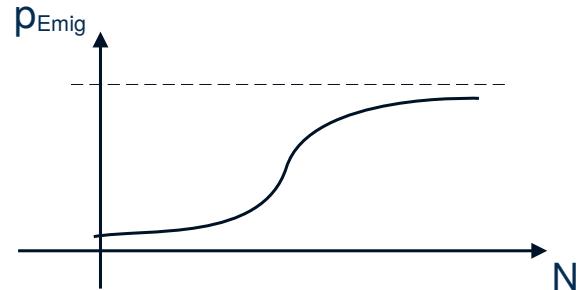
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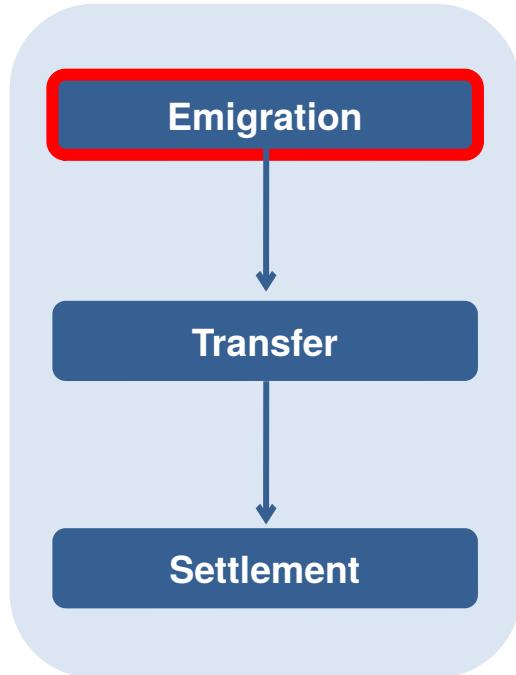


## Emigration probability:

- the probability that an individual will leave its natal patch during the present year
- can be density-dependent

