Modelling of climate change impact on forest tree populations

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Alterra

Evoltree Summer School

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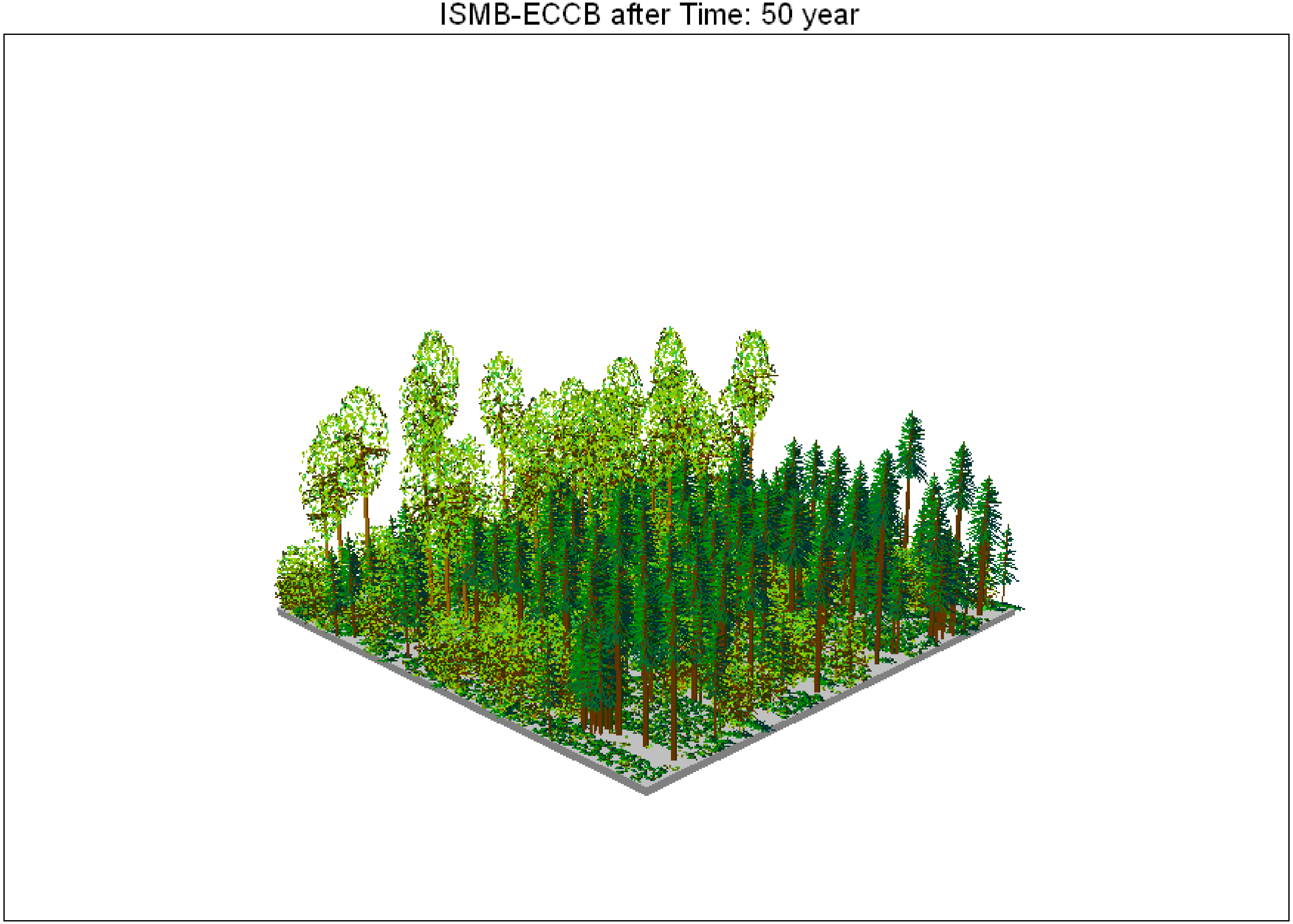
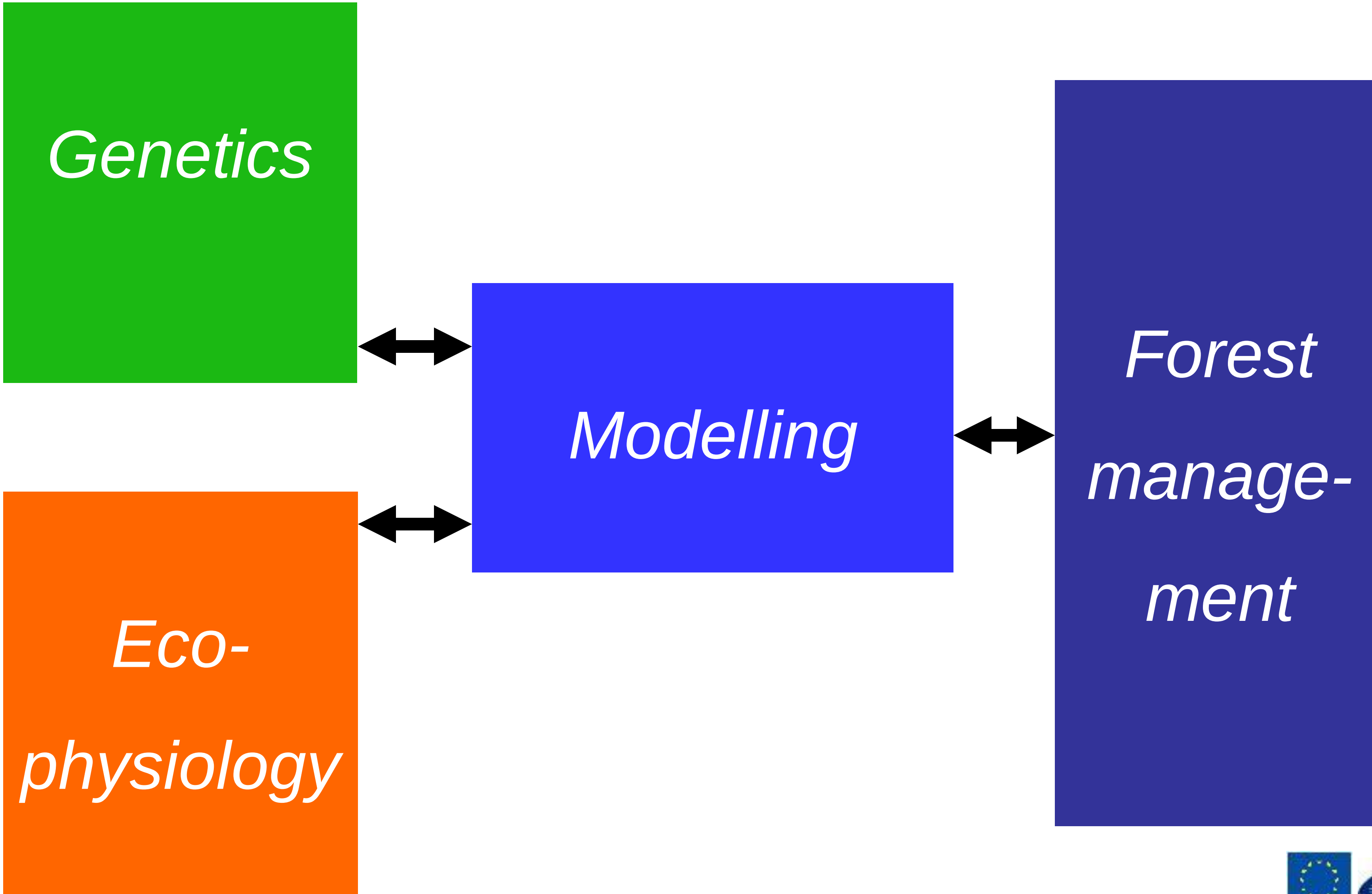
Example: beech and pine



Simulations based on past century climate

Modelling ambition



Structure of the presentation

Modelling principles

The model ForGEM

- genetic components
- eco(physio)logical component
- forest management

Examples: impact of forest management

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Modelling the annual cycle

Examples: impact of climate change

Model characteristics

Mathematical model

Simulates ‘real world’ phenomena

Systems of differential/or difference equations

Deterministic or probabilistic

Event driven

Has a time component: dynamic modelling

Individual based model

- Individual/behavior tracked in time
- Spatially explicit

Defining a model

Important aspects in defining a model

- Elements needed
- Structure and structuring of the data
- Defining the mathematics

Program requirements

- Clear execution flow
- Easy readable and adjustable
- Step size control

The simulated world consists of:

Systems

- One system can contain another system (part of, lies in)
- Relationships between systems are input-output relationships
- Systems differ in state variables and functions
- Differential- or difference equations

Events

- Triggered by state variables and input
- Discrete moment in time

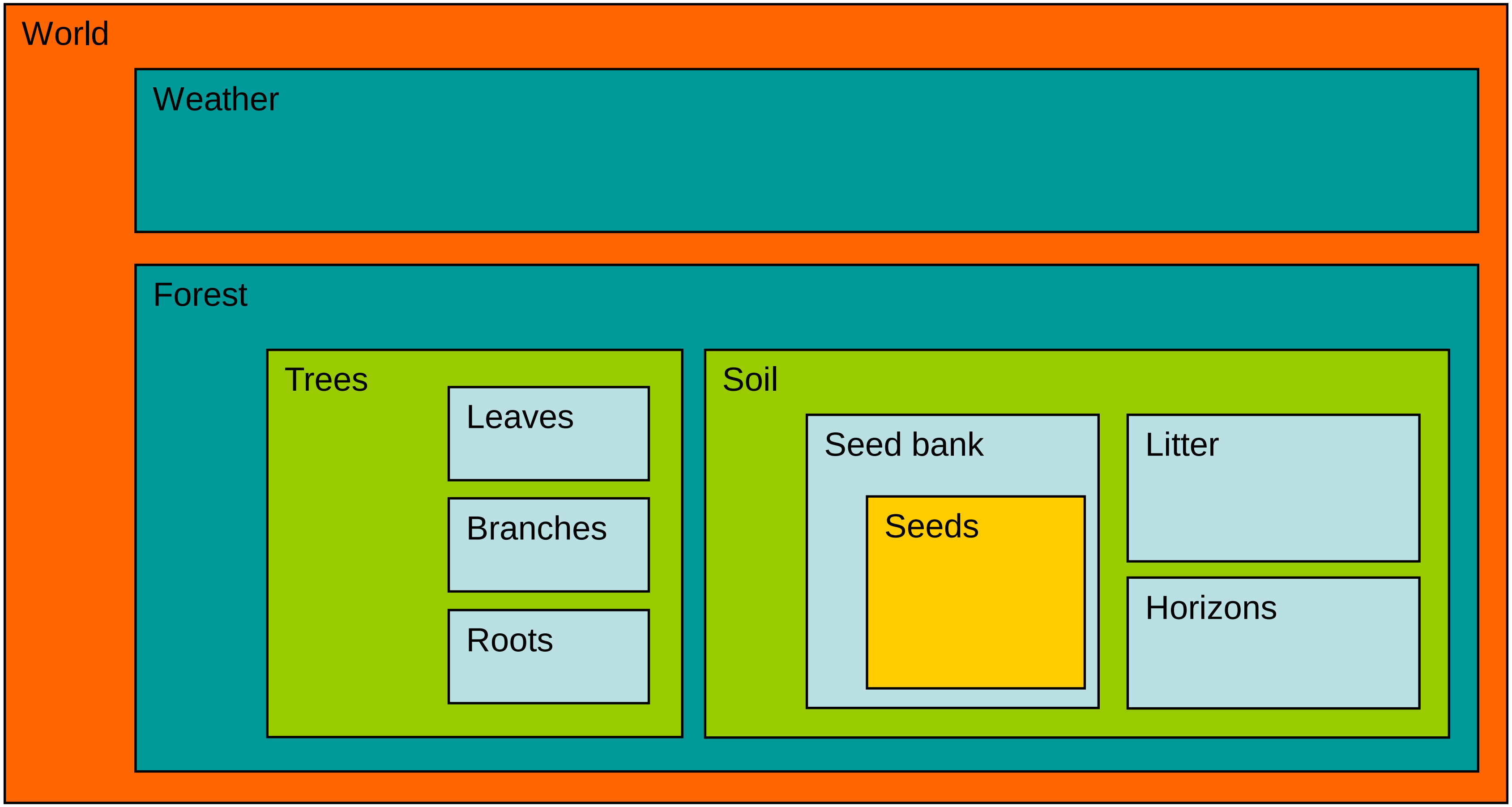
Processes

- Grouped differential-, difference equations across (sub) systems describing a process
- Light interception, Water use, etc.
- Belong to systems (e.g. light interception belongs to forest)

Transitions

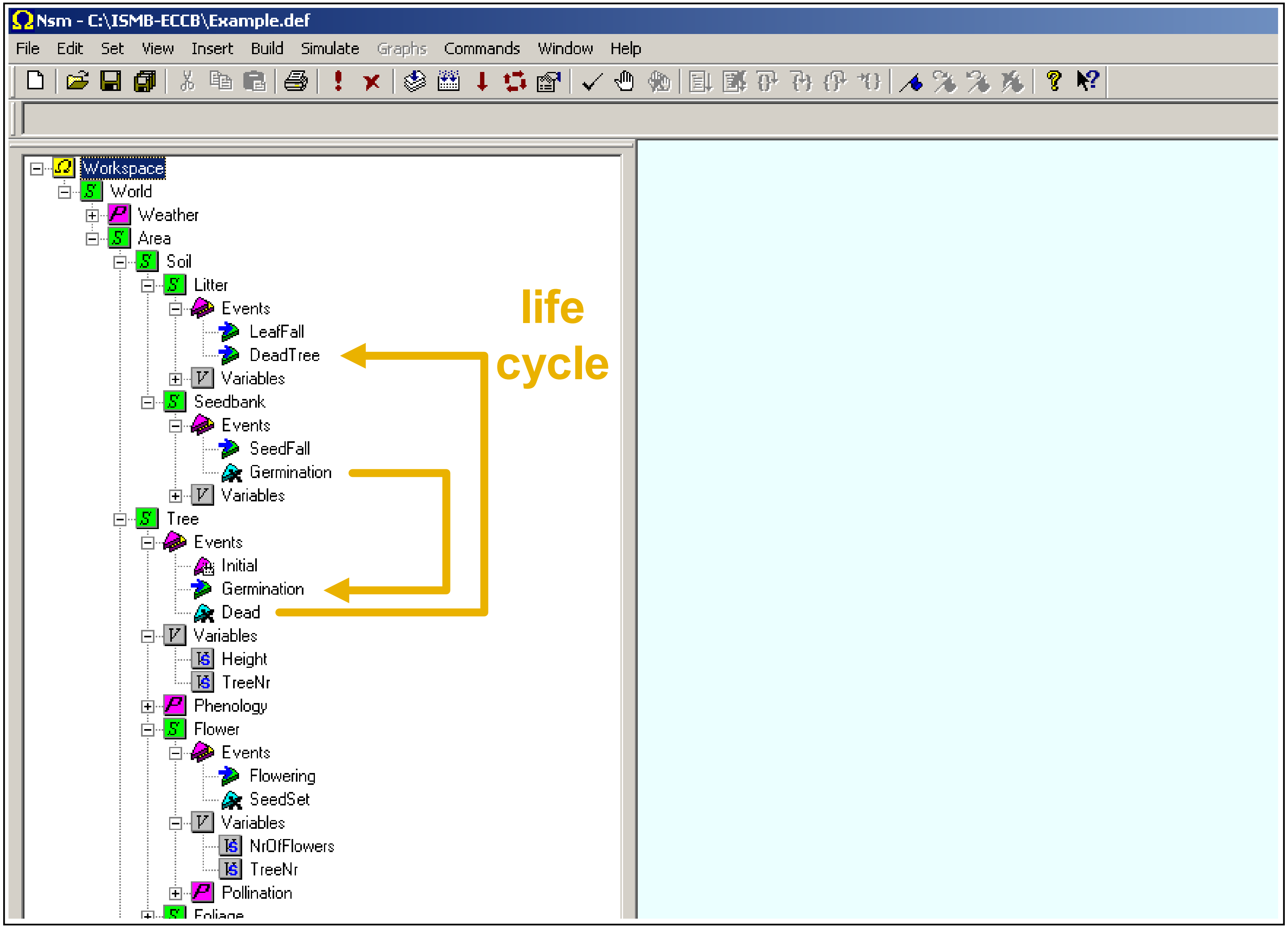
- Some systems can change into other systems due to events

NSM: Nested Simulation Modelling

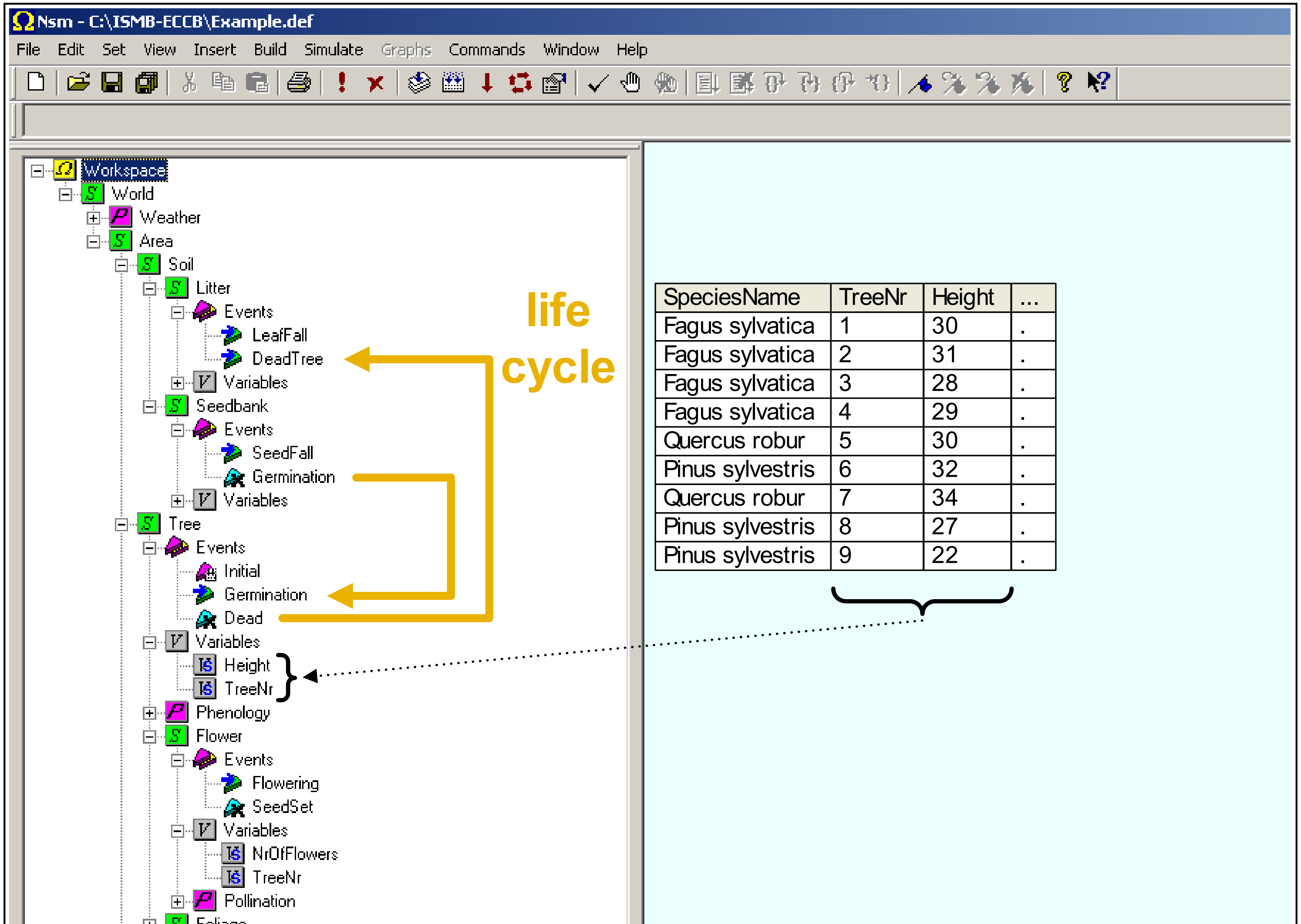


Each system has its own variables and functions and interacts with other systems with input-output relations

Structuring a model

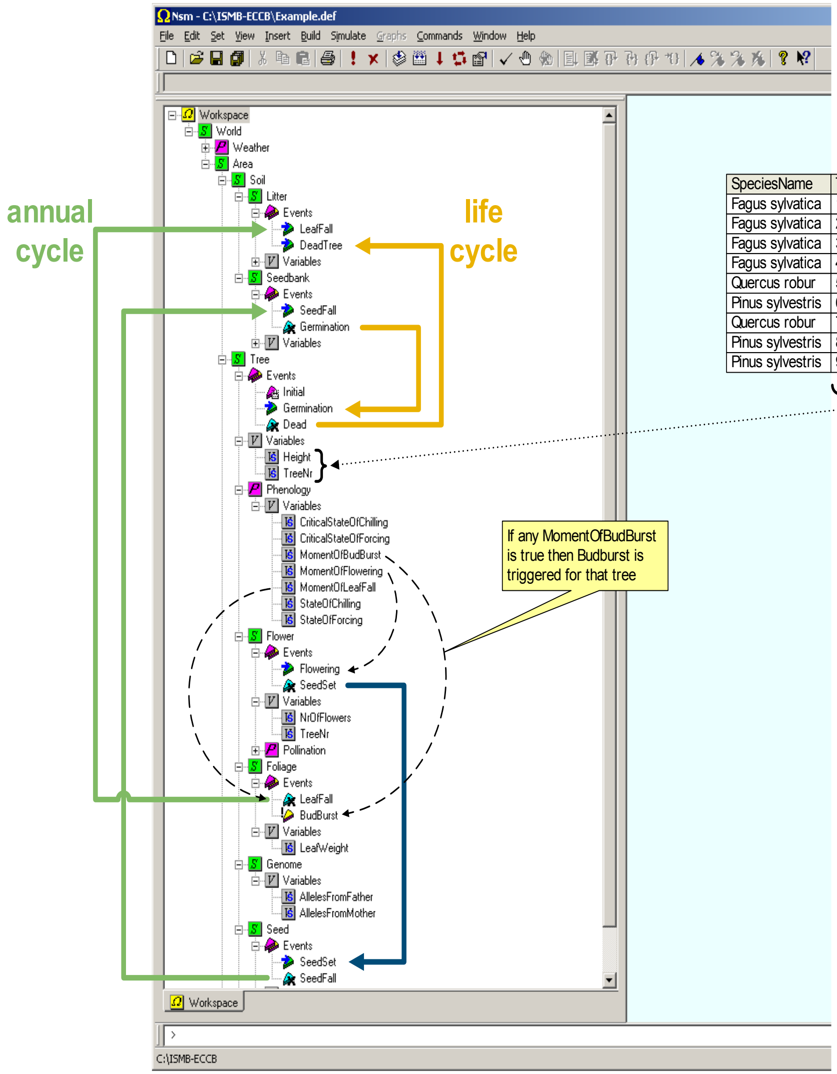


State and Output variables



SpeciesName	TreeNr	Height	...
Fagus sylvatica	1	30	.
Fagus sylvatica	2	31	.
Fagus sylvatica	3	28	.
Fagus sylvatica	4	29	.
Quercus robur	5	30	.
Pinus sylvestris	6	32	.
Quercus robur	7	34	.
Pinus sylvestris	8	27	.
Pinus sylvestris	9	22	.