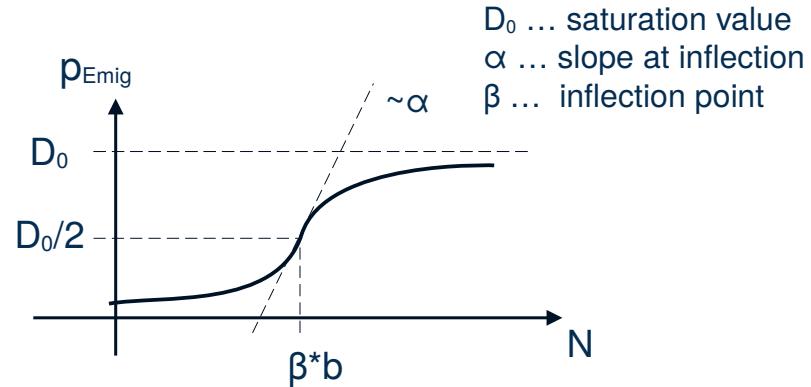


# RangeShiftR: three phases of dispersal



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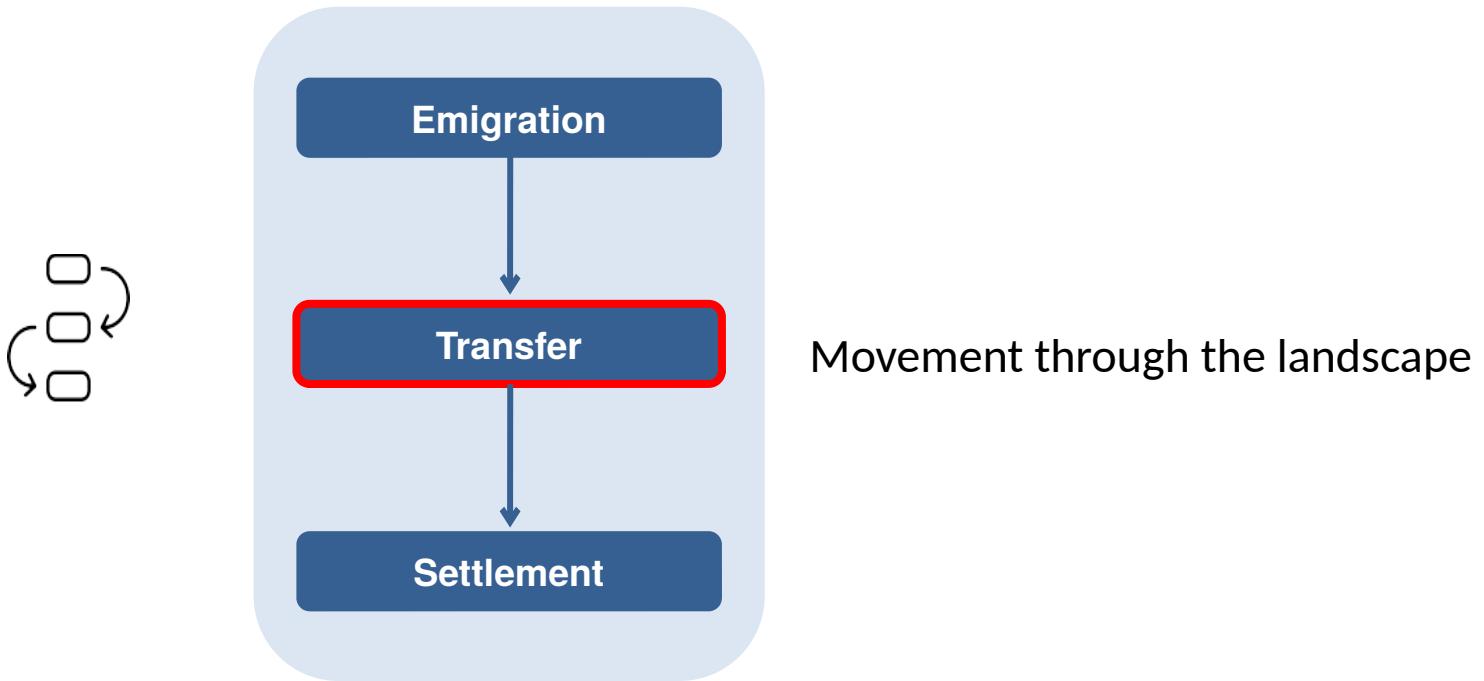
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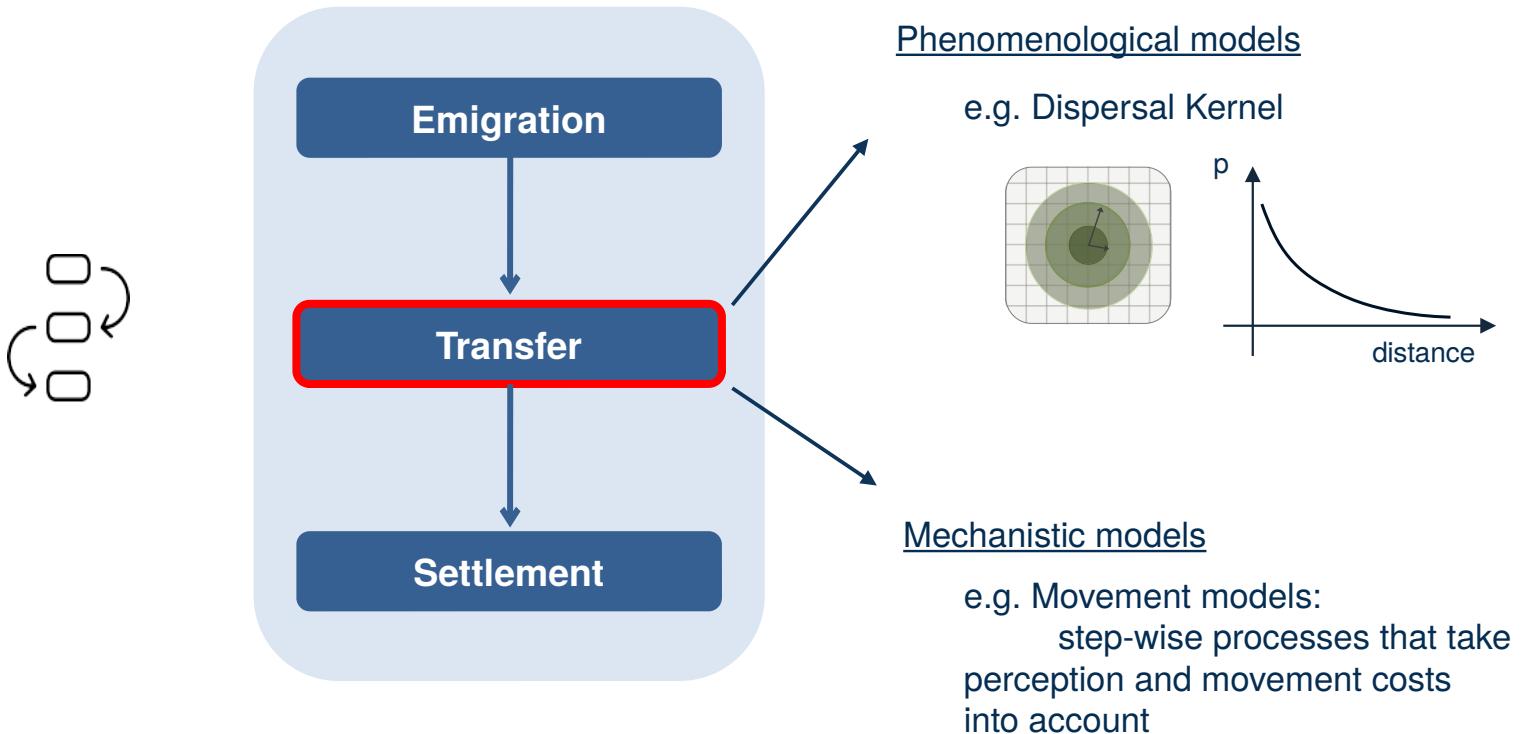
stage	sex	$D_0$	$\alpha$	$\beta$
0	0	0.4	10	1
0	1	0.9	10	1
...	...	...	...	...