Triggering events



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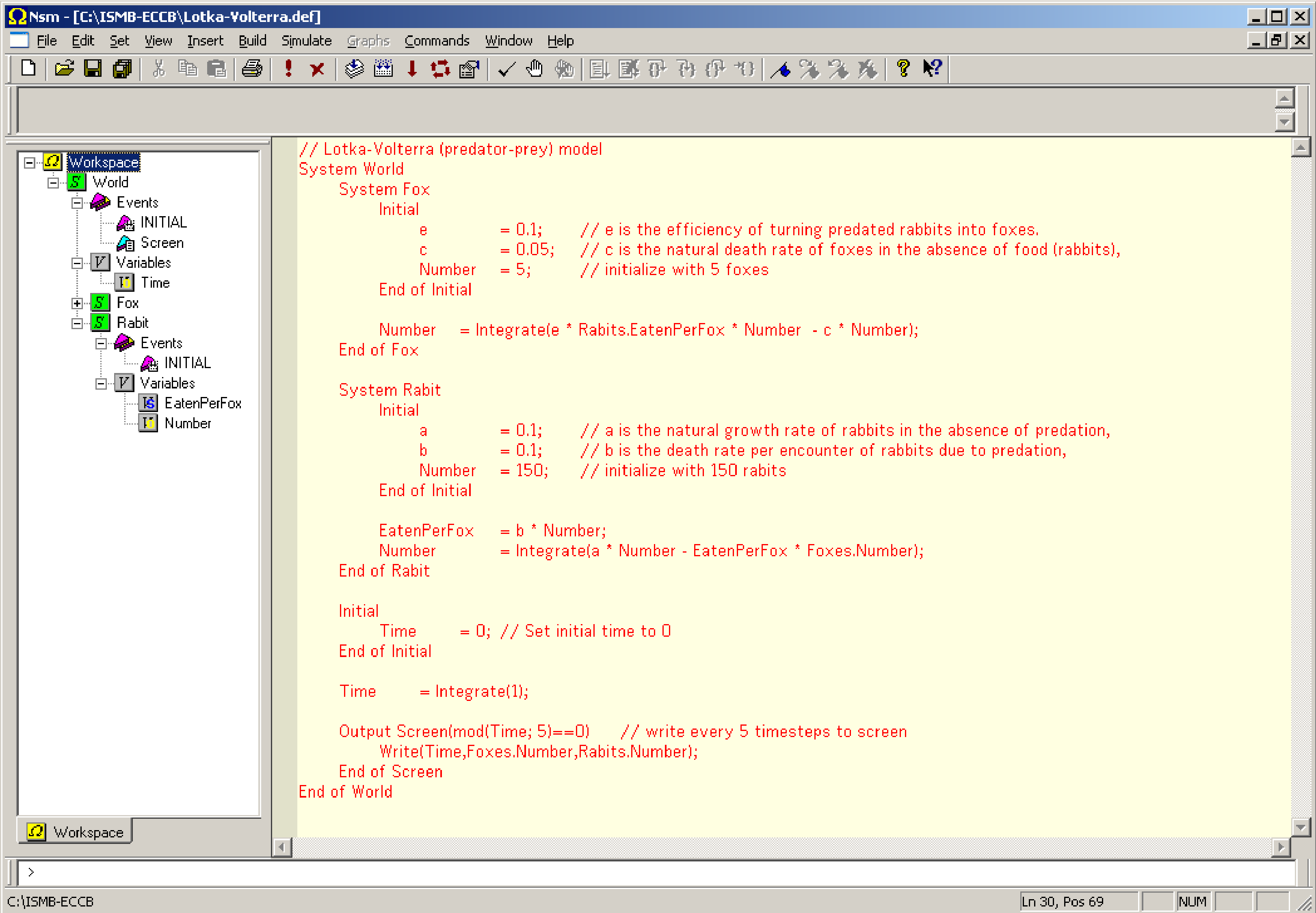
Pinus sylvestris	8	27	.
Pinus sylvestris	9	22	.

Example of model code in NSM:

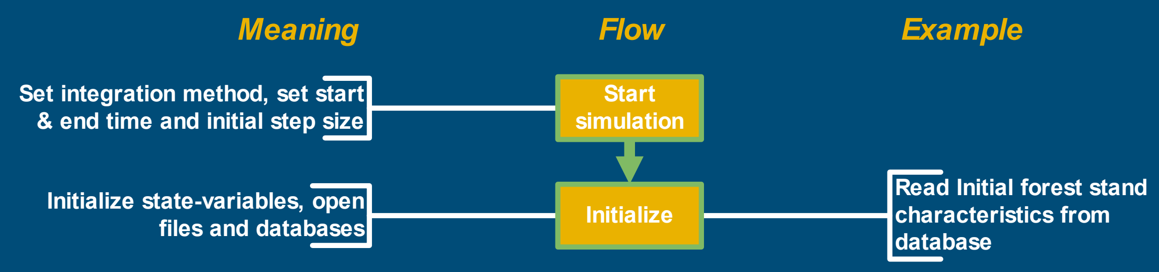


Execution flow

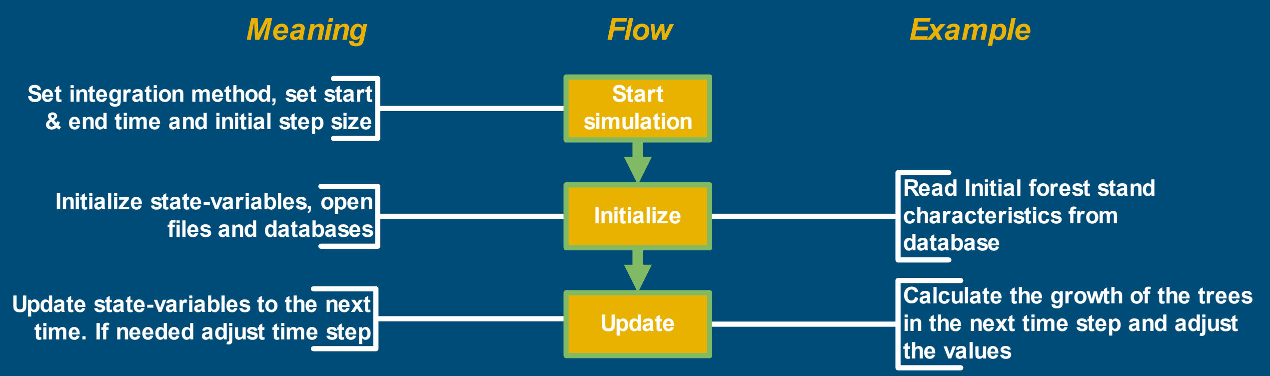
Meaning | *Flow* | *Example*

Set integration method, set start & end time and initial step size → Start simulation

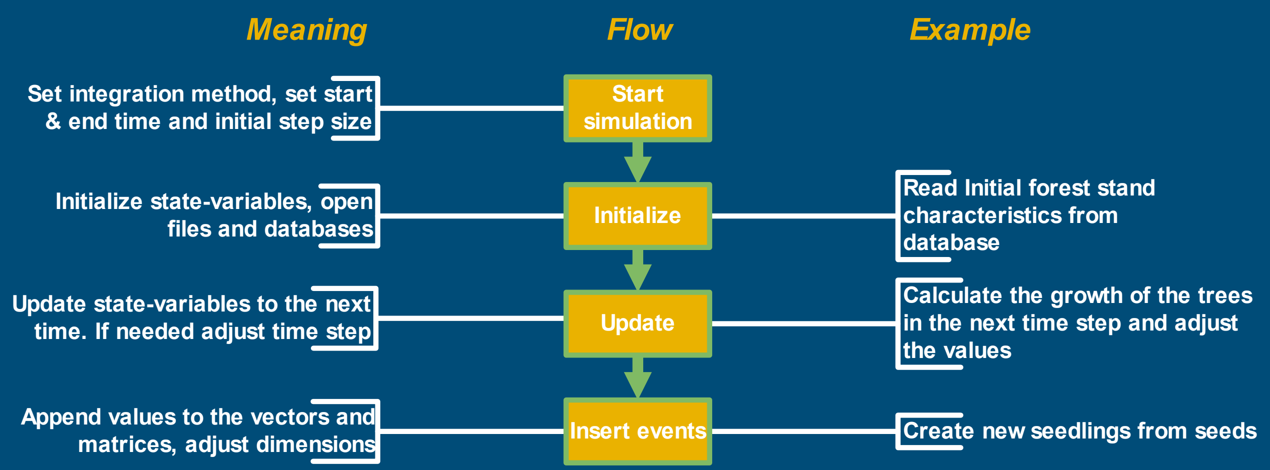
Execution flow



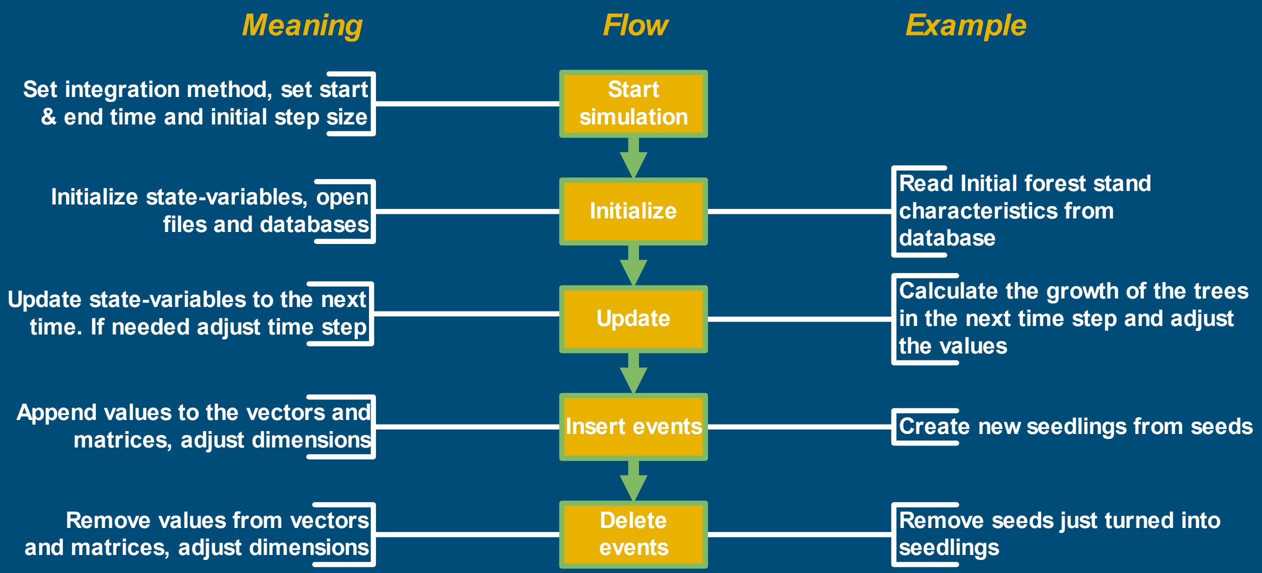
Execution flow



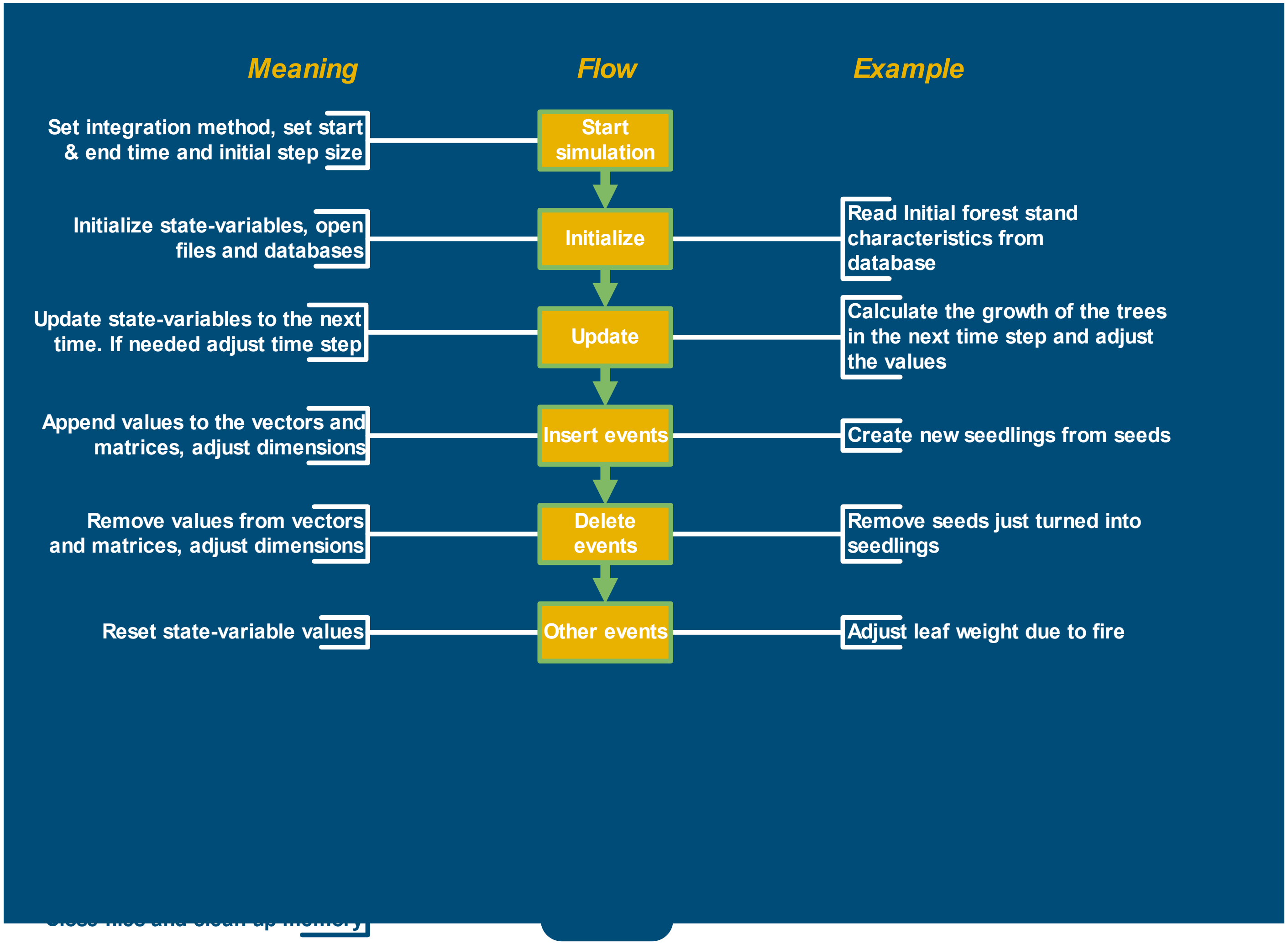
Execution flow



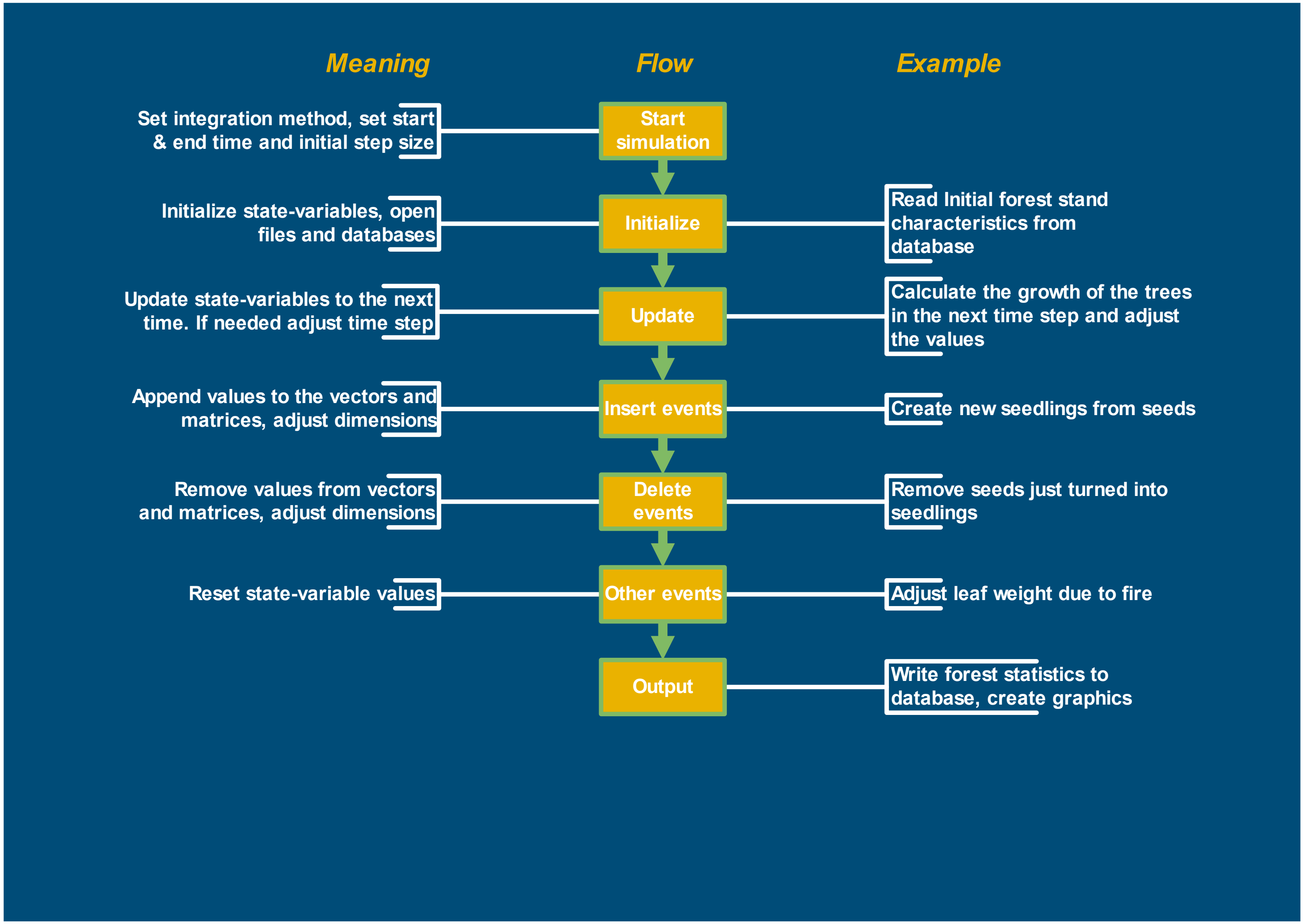
Execution flow



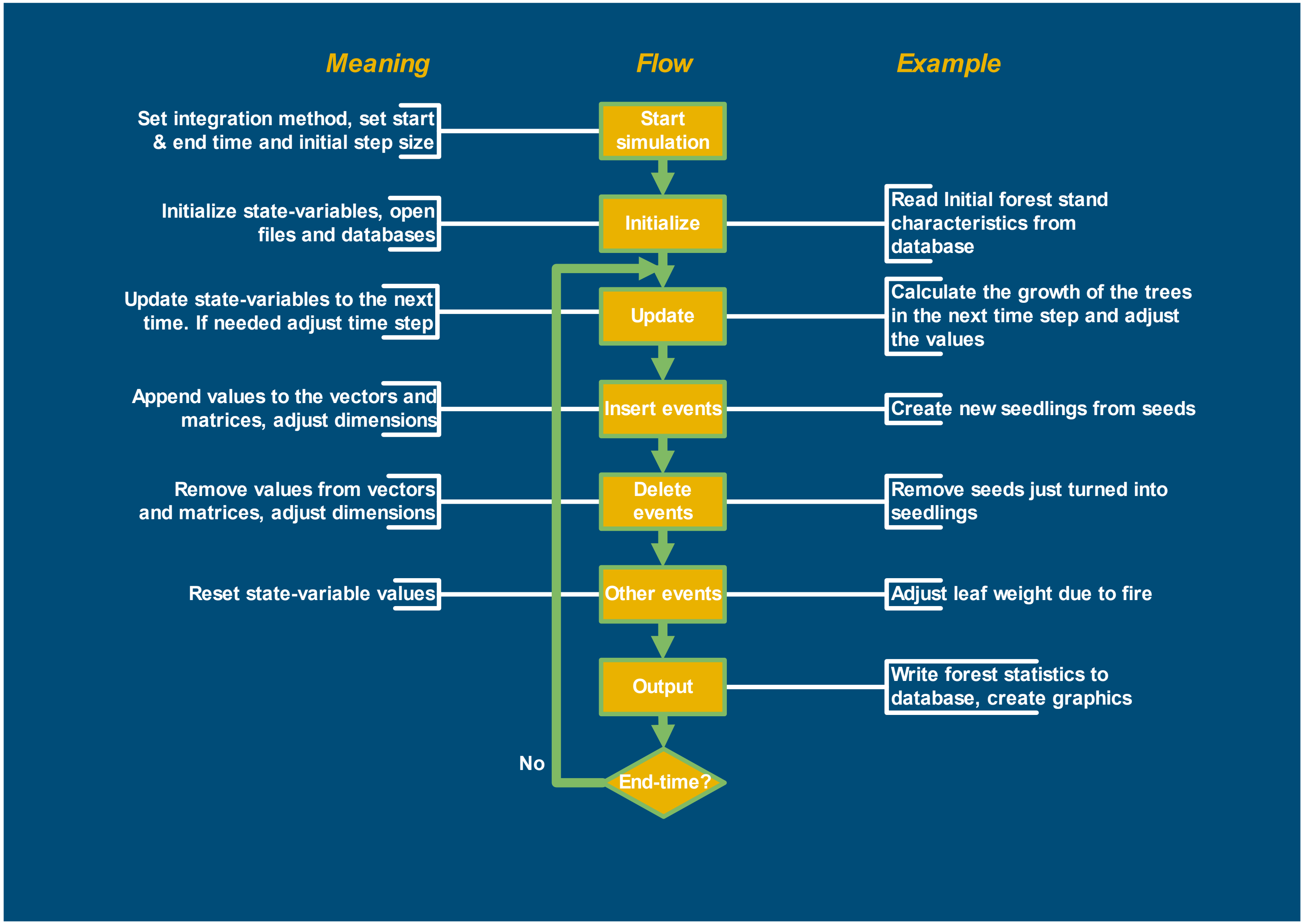
Execution flow



Execution flow



Execution flow



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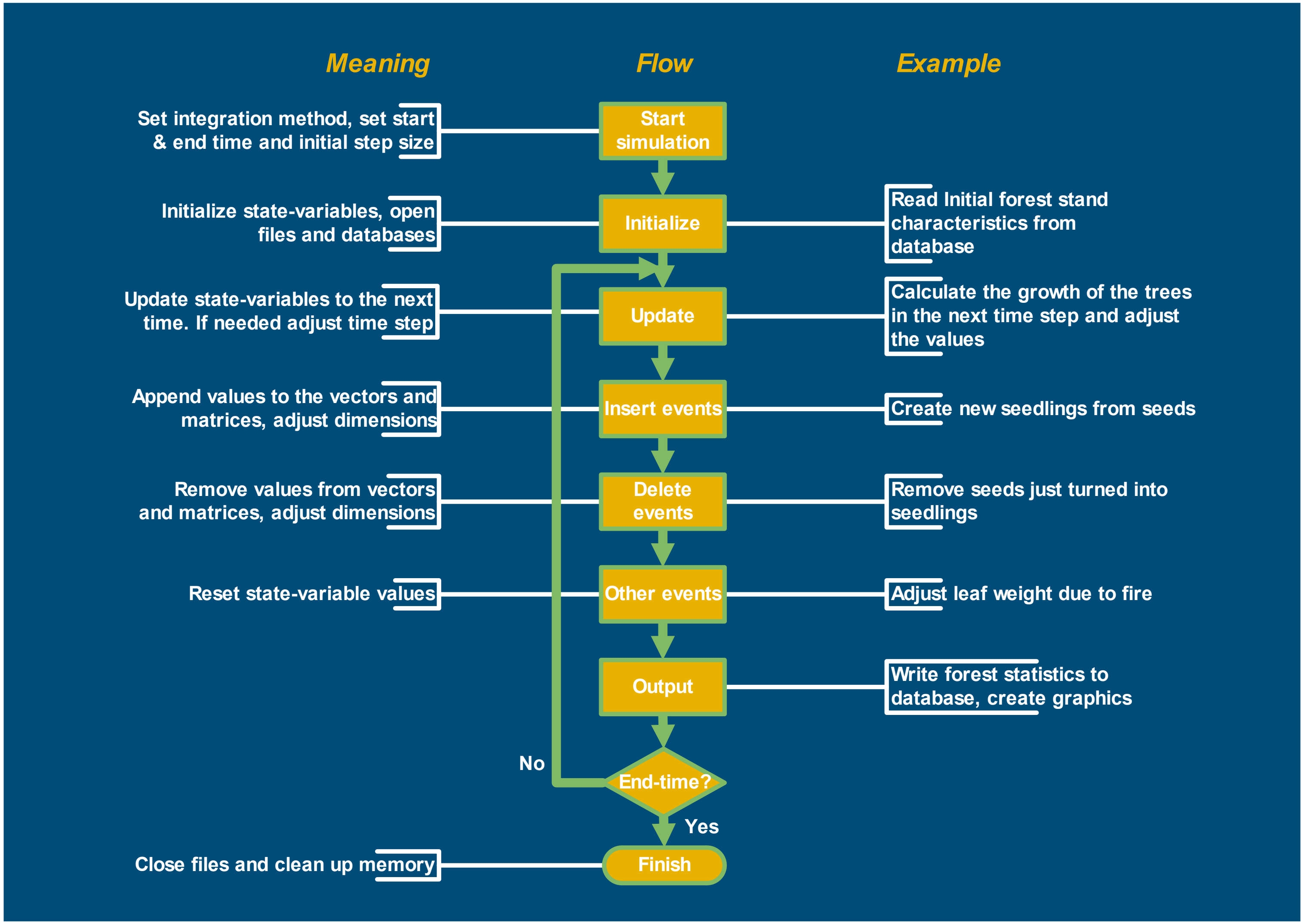