sex = 0 ... female  
sex = 1 ... male

# RangeShiftR: three phases of dispersal



# RangeShiftR: three phases of dispersal



# RangeShiftR: mechanistic movement models

## 1.) Stochastic Movement Simulator

- step-wise process

Movement costs

3	4	1	0	0
1	1	3	3	5
2	3	1	1	4
1	1	0	0	0
5	4	1	0	0



Habitat cell



Matrix cell

# RangeShiftR: mechanistic movement models

## 1.) Stochastic Movement Simulator

- step-wise process
- takes perception into account
  - perceptual range (e.g. 1 cell)

Movement costs

3	4	1	0	0
1	1	3	3	5
2	3	hog	1	4
1	1	0	0	0
5	4	1	0	0



Habitat cell



Current cell



Matrix cell



Perceptual area

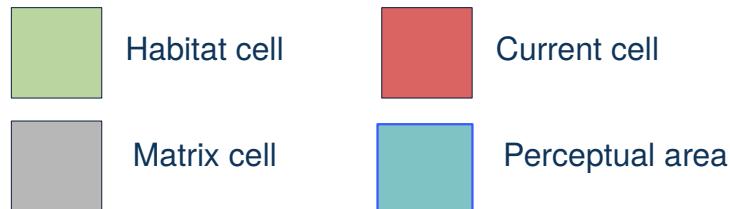
# RangeShiftR: mechanistic movement models

## 1.) Stochastic Movement Simulator

- step-wise process
- takes perception into account
  - perceptual range (e.g. 1 cell)
- decision of next direction based on:
  - lowest average cost
  - preceding steps in memory (e.g. 3 steps)
  - directional persistence