Individual based modeling: advantages

- Population does not need to be in equilibrium state
- Focus on mechanisms between individuals
- Feedback of individuals/population with environmental changes
- It's the individual who reacts to changes in the environment
- Keeps as close as possible to biological processes
- Interactions are too complex to model at higher level of aggregation
- Statistics at population level (up scaling to higher level) can always be computed

Individual based modeling: disadvantages

Lower speed of simulation due to high number of computations

Smaller spatial scale due to memory limitations

Needs a lot of parameters

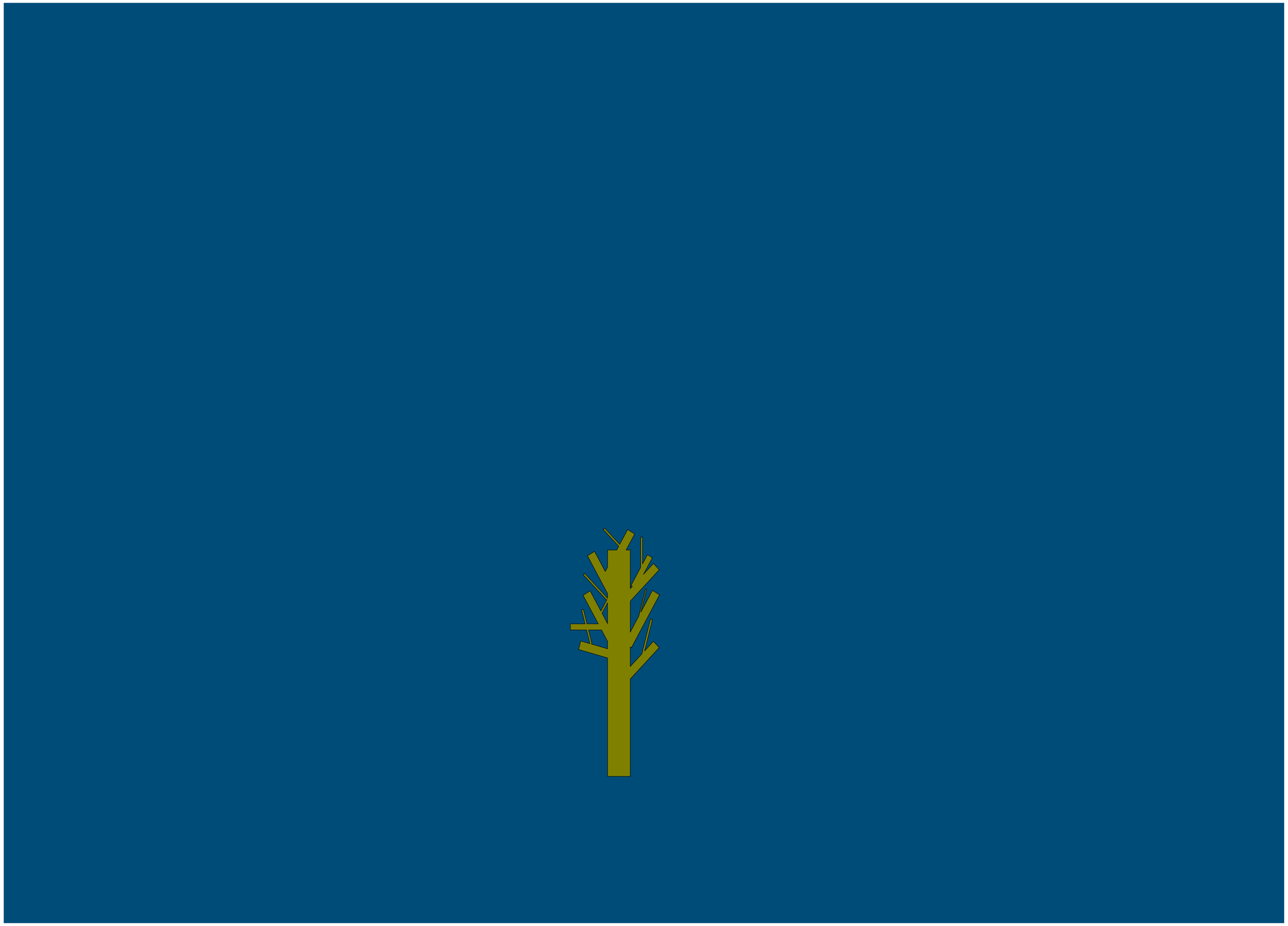
BUT:

- Can be used as a basis for models at an aggregated scale

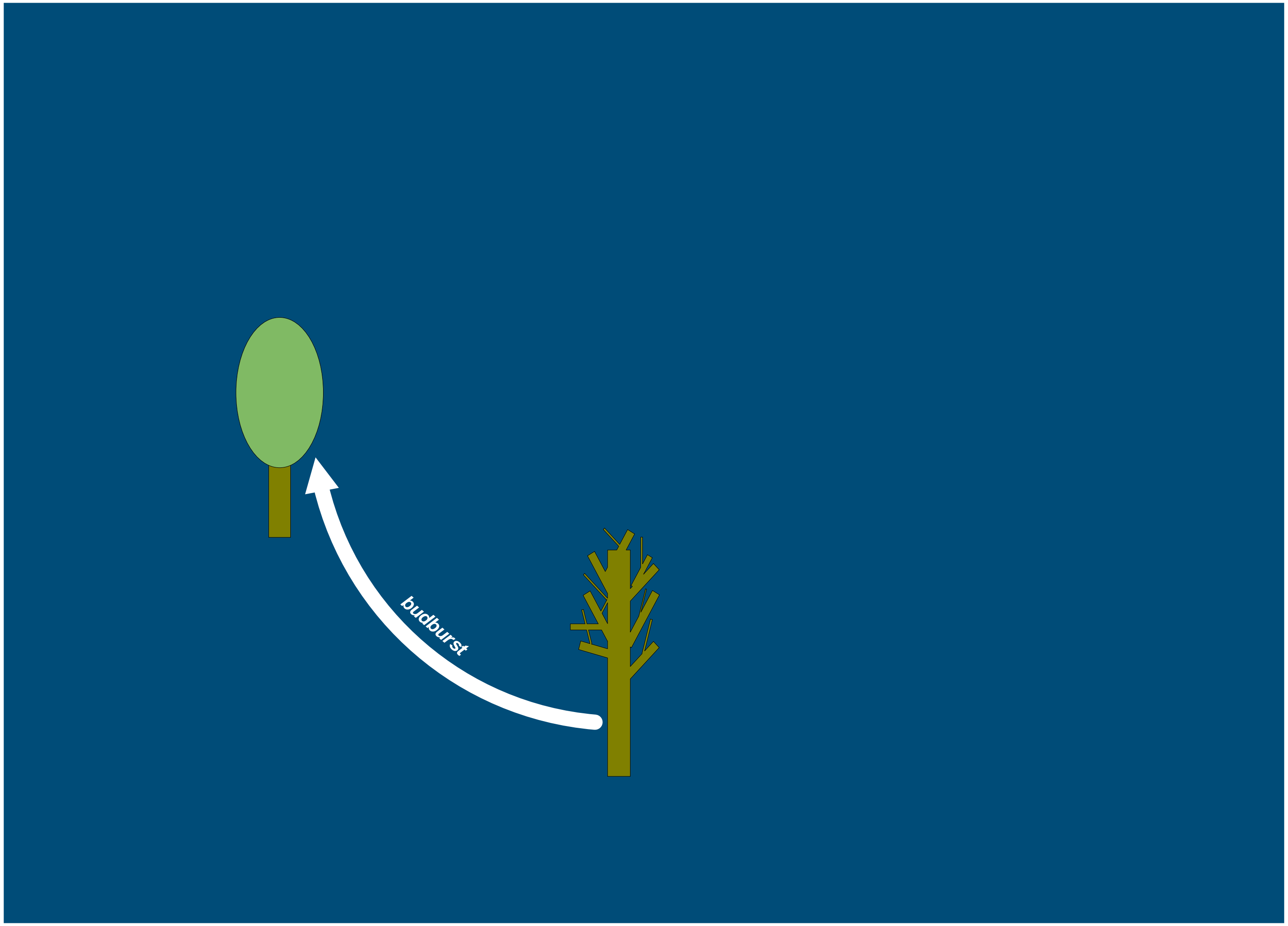
AND:

- A population based model is a special case of individual based model

Life and annual cycle



Life and annual cycle



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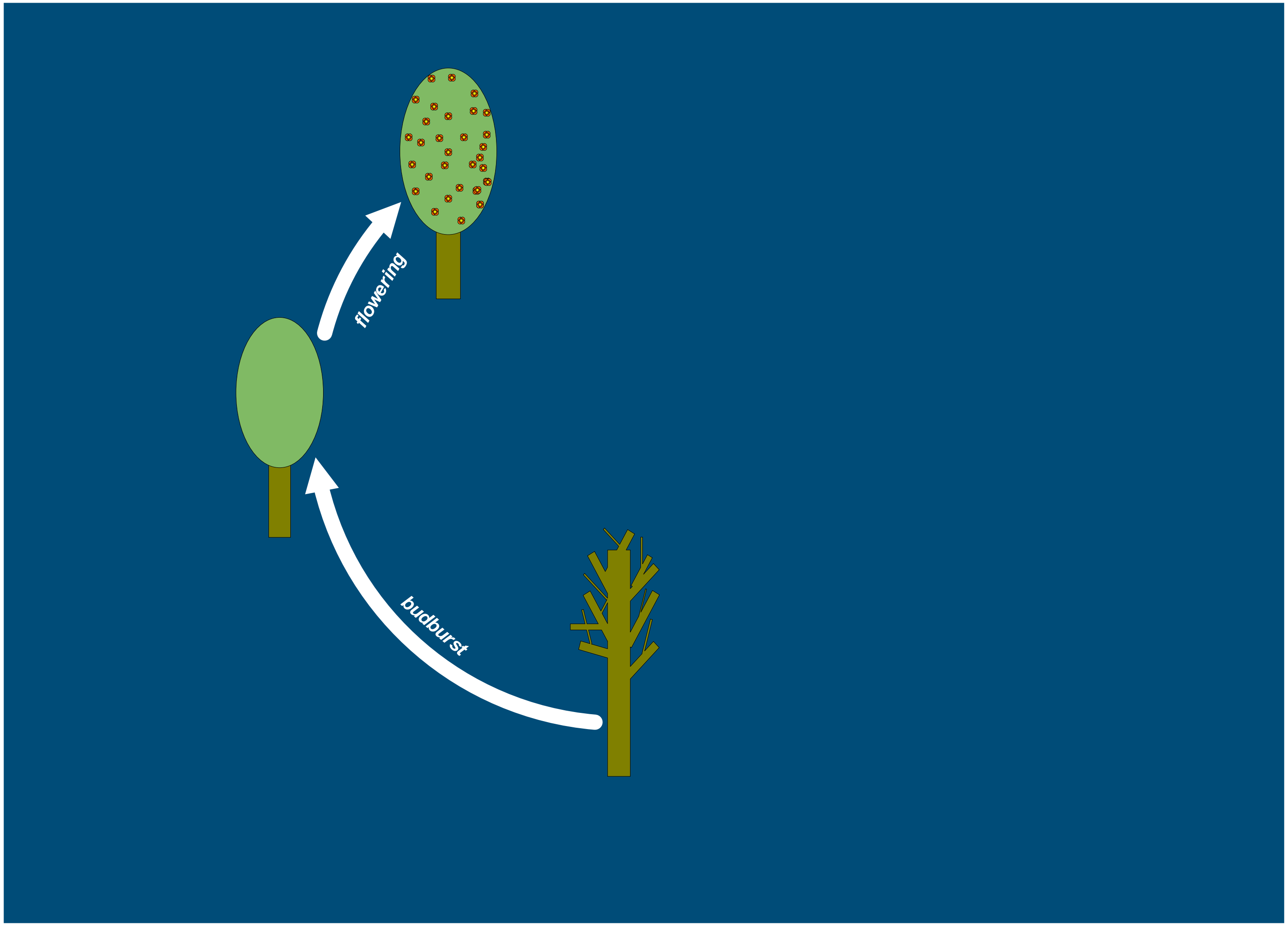

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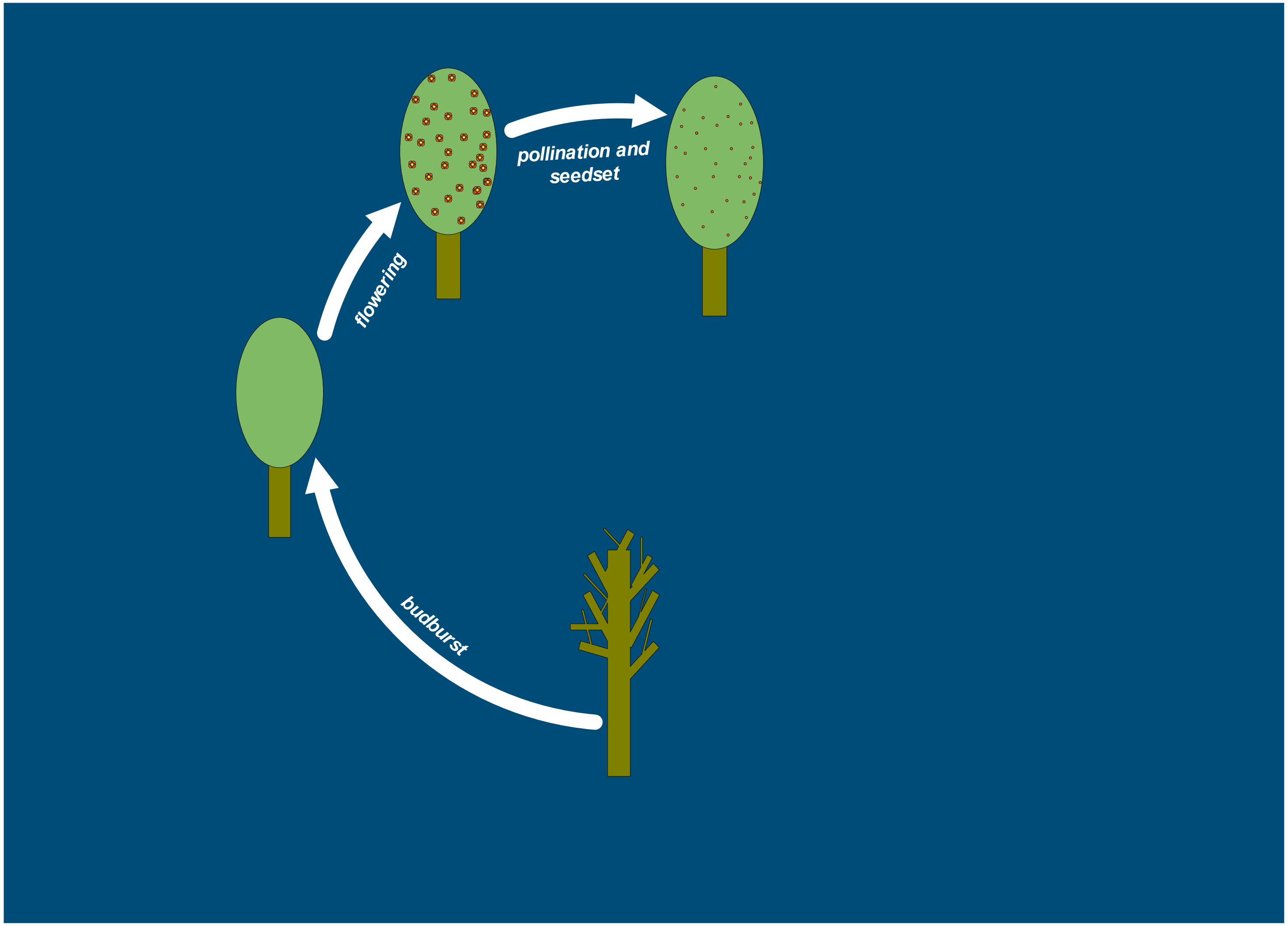
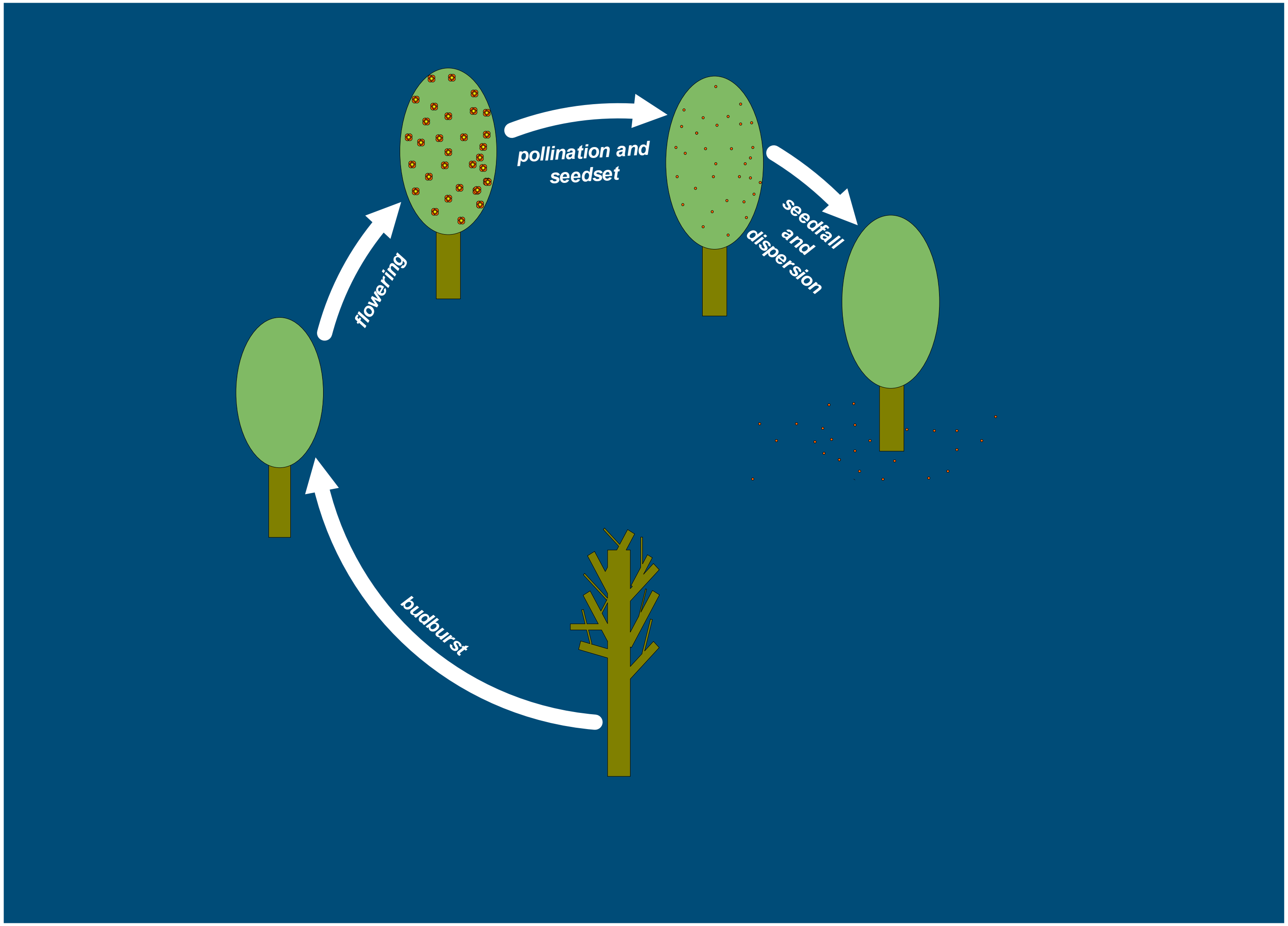
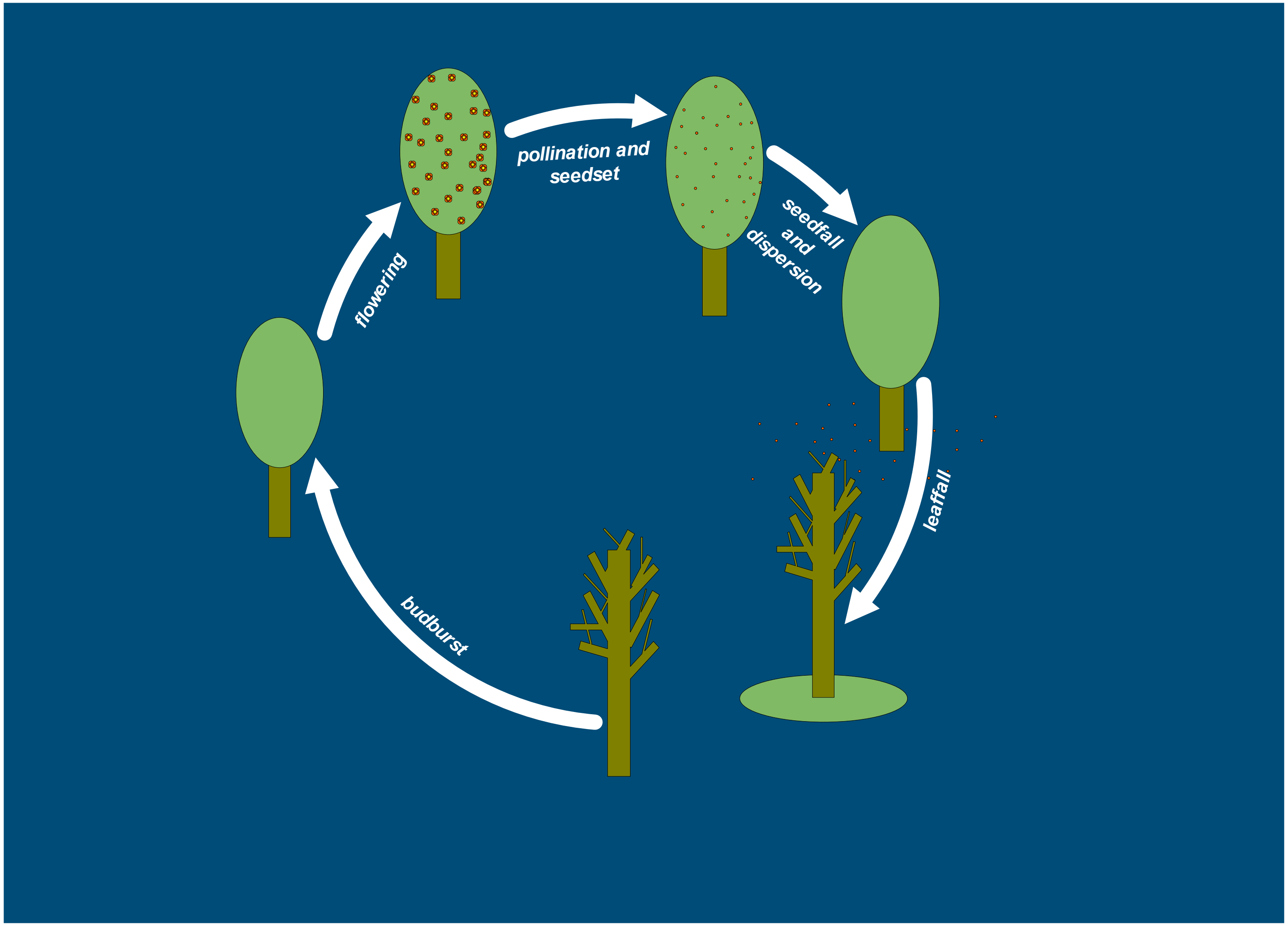


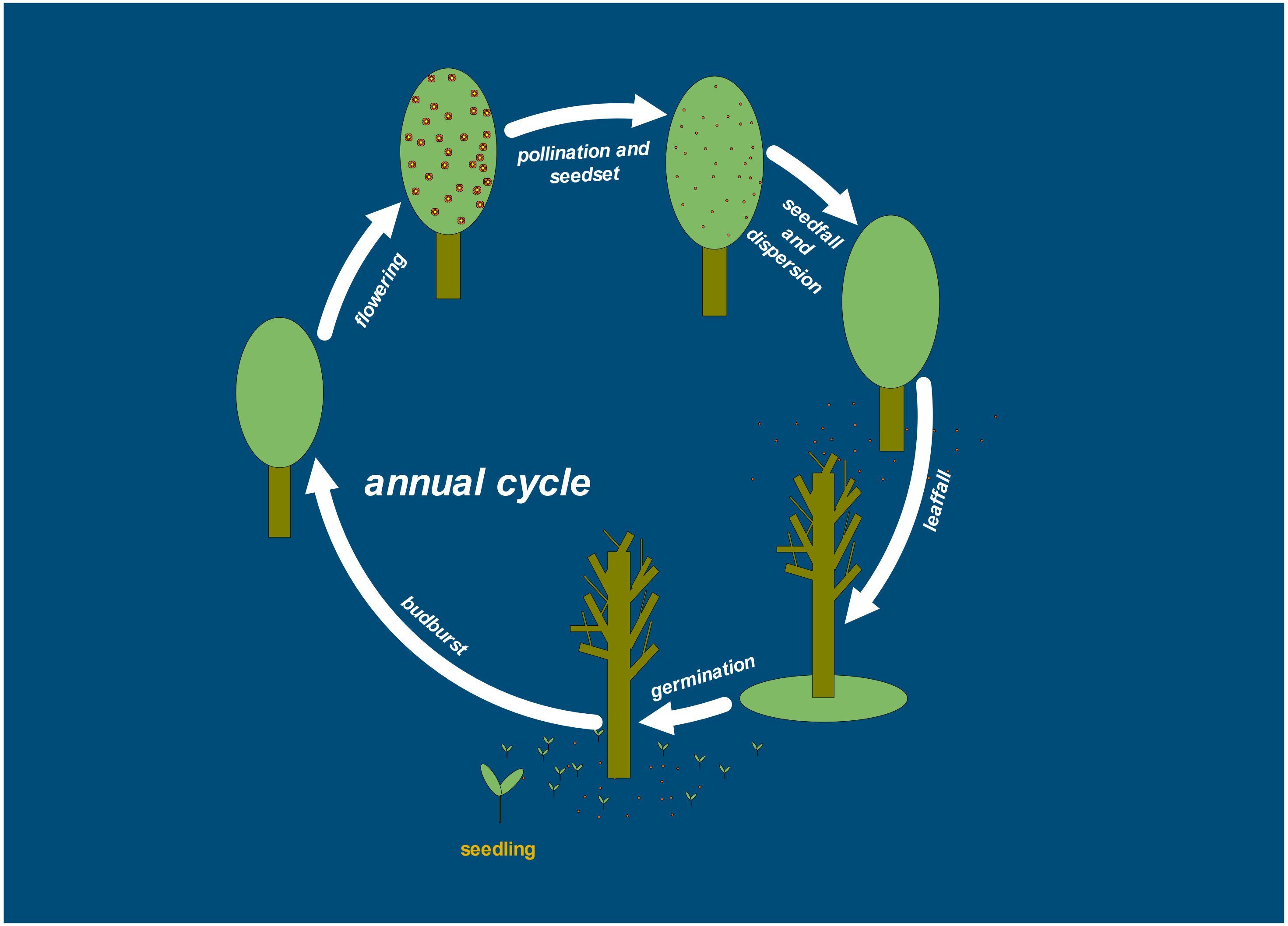
Life and annual cycle



Life and annual cycle



Life and annual cycle



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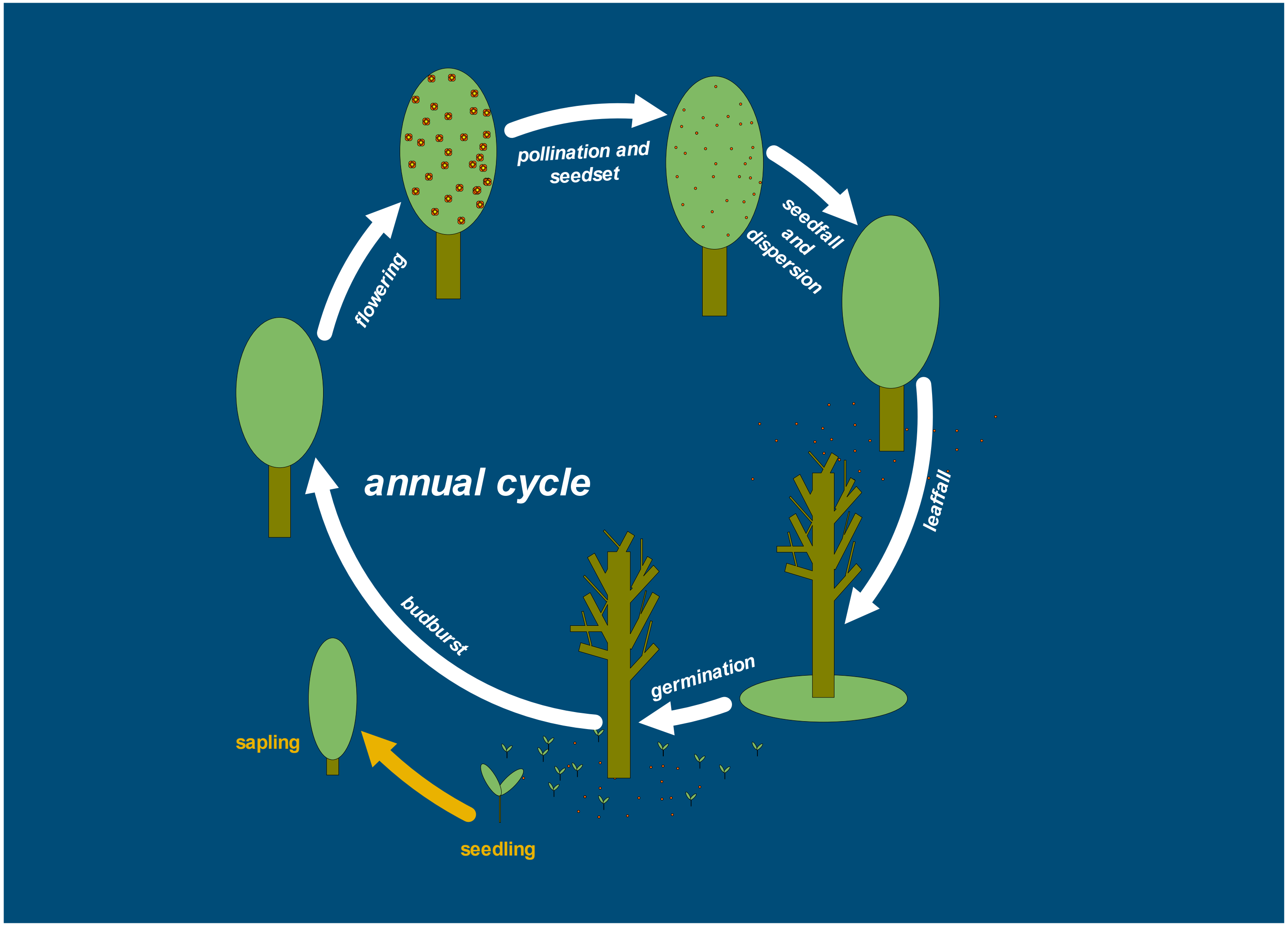
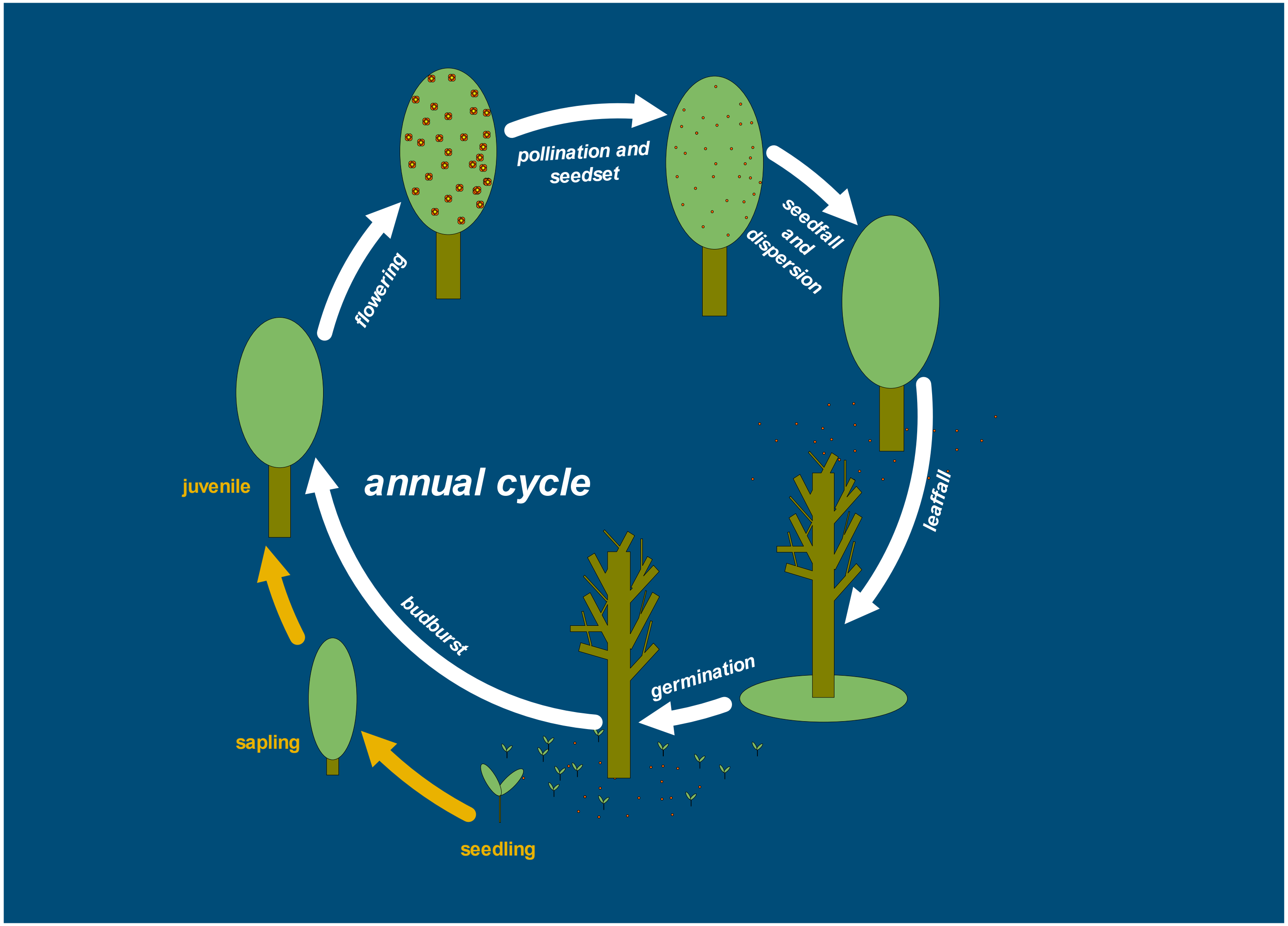


Life and annual cycle



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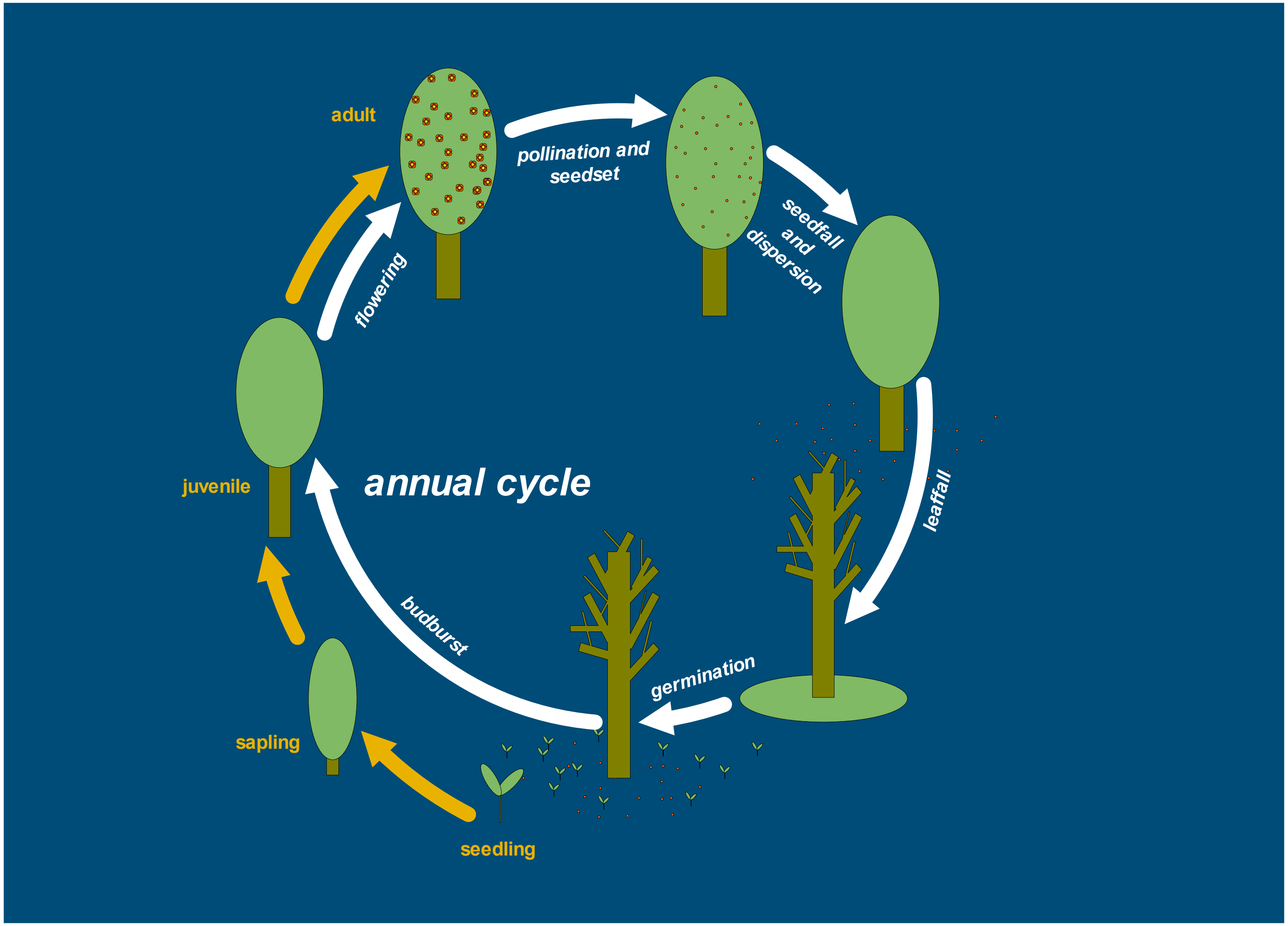

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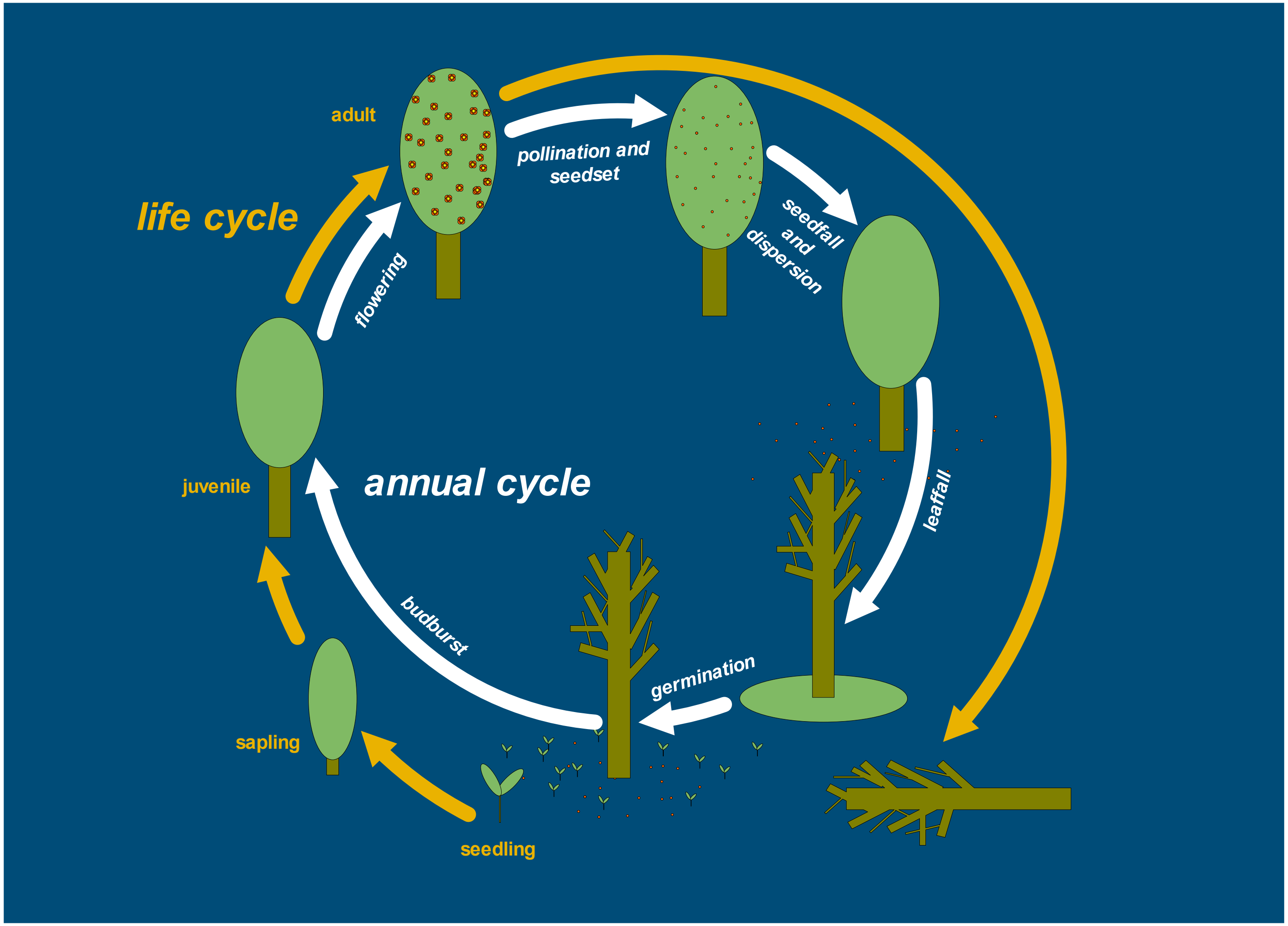
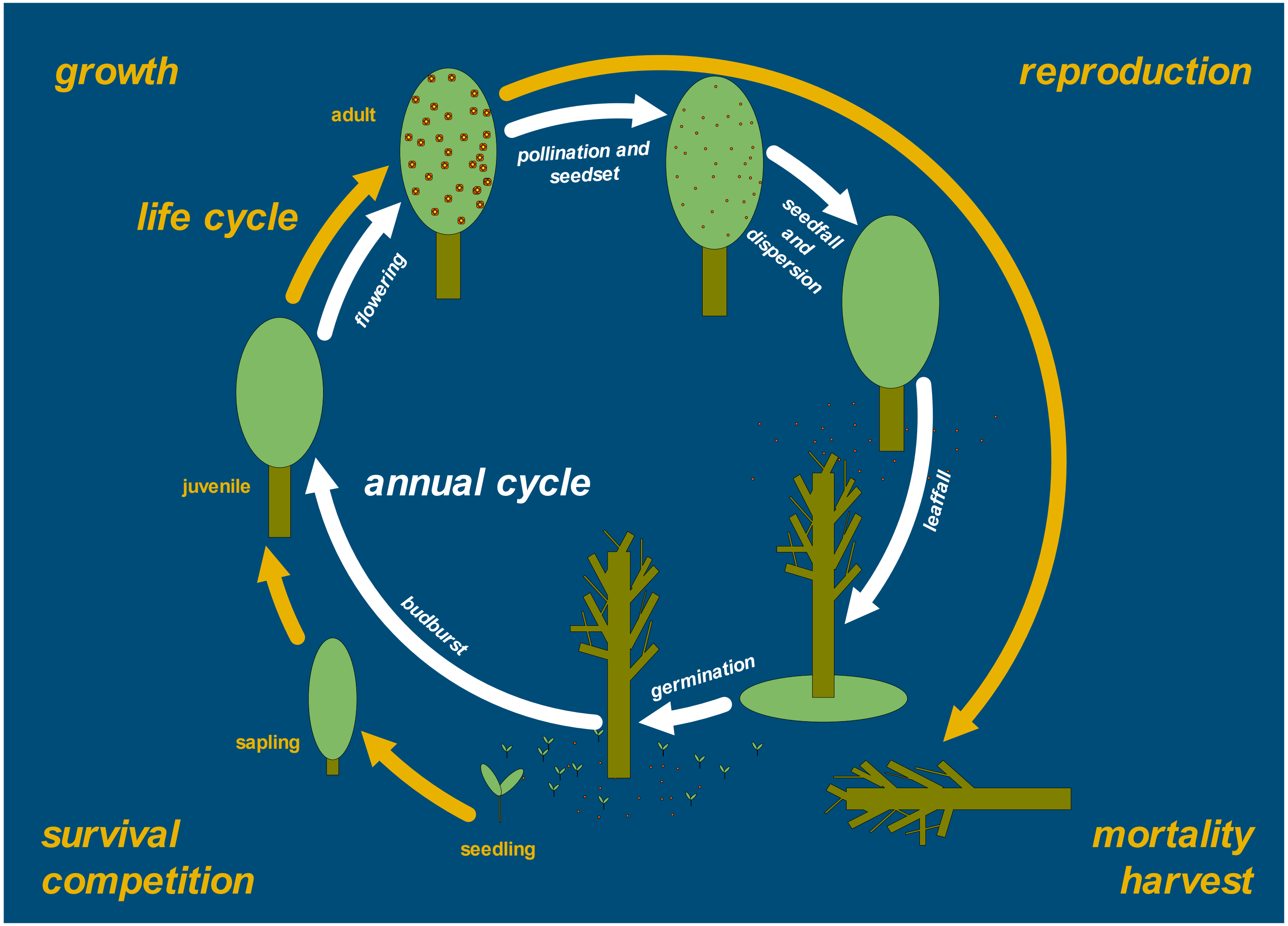