Movement costs

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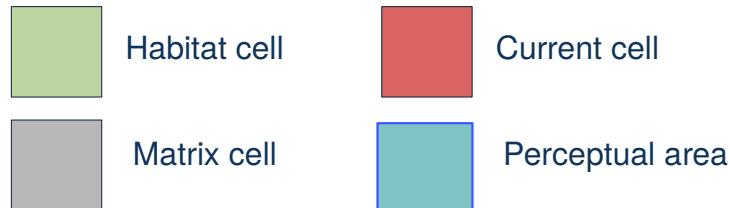
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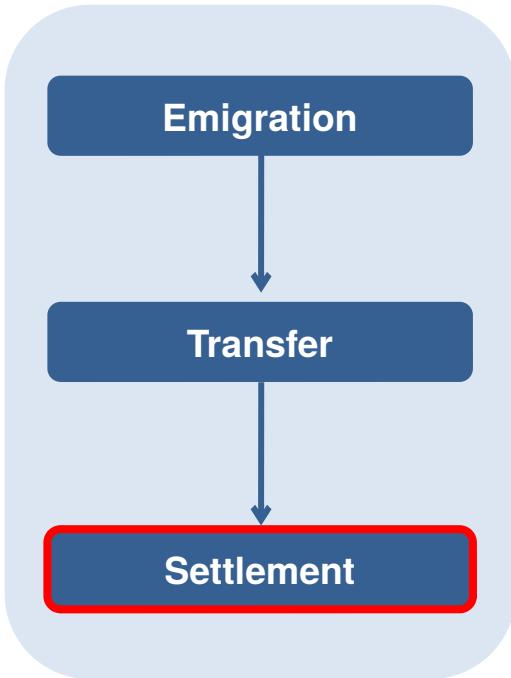
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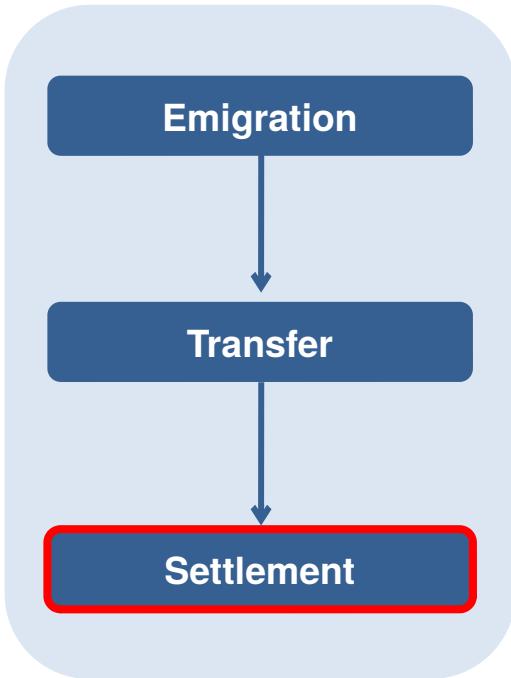