Life and annual cycle



Approach of genetic component of ForGEM

Selection of phenotypic feature relevant in for competition, survival or establishment. E.g.:

- **Timing** (budburst, flowering, germination, ….)
- **Tolerance** (frost, wind throw, drought, ….)
- **Efficiency** (resource utilization => Competition)

Genetic processes: selection & migration

Quantify genetic model for phenotypic trait, default:

- 10 loci; 2 alleles per locus per trait
- no recombination
- additive genetic variance
- no mutation
- initial allelic frequency based on equilibrium assumption (Nei)
- allelic effects such that mean and variance of trait in observed population are met

Modeling genetics

Creating new individuals from parents:

New (parameter) *value* = genetic model + value drawn from distribution (based on environmental variance)

Deterministic part:

- To keep track of genome define Genome subsystem of tree/seed
- DNA model (e.g. GLM): Allele value on Locus defines a parameter value in equation
- Haploid, diploid, …
- Multi locus, multi alleles, initial allele distribution

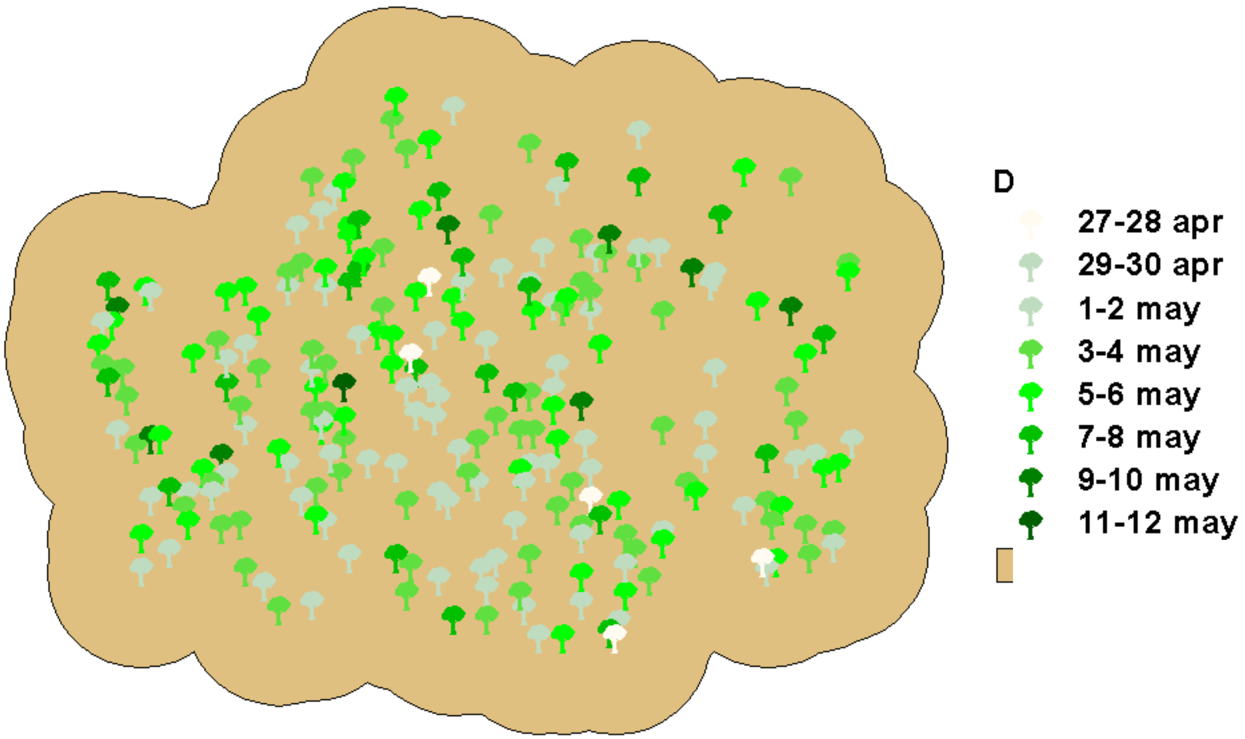
Probabilistic part:

- Create new distribution on basis of the *value* of parents and draw from that distribution
- Need genetic variance and environmental variance

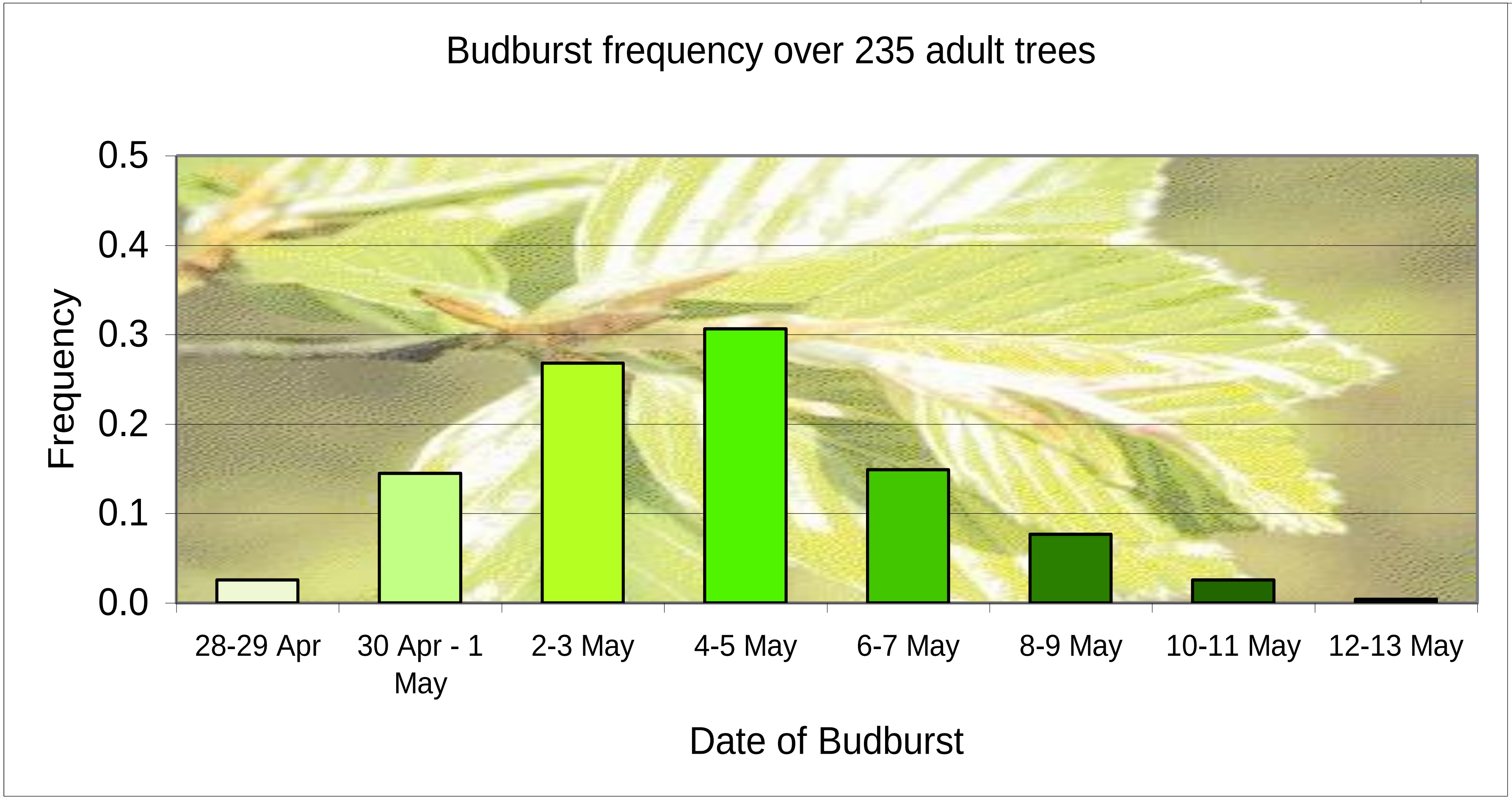
Import pollen, seeds or even individuals from outside study area

example of link genotype-phenotype

Phenotype (budburst) parent trees



Example link genotype-phenotype



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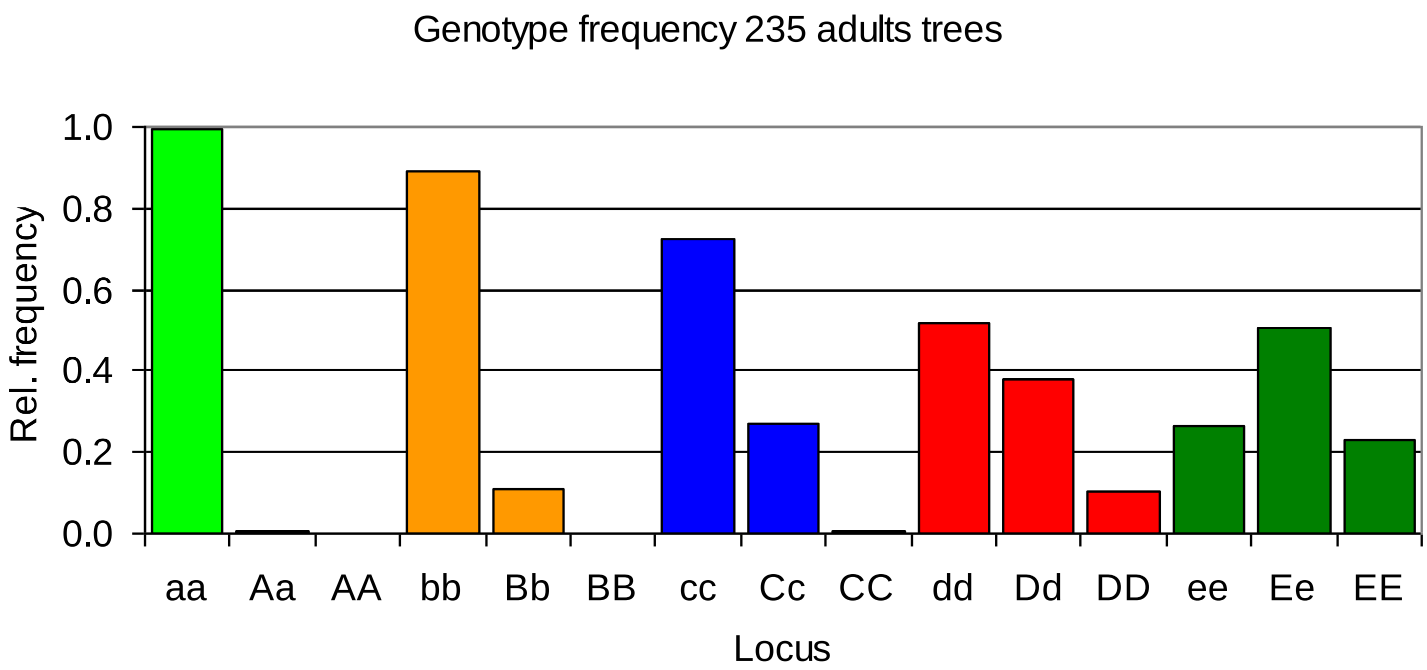
Example allele frequencies in population



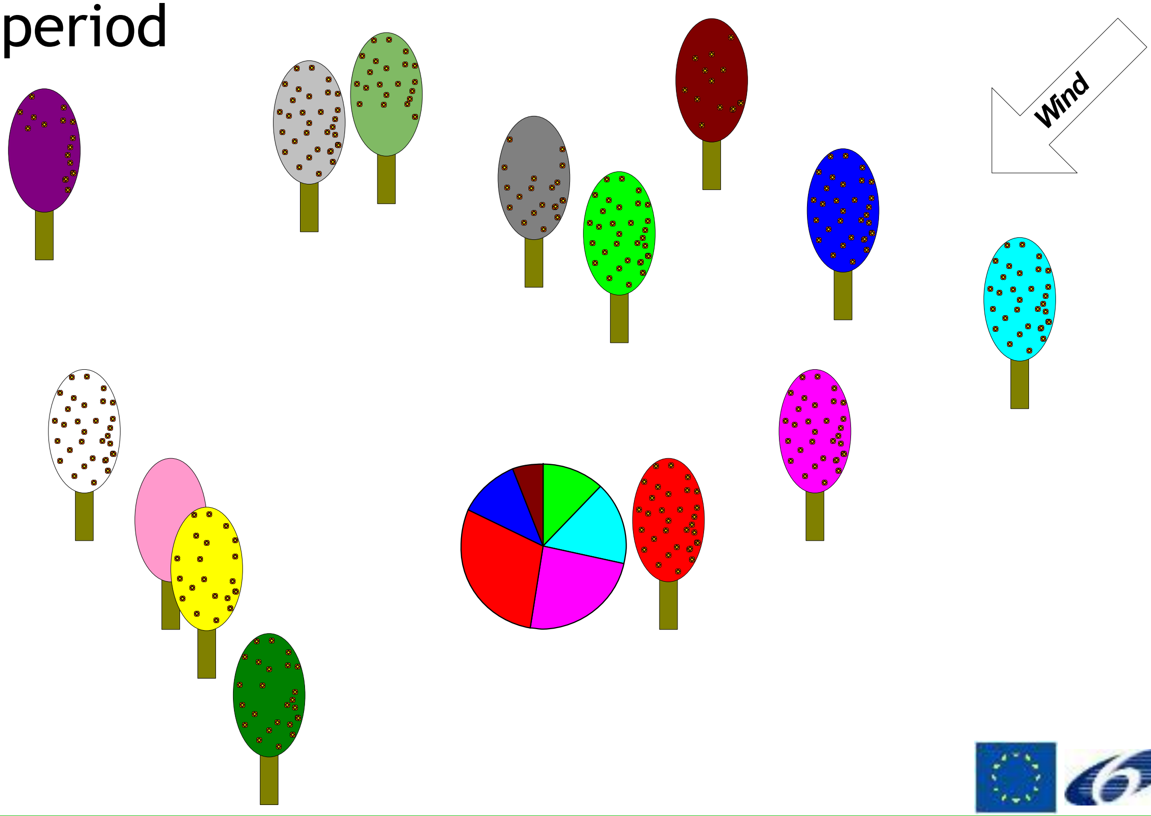
Procedure:

- Assign a allelic value to each allele
- Add all values together
- Add environmental deviate

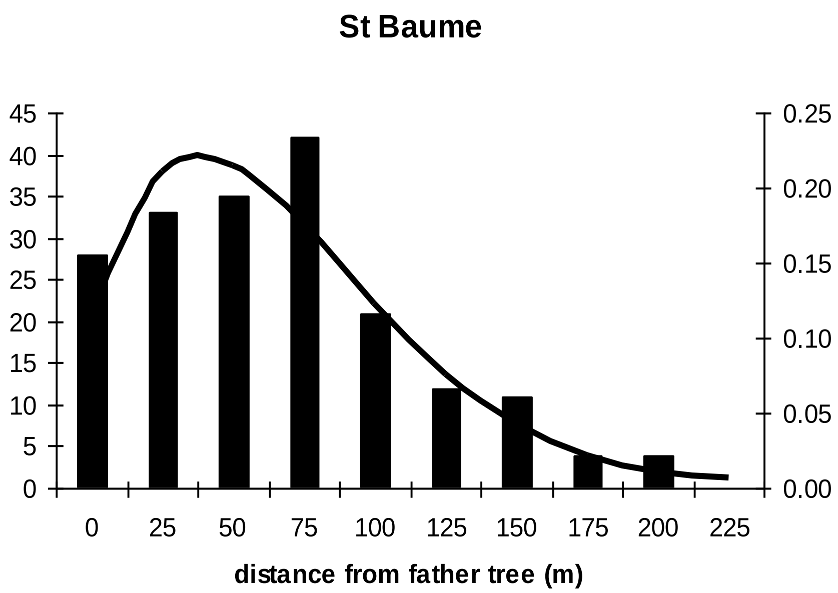
Pollination

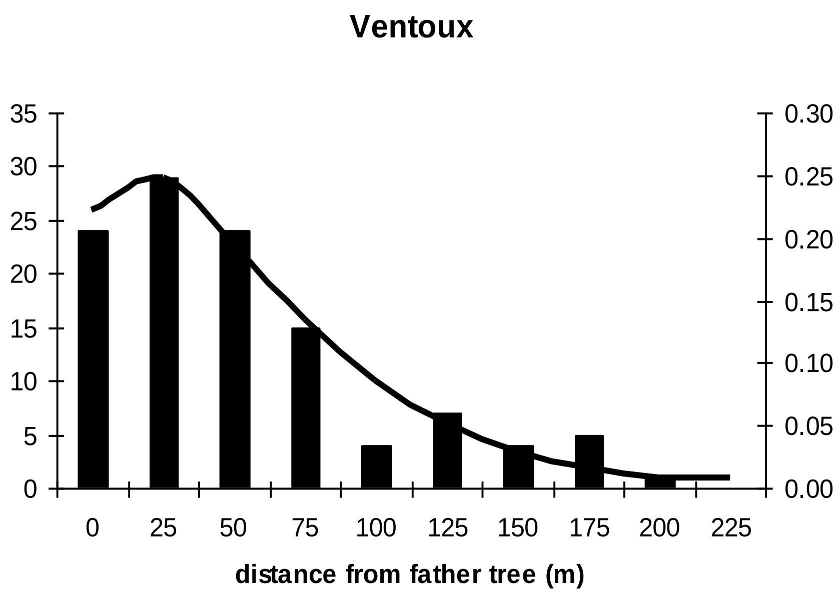
Fraction pollen at mother tree:

- Wind direction and –speed
- Number of flowers
- Overlapping flowering period
- Self pollination
- Pollen from outside
- Compatibility



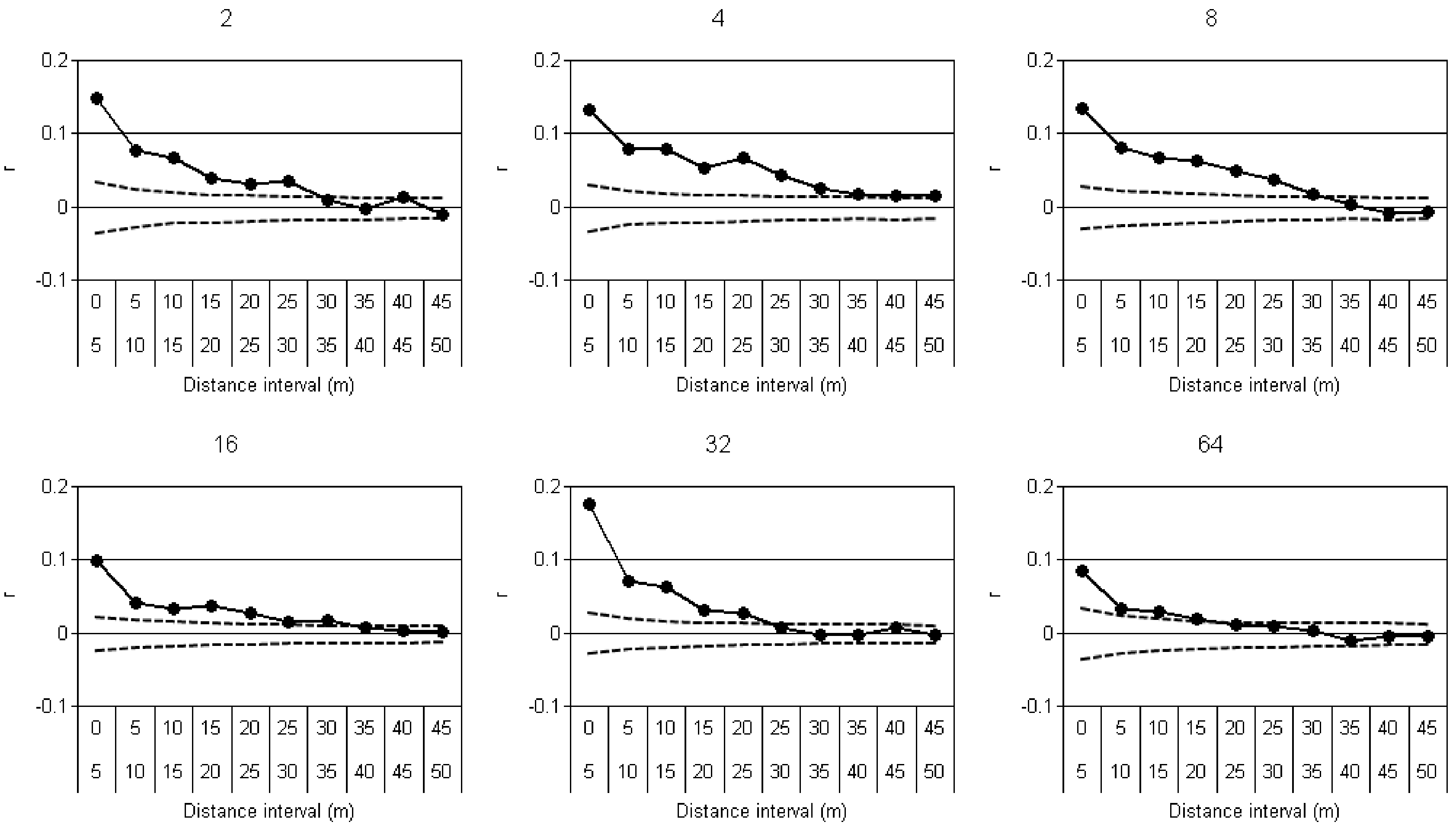
Pollen dispersal curve





Observed and estimated pollen dispersal curve in France.

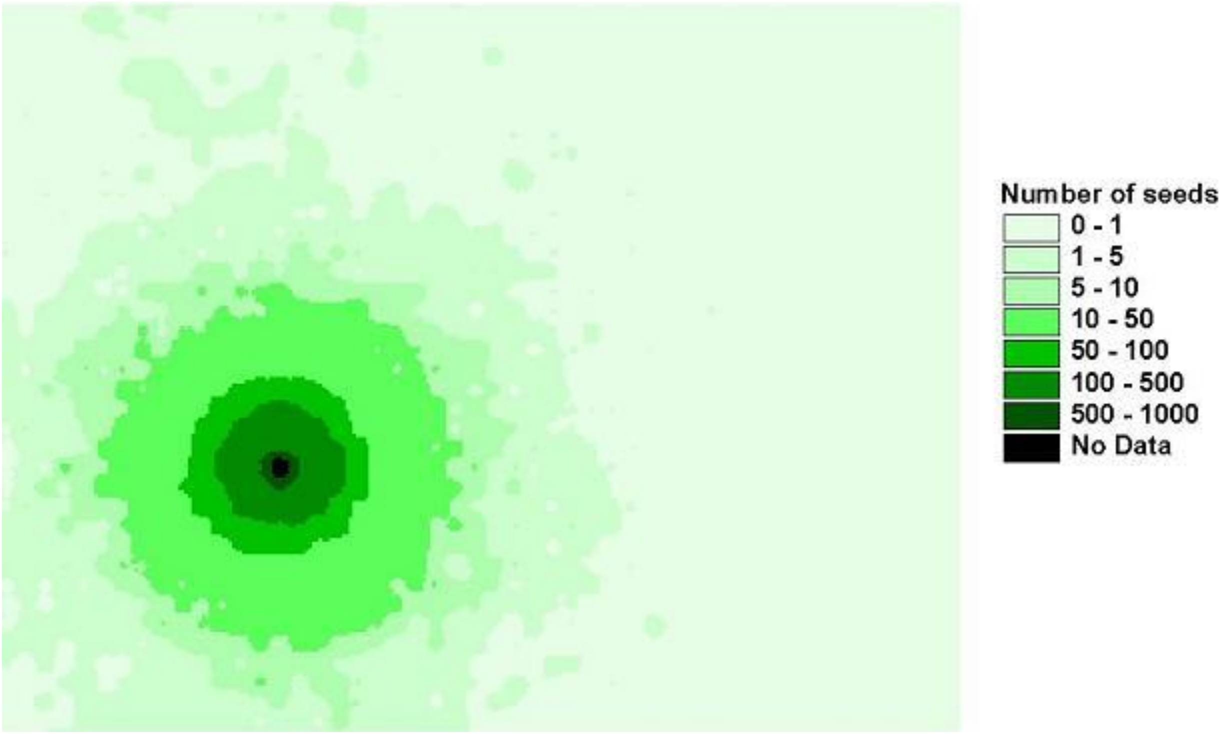
Sensitivity analysis



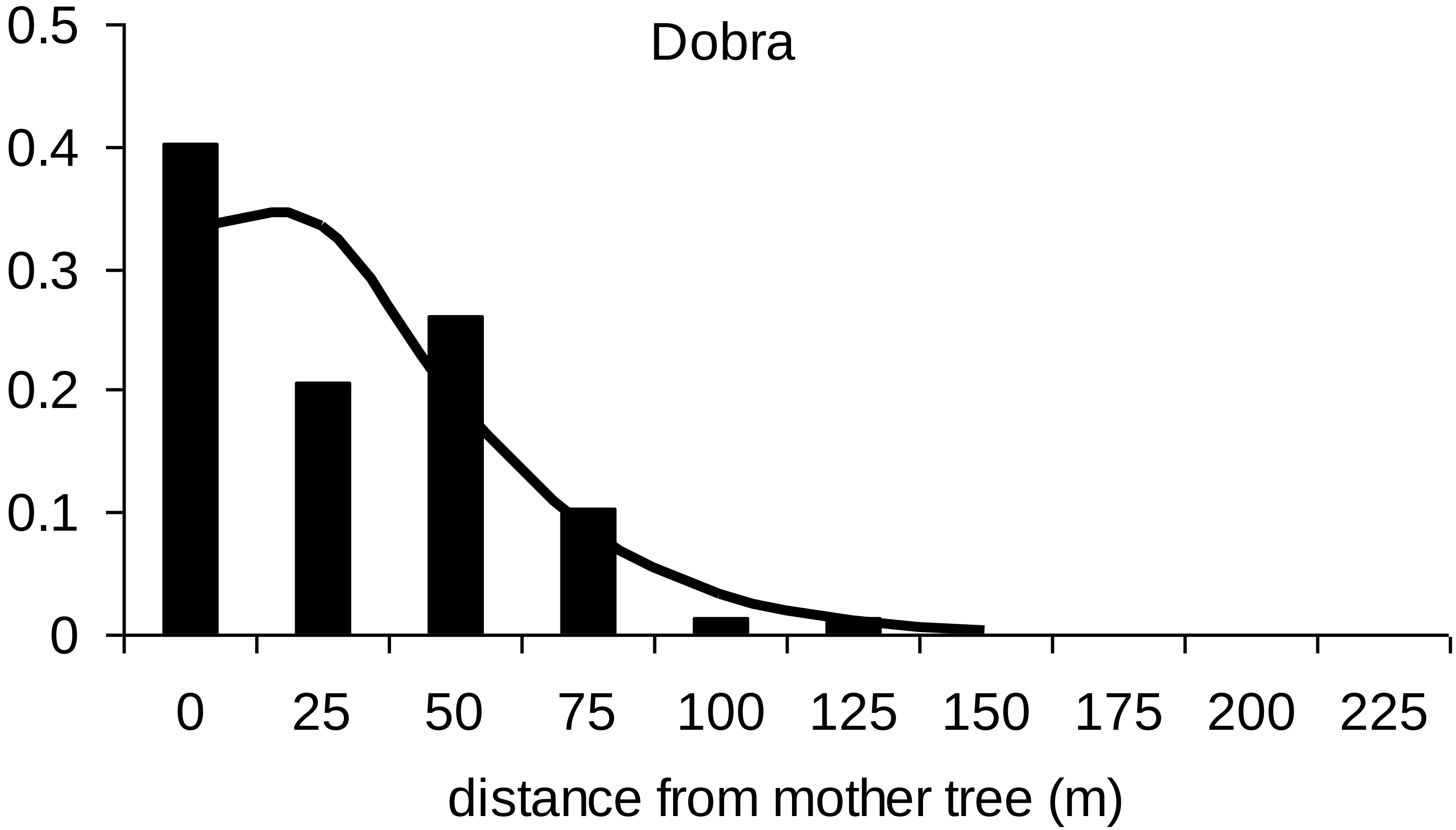
Effect of pollen dispersal distance (expectation of Weibull curve) on spatial genetic structure (t=300yr)

Seed dispersal

Depends on distance function to tree

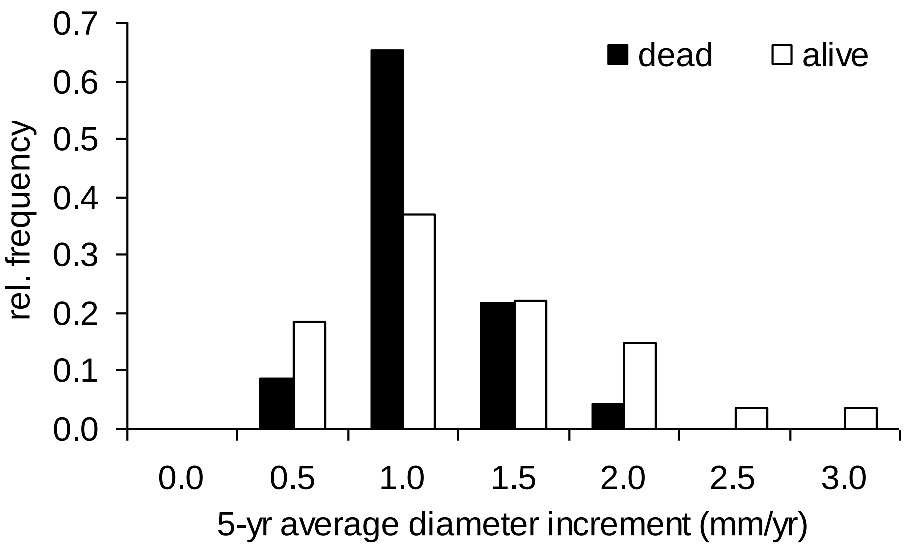


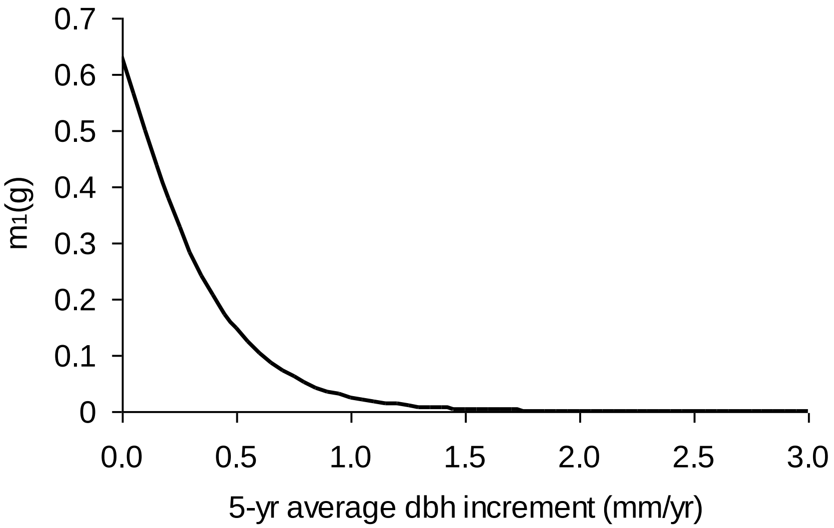
Seed dispersal function



Observed and estimated seed dispersal curve in Austria

Mortality





Observed distribution of diameter increment of currently living and currently dead trees

Derived probability of annual mortality depending on growth (Kobe & Pacala)

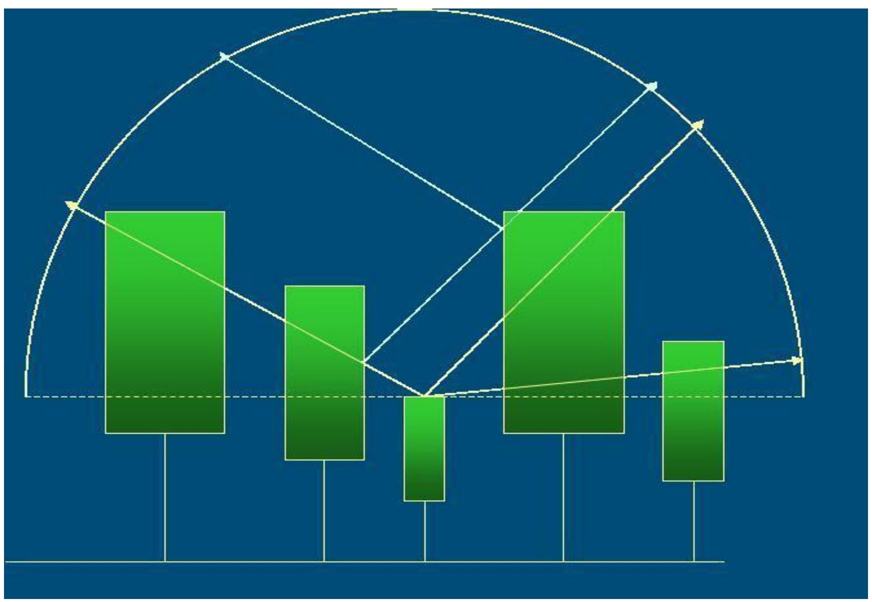
observations: Nico van Kappel

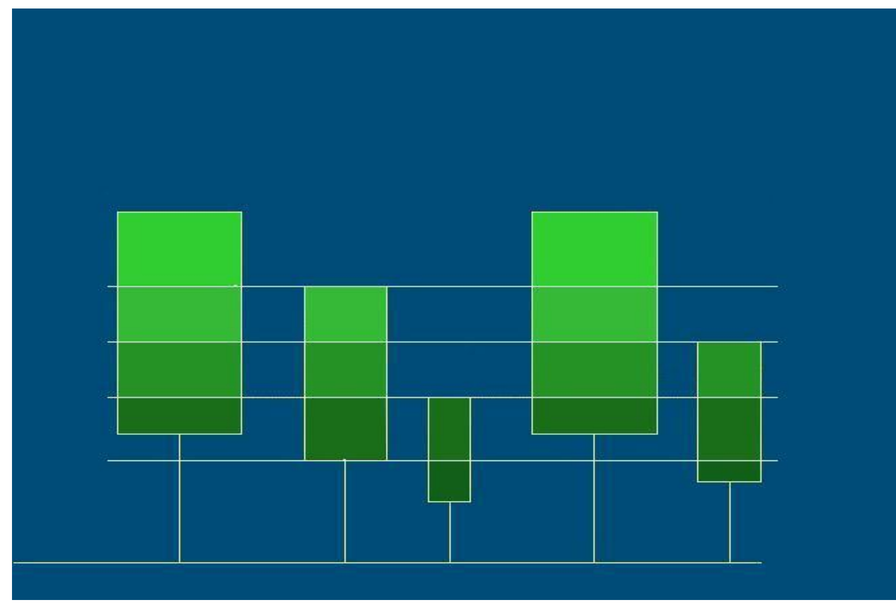
Light interception

Ray tracing or Gap model

Gap model for seedling and ray tracing for ‘adults’

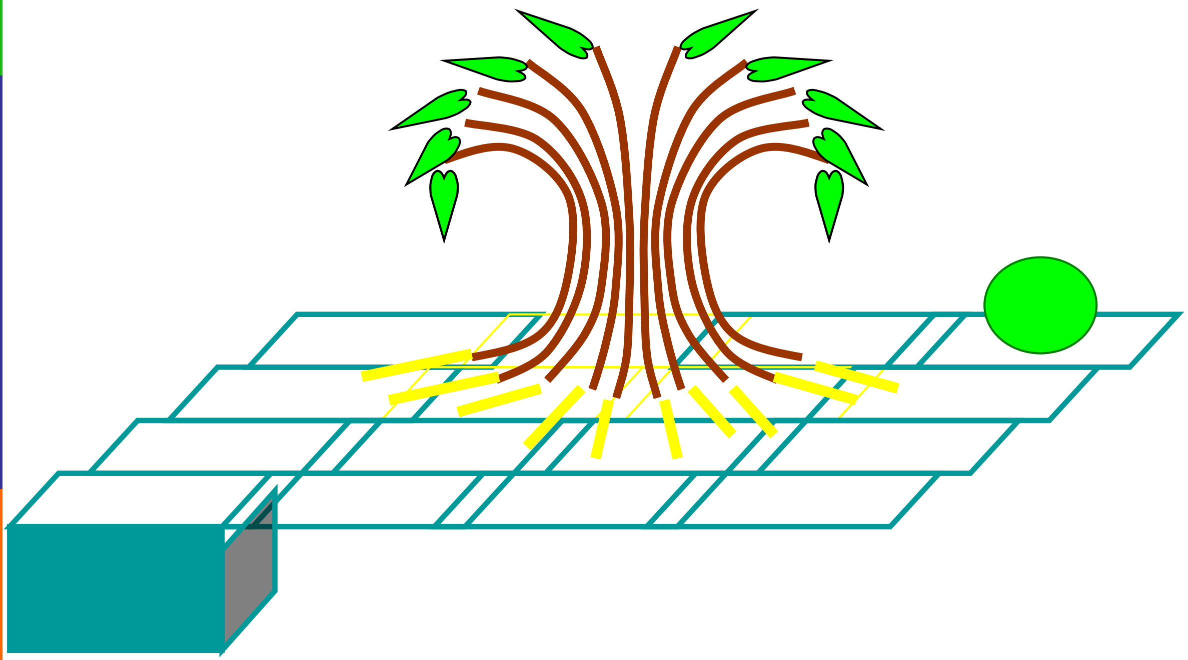
Purpose: amount of energy intercepted by the plant

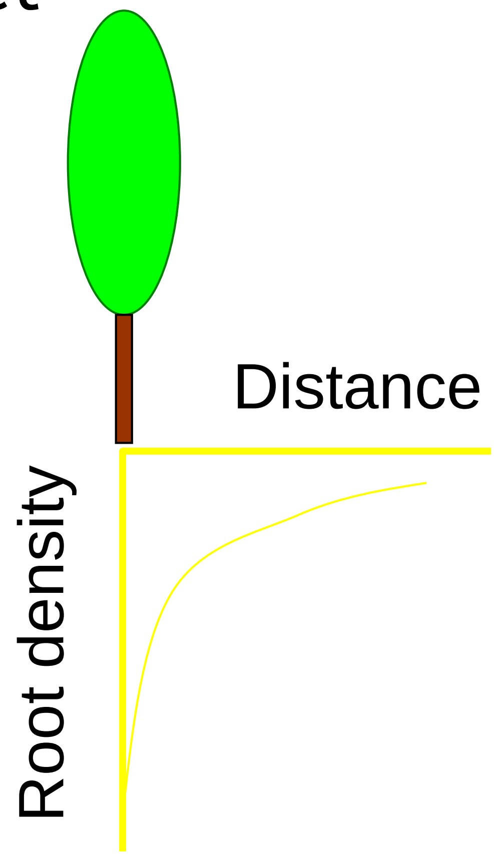




Water use

- Gas exchange (e.g. temp, humidity, radiation) => water need
- Dependent on root density per pocket
- Water exchange between pockets