# RangeShiftR: three phases of dispersal



Establish in a new habitat site /area

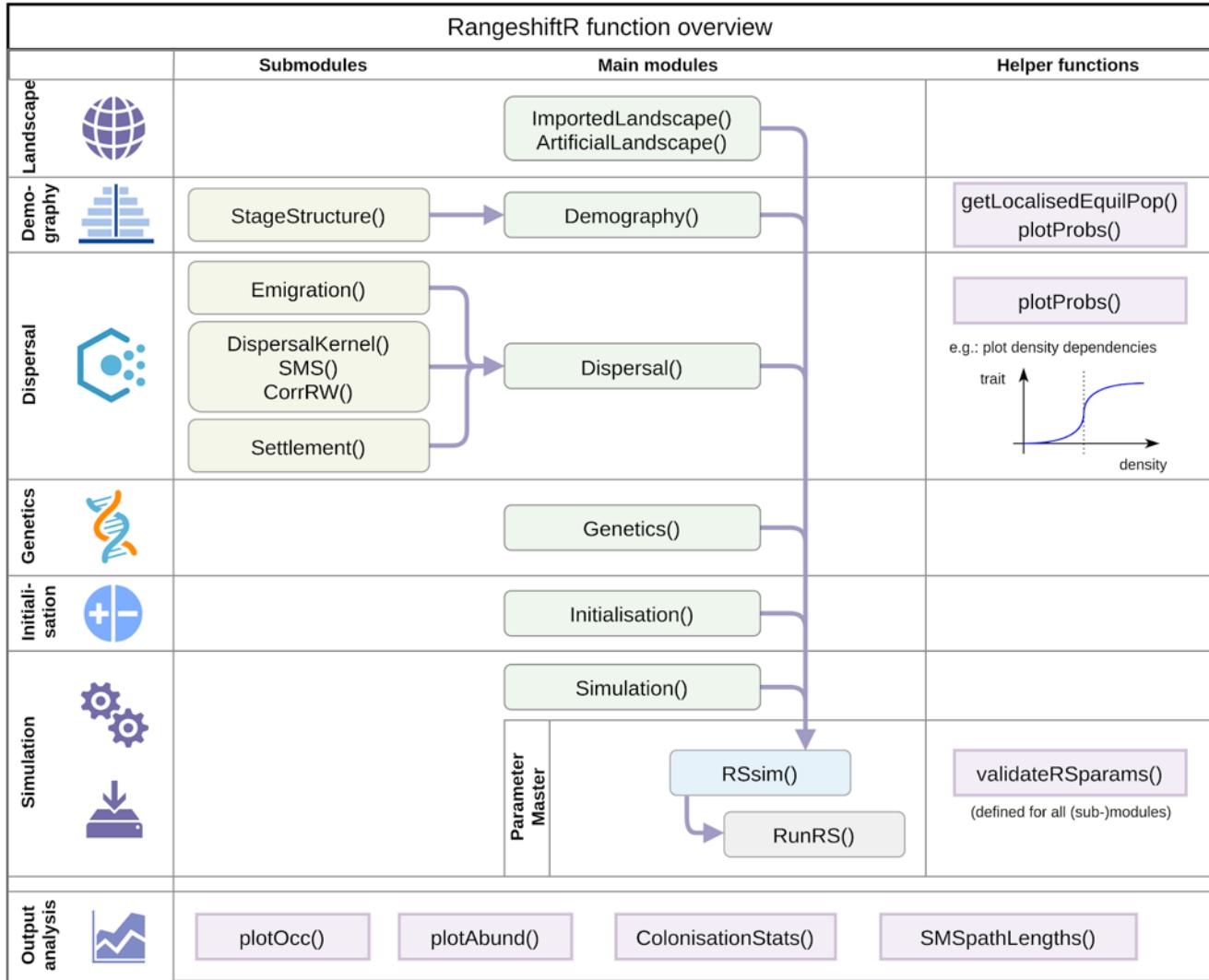
# RangeShiftR: three phases of dispersal