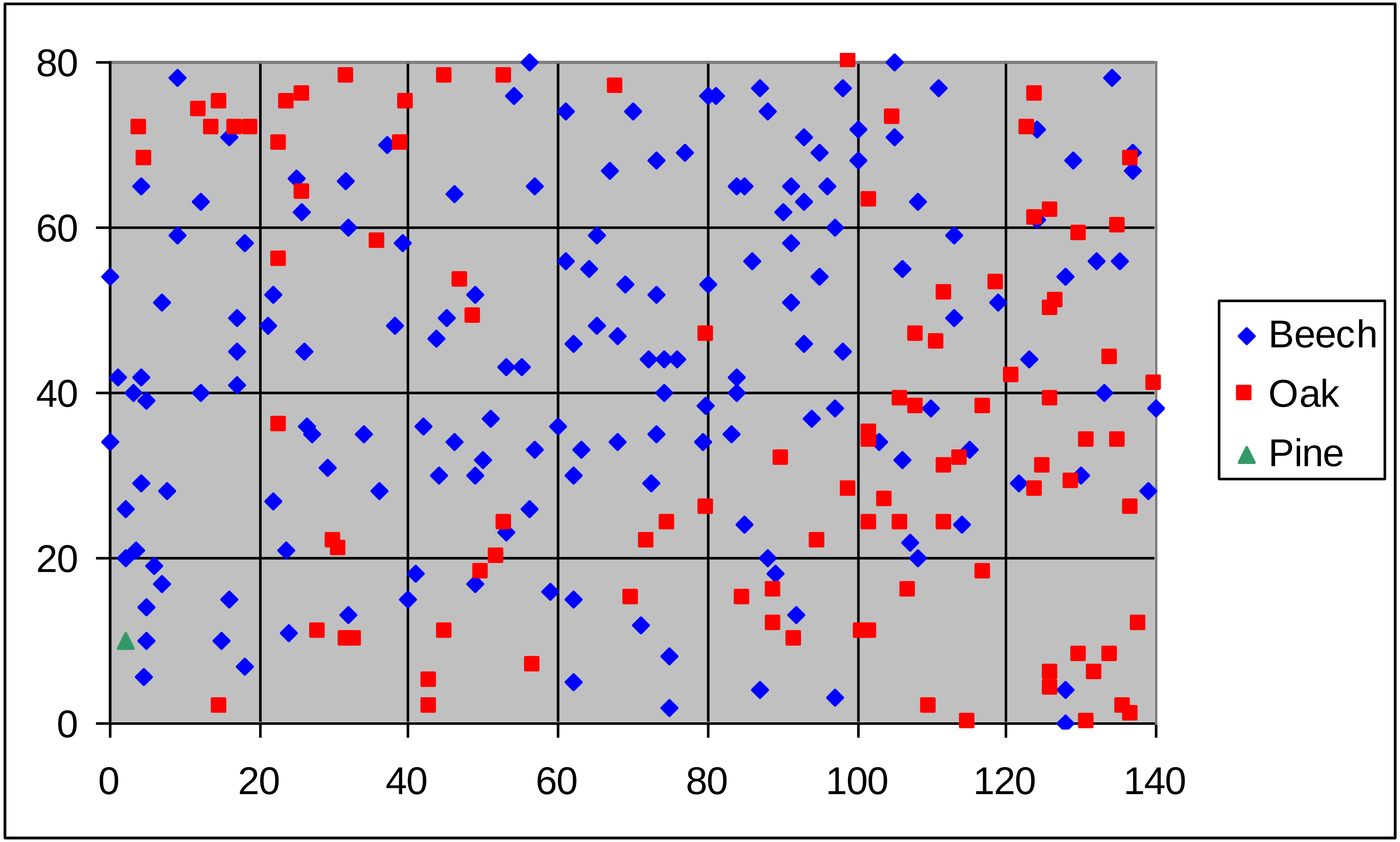




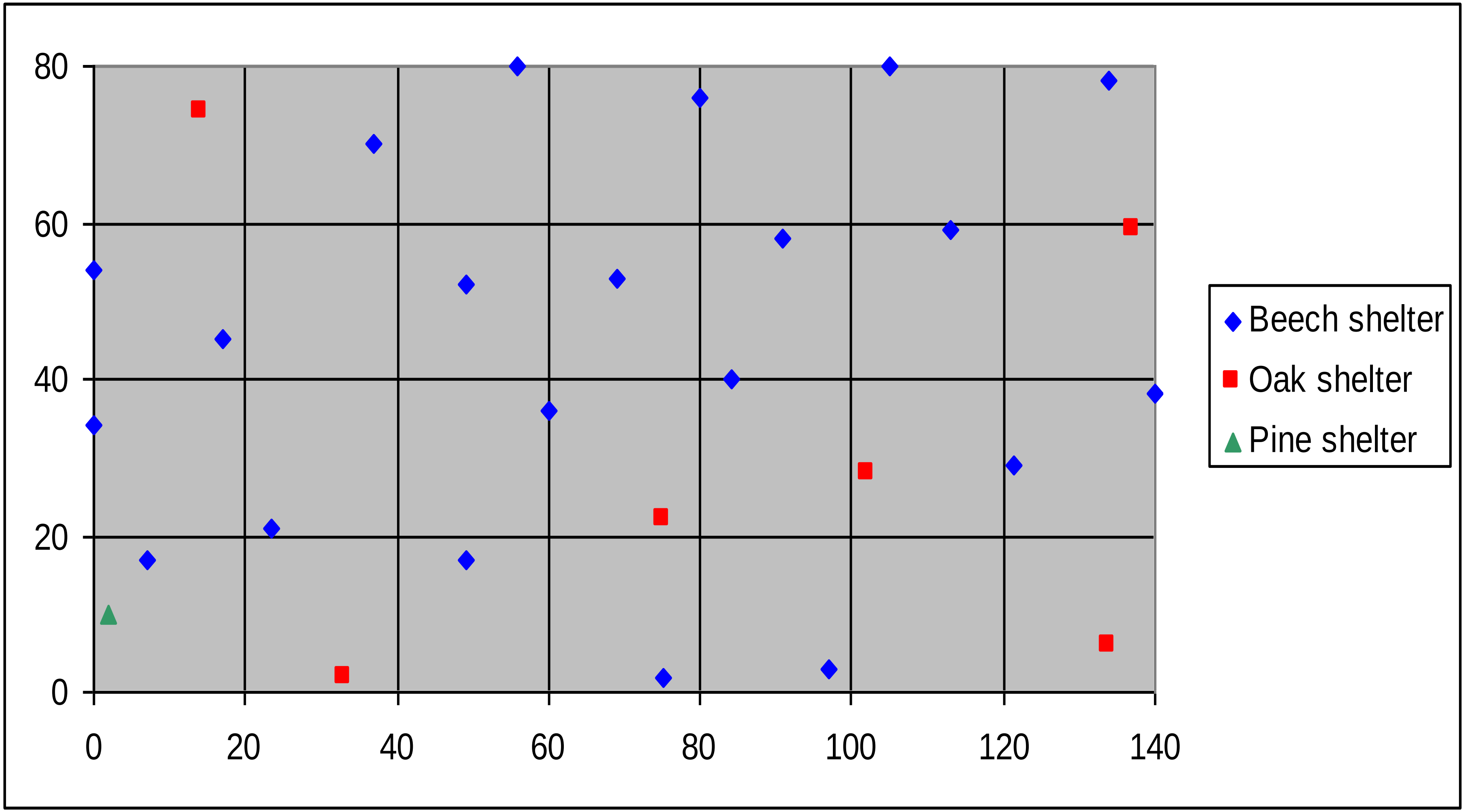
Forest management

- Sheltercut
- Group selection
- Future tree selection

Sheltercut: initial situation



Sheltercut: regeneration felling



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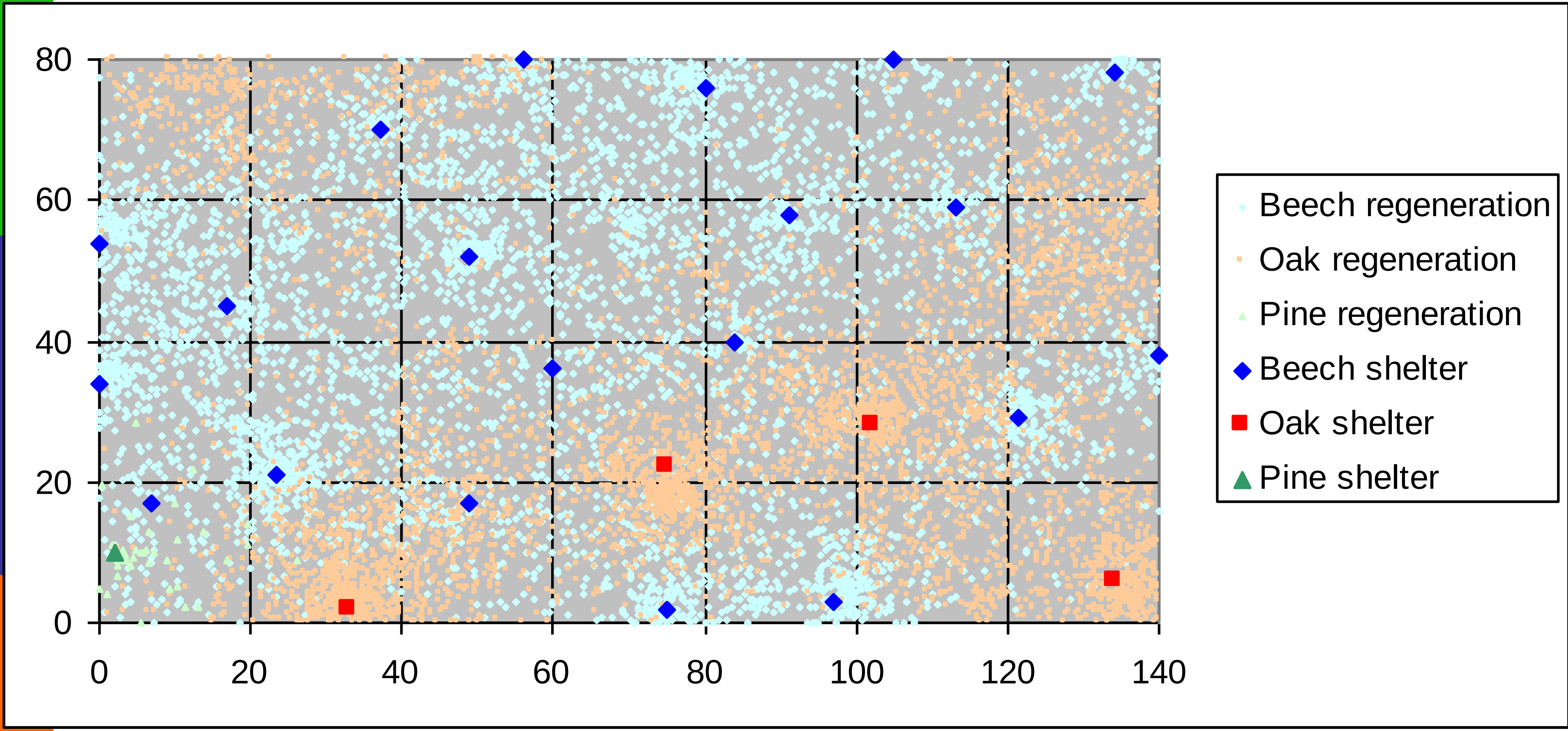
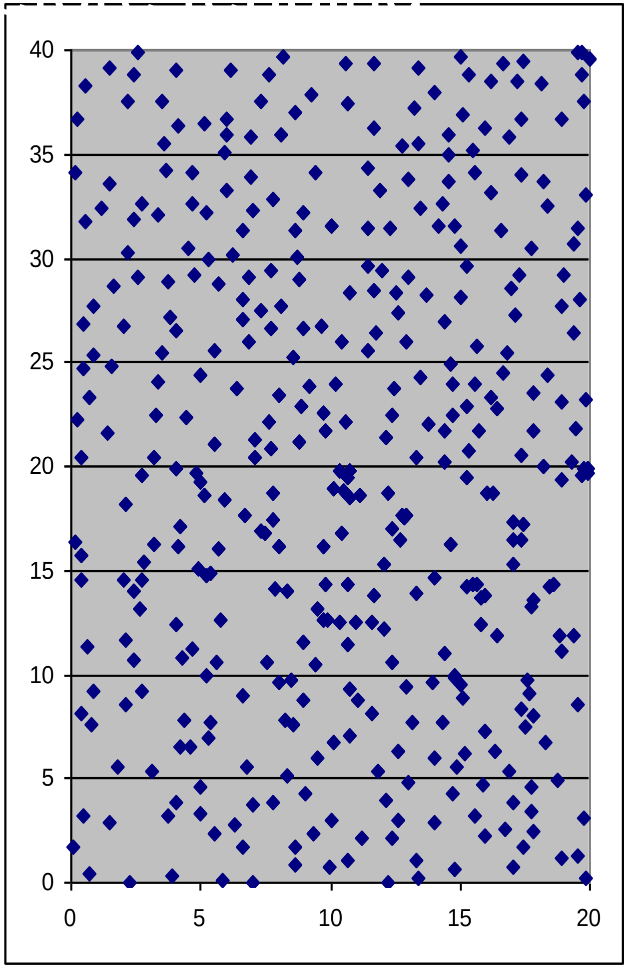
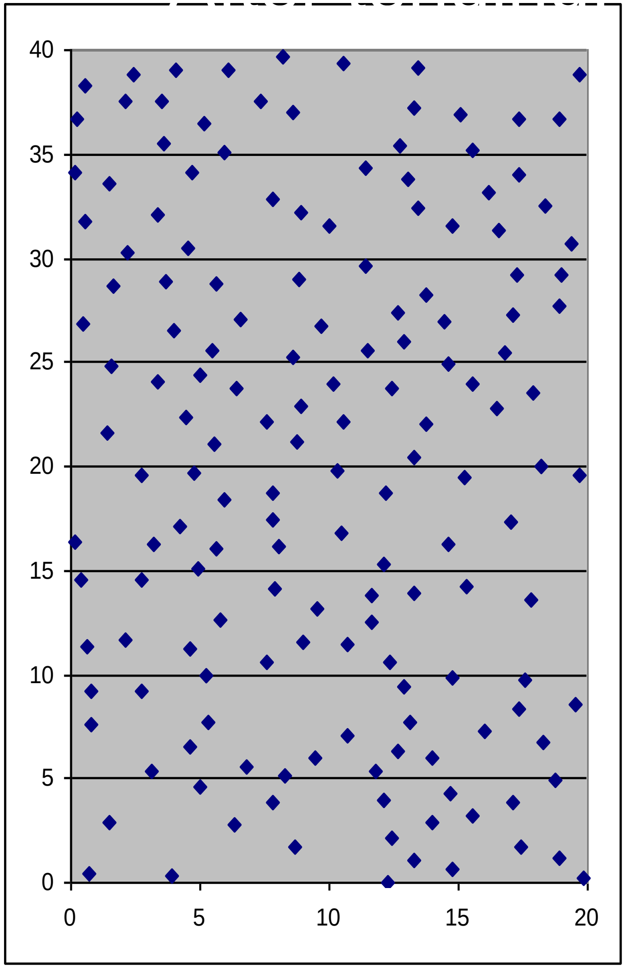


Sheltercut: tending

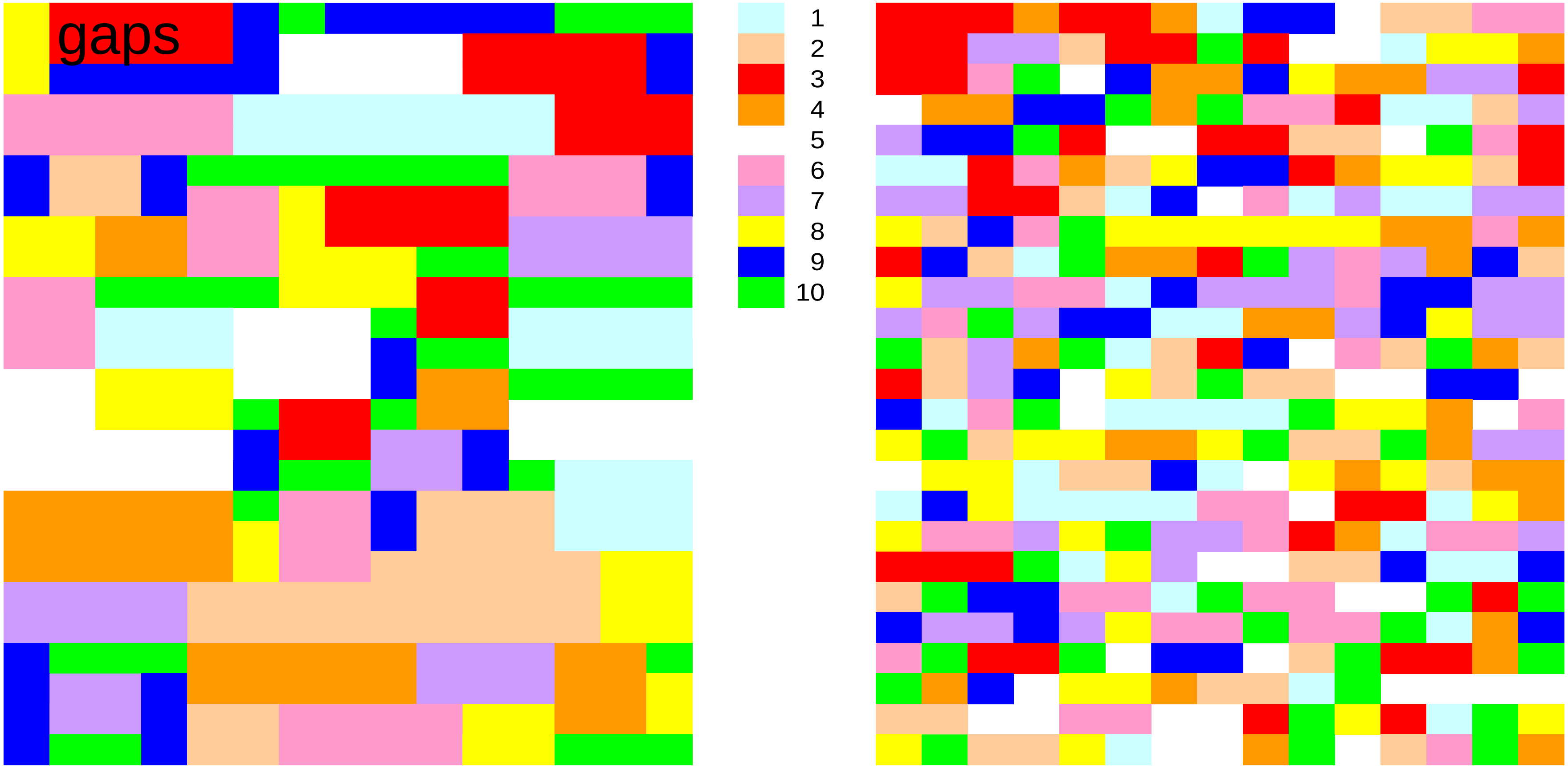




Group selection

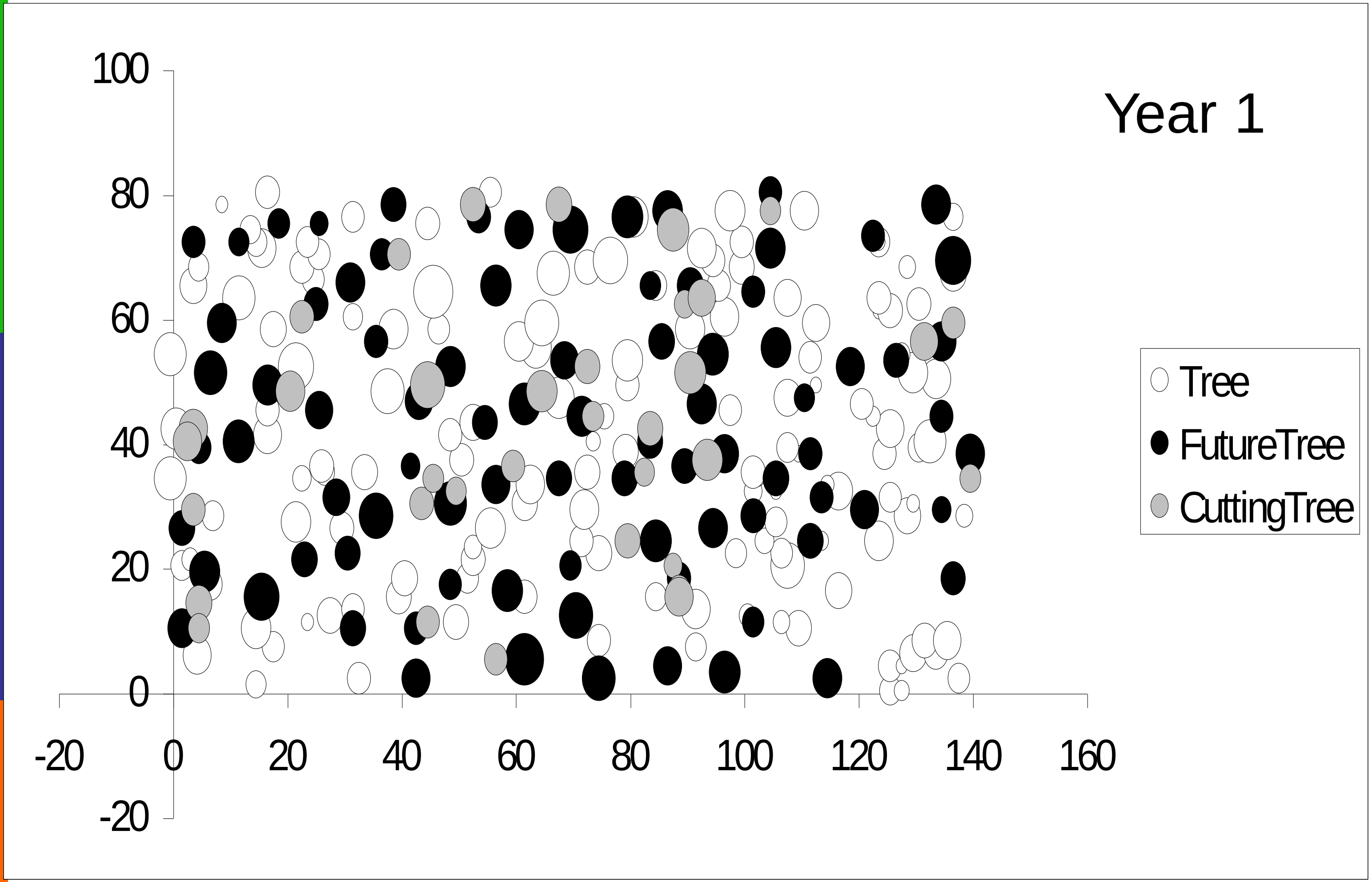
Small and large gaps

Mainly small

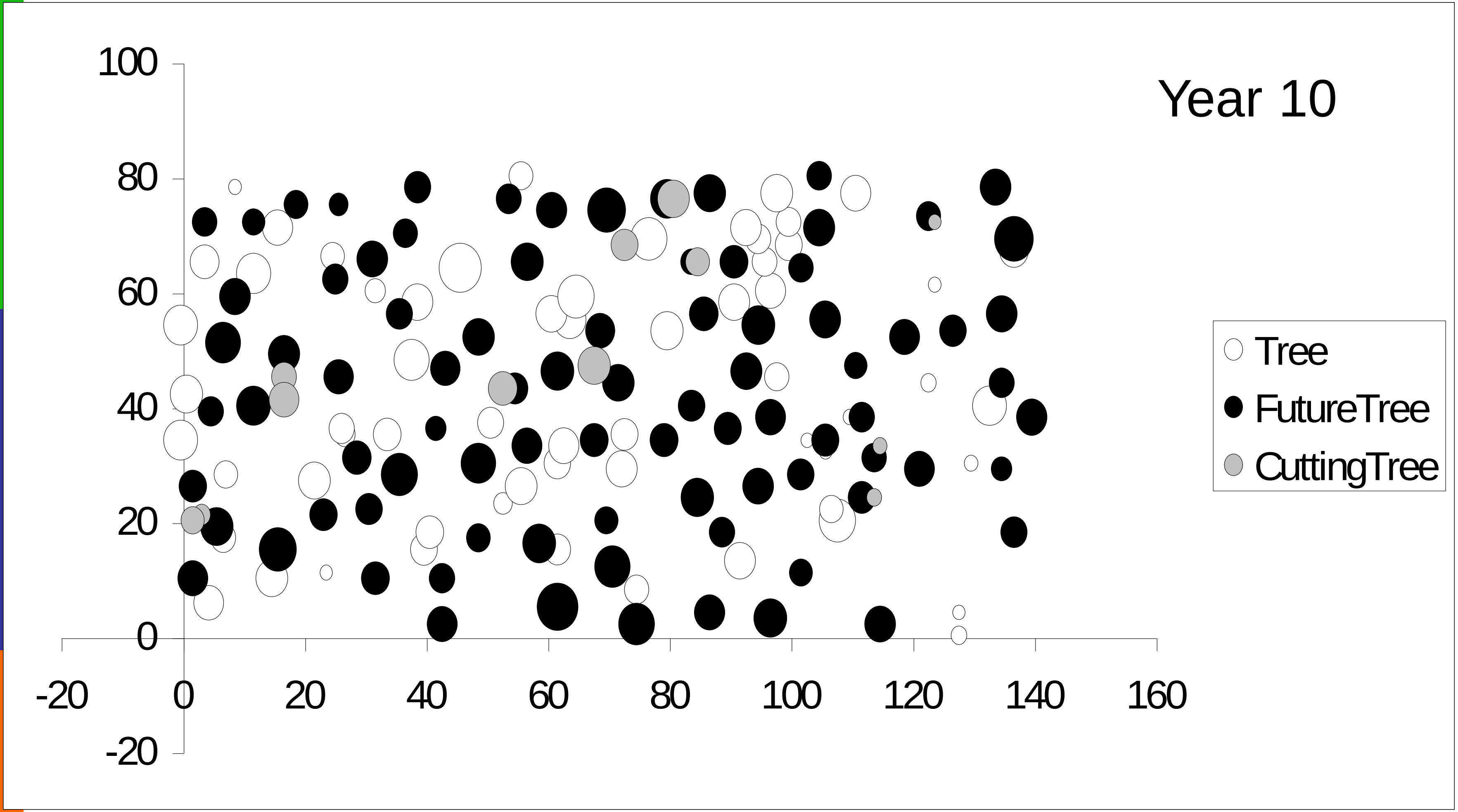


Gridsize: 20x20m

Future tree selection



Future tree selection



Structure of the presentation

Modelling principles

The model ForGEM

- genetic components
- eco(physio)logical components
- forest management

Examples: impact of forest management on:

- basal area
- tree density
- phenotypic value of genetic traits
- response of phenotypic trait values
- genetic diversity
- spatial genetic structure