## Settlement probability:

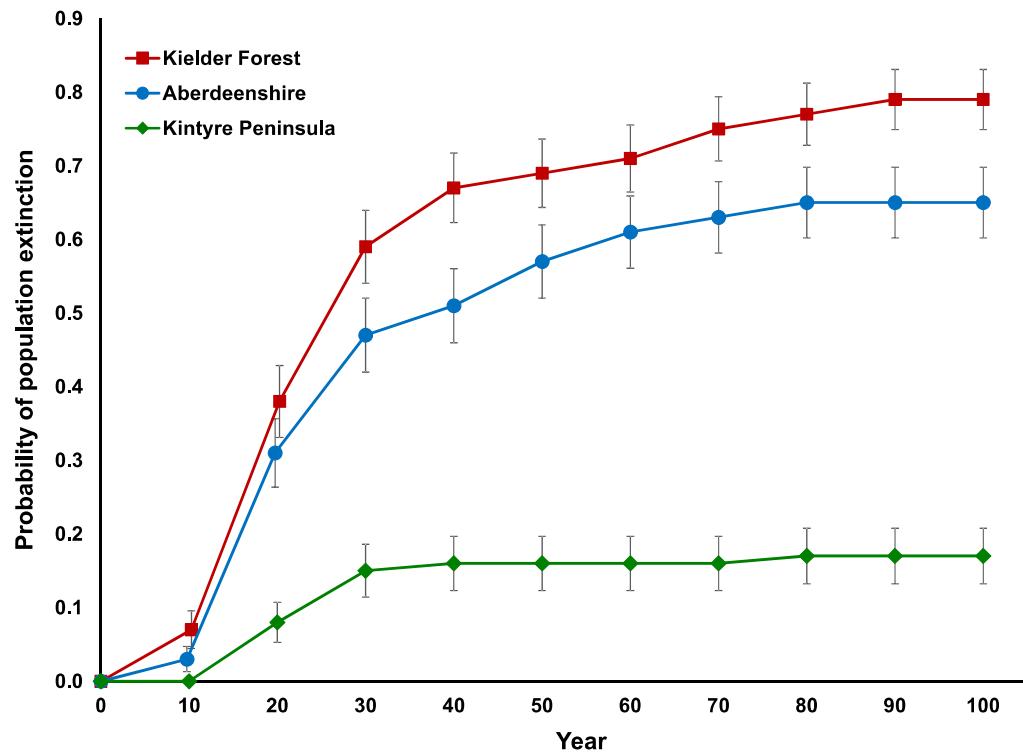
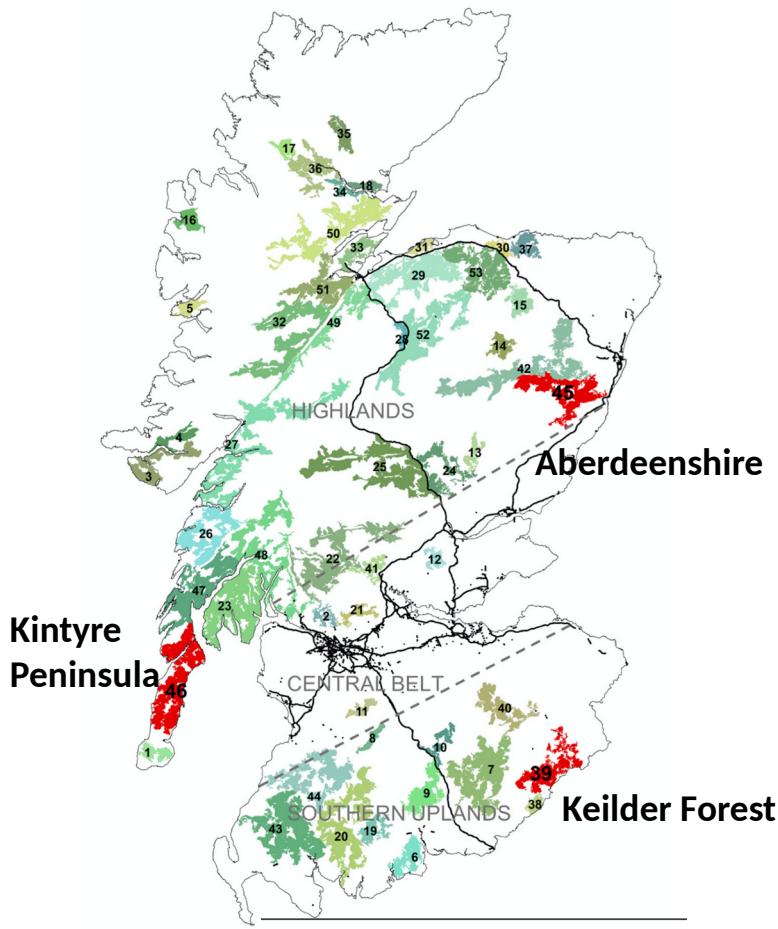
- the probability that an individual will stay in a new habitat patch
- can be density-dependent (analogous to emigration probability)

# RangeShiftR overview



# Example: Eurasian lynx, reintroduction Scotland

- Break-out rooms of 4-5 participants per group
- Time: 45 mins
- Script: IBS2022\_RS\_workshop/code/Prac2\_RangeShiftR\_Lynx.R

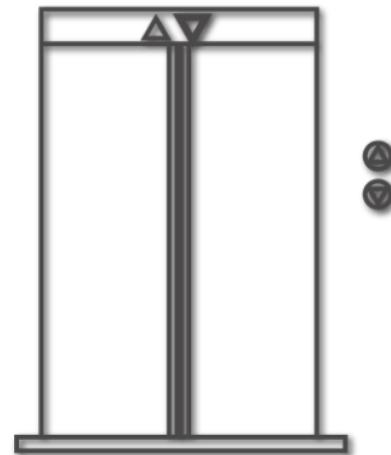


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Break: 15 mins

# Pitch your project idea!

- In break-out rooms of 4-5 participants per group:  
Discuss your own research ideas using RangeShifter !
- Prepare a 1-min elevator pitch on your Research Concept:  
Research question, species, spatial and temporal scale, data sources, ...
- Time: 20 mins
- Afterwards:  
Pitch your research idea to the panel !



# The RangeShifter project



Thanks for attending our workshop!

The Team:



Our Website:

<https://rangeshifter.github.io>



RangeShifter 2



RangeShiftR