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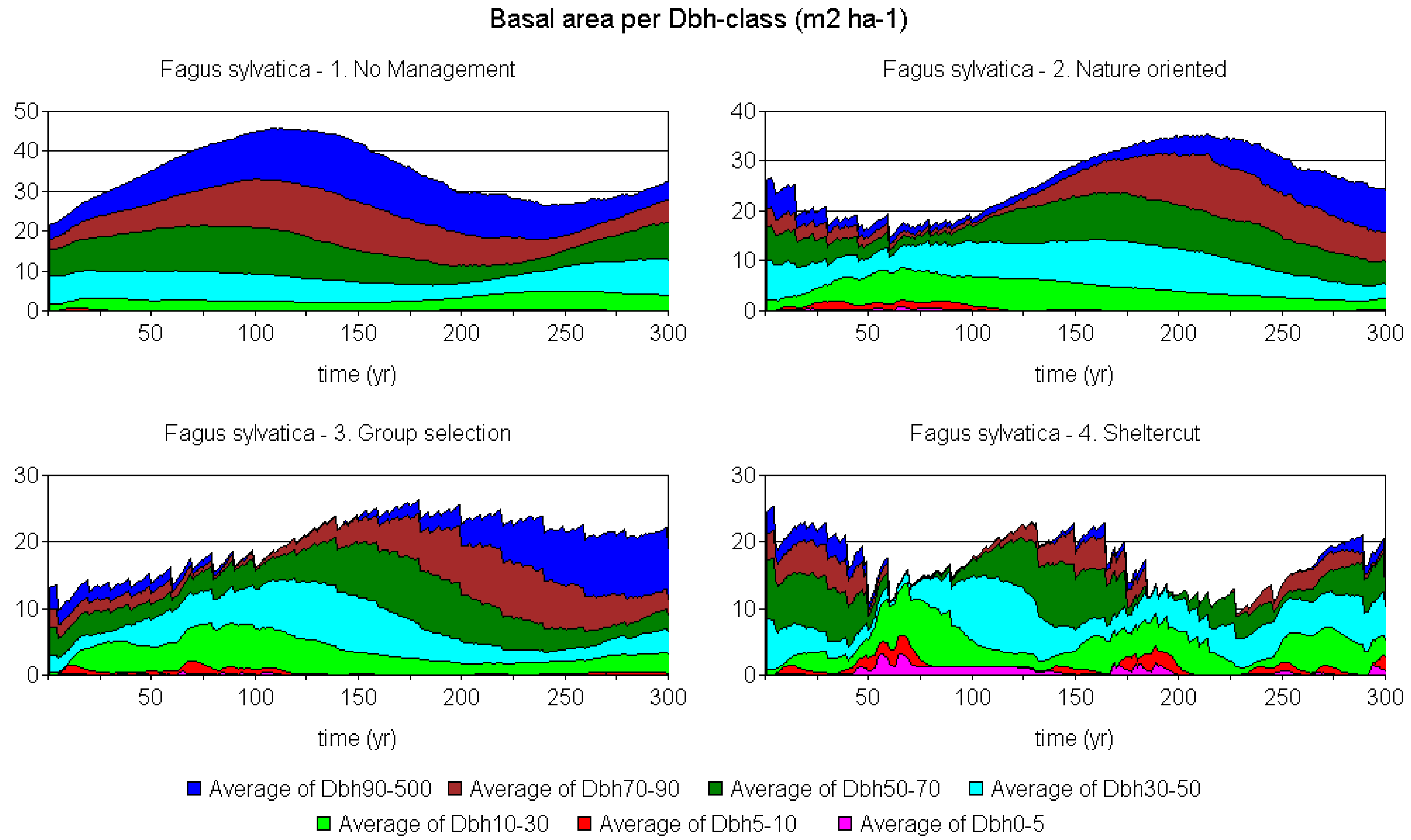
Modelling the annual cycle

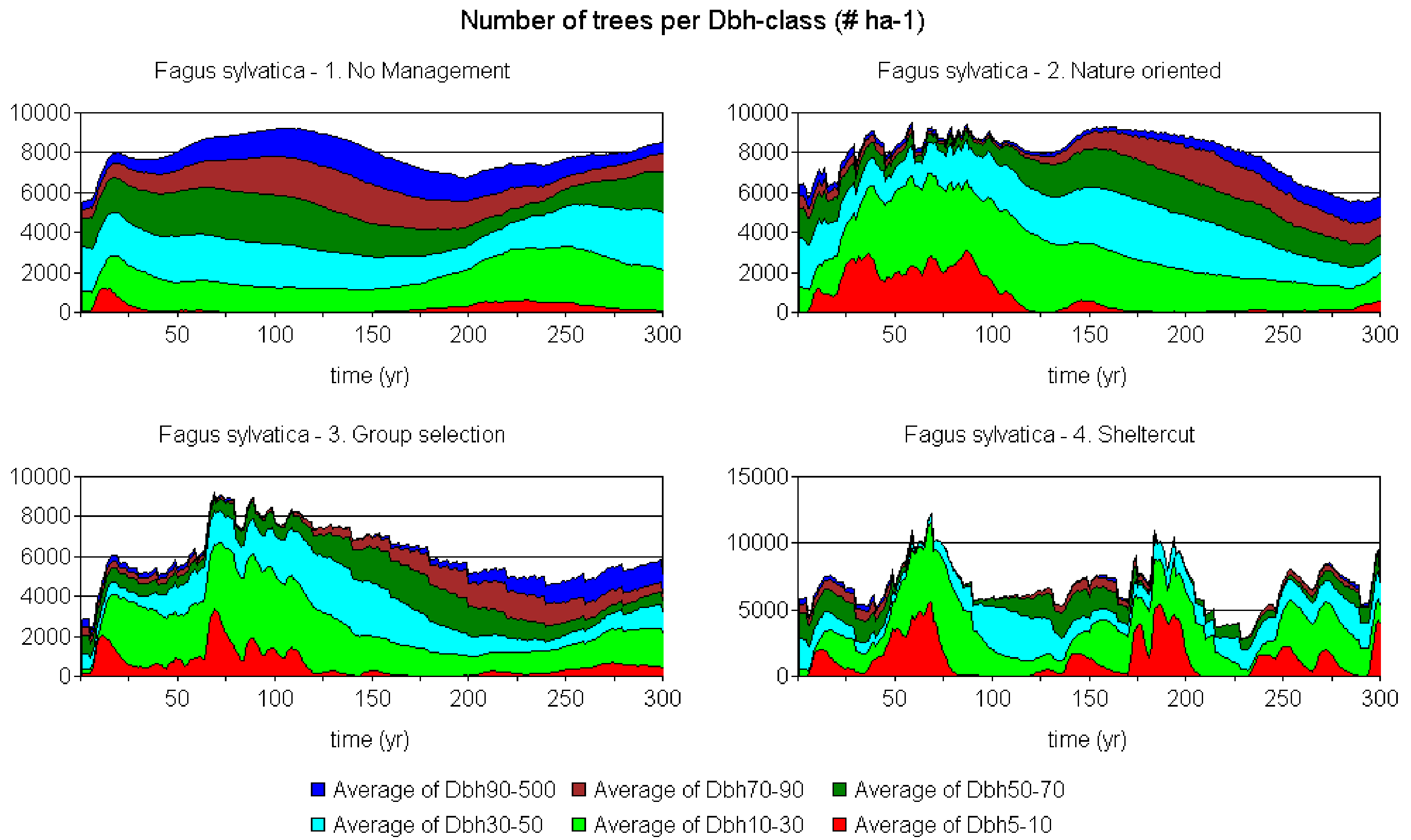
Examples: impact of climate change

Basal area

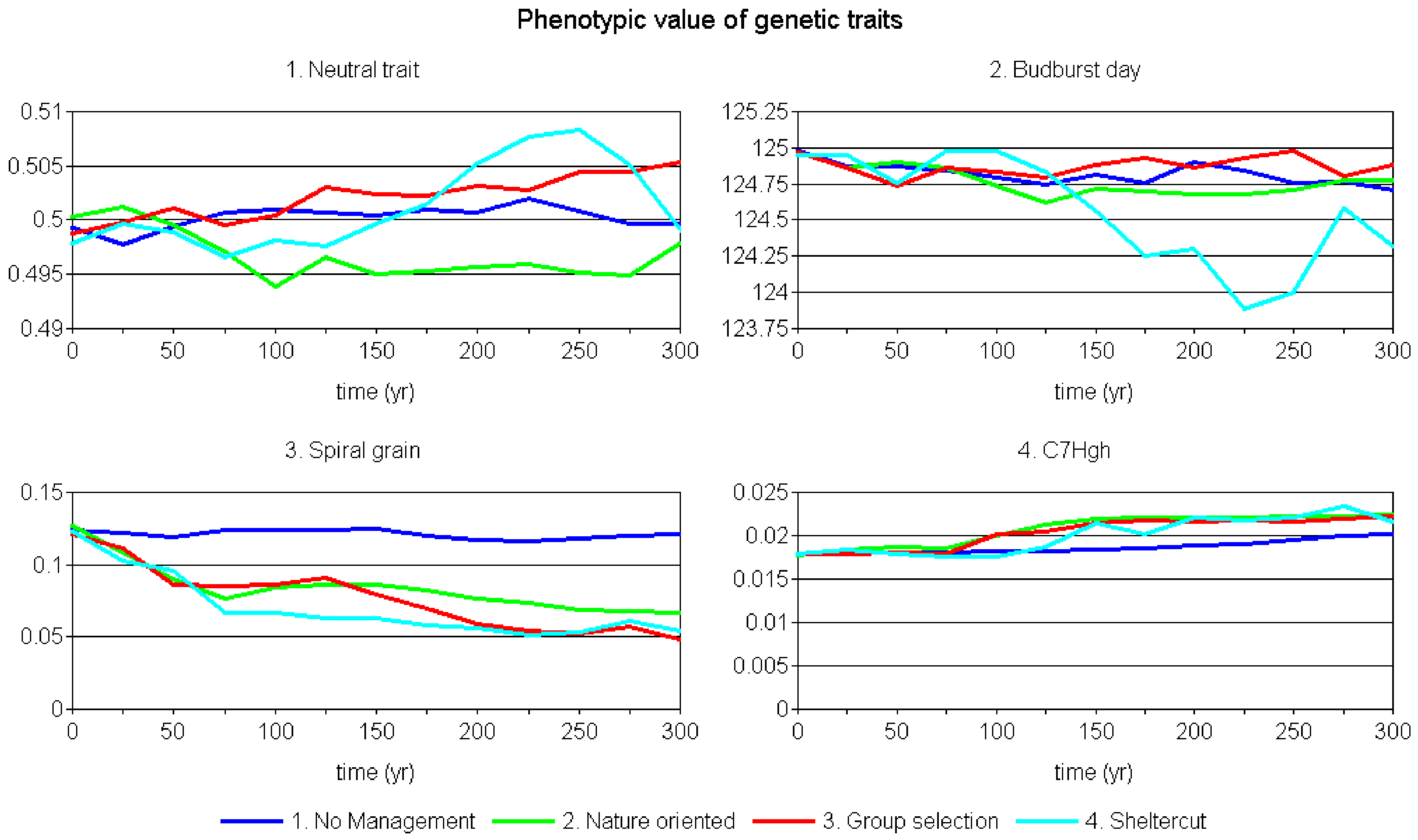


Basal area per Dbh-class (m2 ha-1)
Fagus sylvatica - 1. No Management
Fagus sylvatica - 2. Nature oriented
Fagus sylvatica - 3. Group selection
Fagus sylvatica - 4. Sheltercut
time (yr)
Average of Dbh90-500
Average of Dbh70-90
Average of Dbh50-70
Average of Dbh30-50
Average of Dbh10-30
Average of Dbh5-10
Average of Dbh0-5

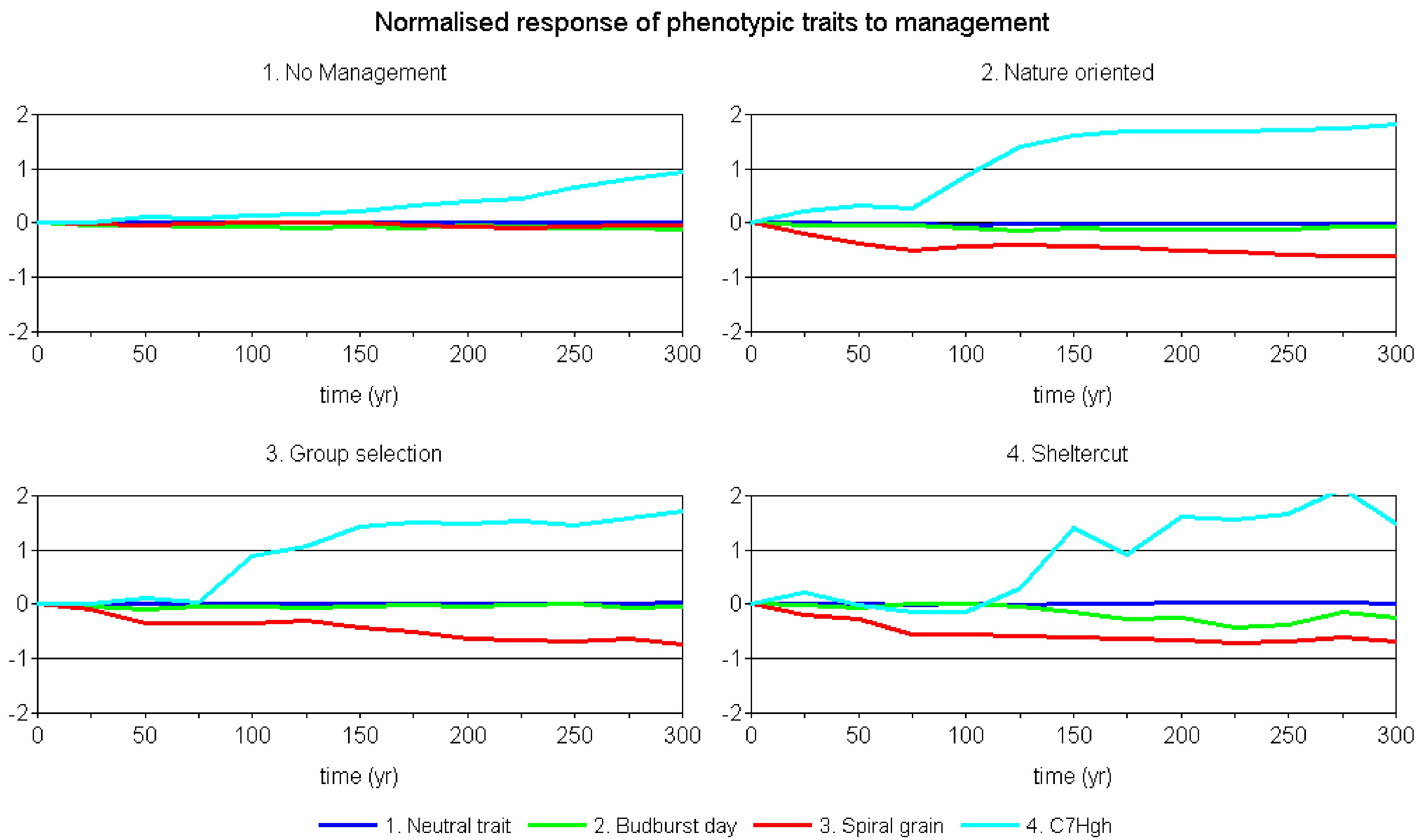
Tree density



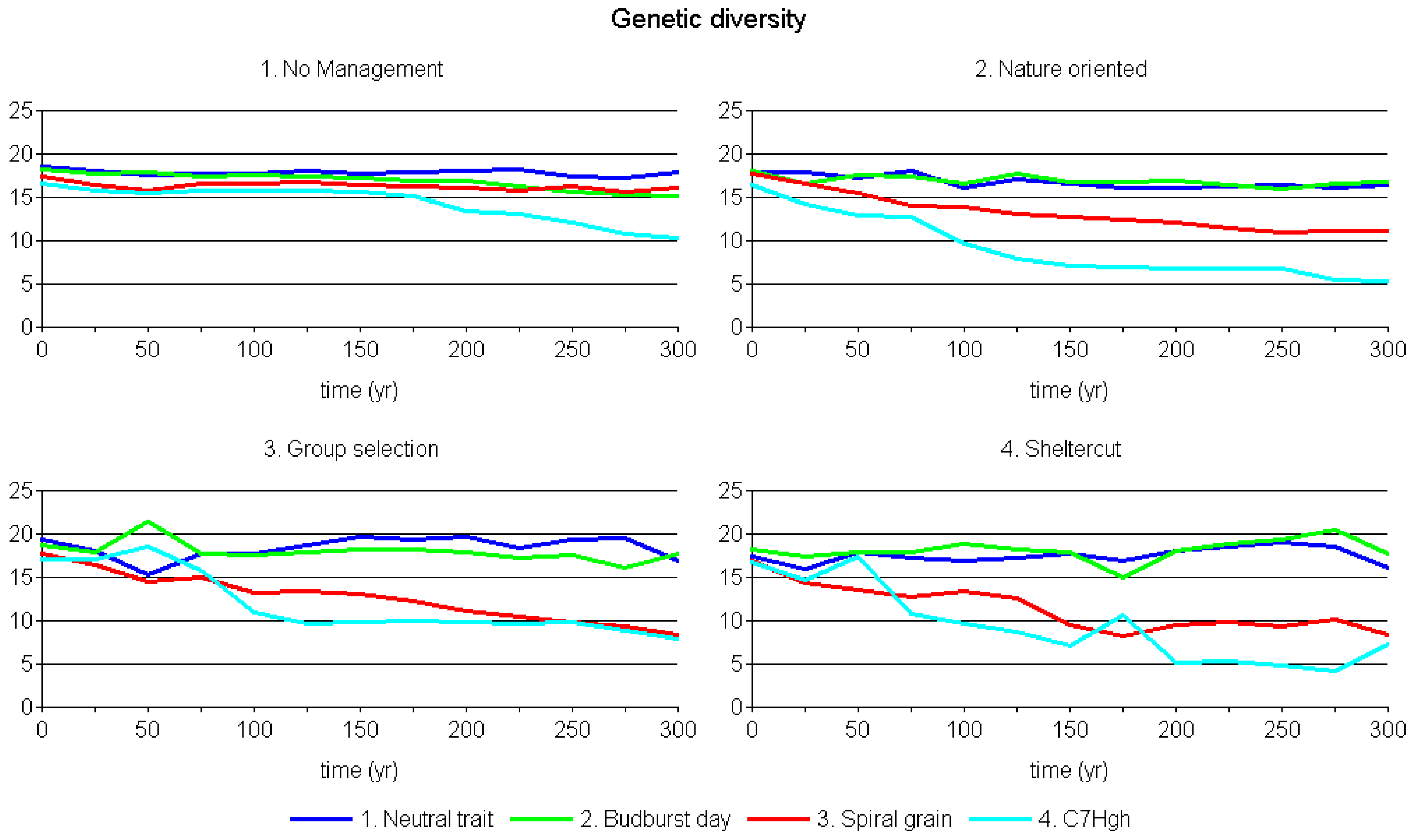
Genetic traits



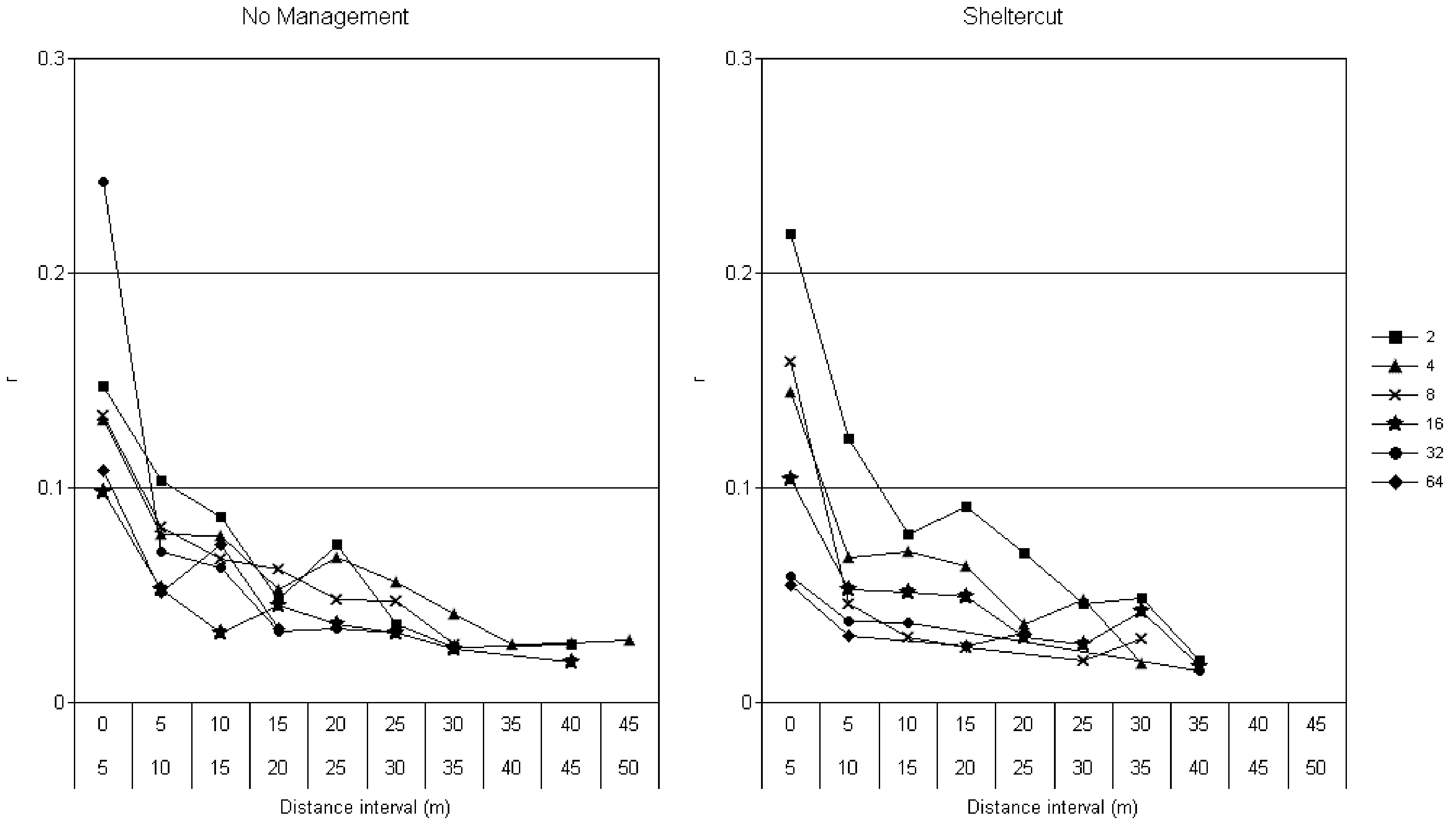
Normalized responses



Genetic diversity



Interaction of management and pollen dispersal distance on spatial genetic structure



Significant autocorrelations at varying expectations of Weibull distance curve for pollen dispersal (t=300yr)

Some conclusions:

Adaptive ability of a population to environmental changes depends on:

- Available genetic variation for adaptive traits
- Rate of change in genetic composition

Role of management in adaptive response of trees:

- Strongly influences regeneration interval of beech
- => allows population to adapt quicker to environmental changes
- => however, reduces the genetic diversity

time to break...