Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems

Forest Systems 2010 19(SI), 100-112
ISSN: 1131-7965
eISSN: 2171-9845

Equilibrium and non-equilibrium concepts in forest genetic modelling: population- and individually-based approaches

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Structure of the presentation

- Equilibrium vs. non-equilibrium approaches in forest genetic modeling
  - Eq.: Population-genetic modeling
  - Non-eq.: Individually-based modeling

- Exampes non-eq modelling - traits under rapid evolution:

- Discussion
  - Pros and cons of eq. and non-eq. genetic modeling to include in regular forest models

- Conlusion
  - On which genetic model to add to existing forest model

Equilibrium or demographic approach

- Assumption:
  - Environment is stationary (no trends in space nor time) relative to the rate of recovery after a perturbation
  - => following a perturbation the population returns to a previous (thus know) stable state: equilibrium
  - => we can use current knowledge on dependency of stable state to environmental factors to assess future stable states
- Traits to differentiate populations, e.g.:
  - Fecundity, survival, competition, dispersal, biomass, height, bud burst
  - i.e. usually phenotypic plastic traits (GxE interaction)
- Model parameters under study e.g:
  - Demographic: carrying capacity (K), per capita growth rate (r)
  - Genetic: optimal phenotype (Z_{opt}), selection coeficient (ω)
- Model analyses, e.g.:
  - Recovery time (# generations) to a known (future) stable state, depending on genetic structure (dominance, epistacy) and / or spatial structure of the population
- Use:
  - Provides insight in system dynamics
  - Understanding of current patterns based on historic processes

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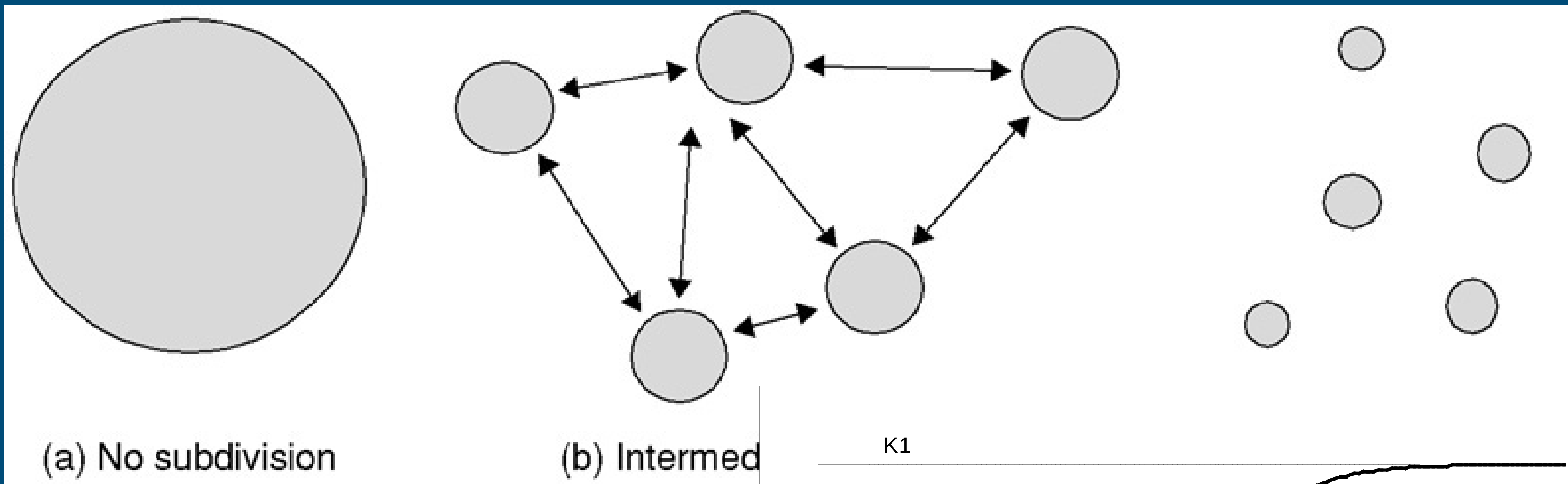
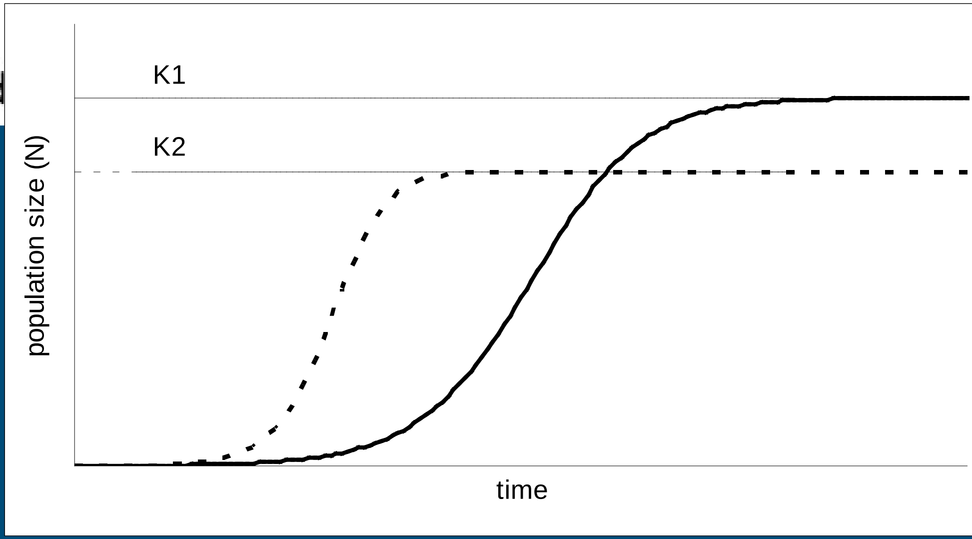
Demography in equilibrium model

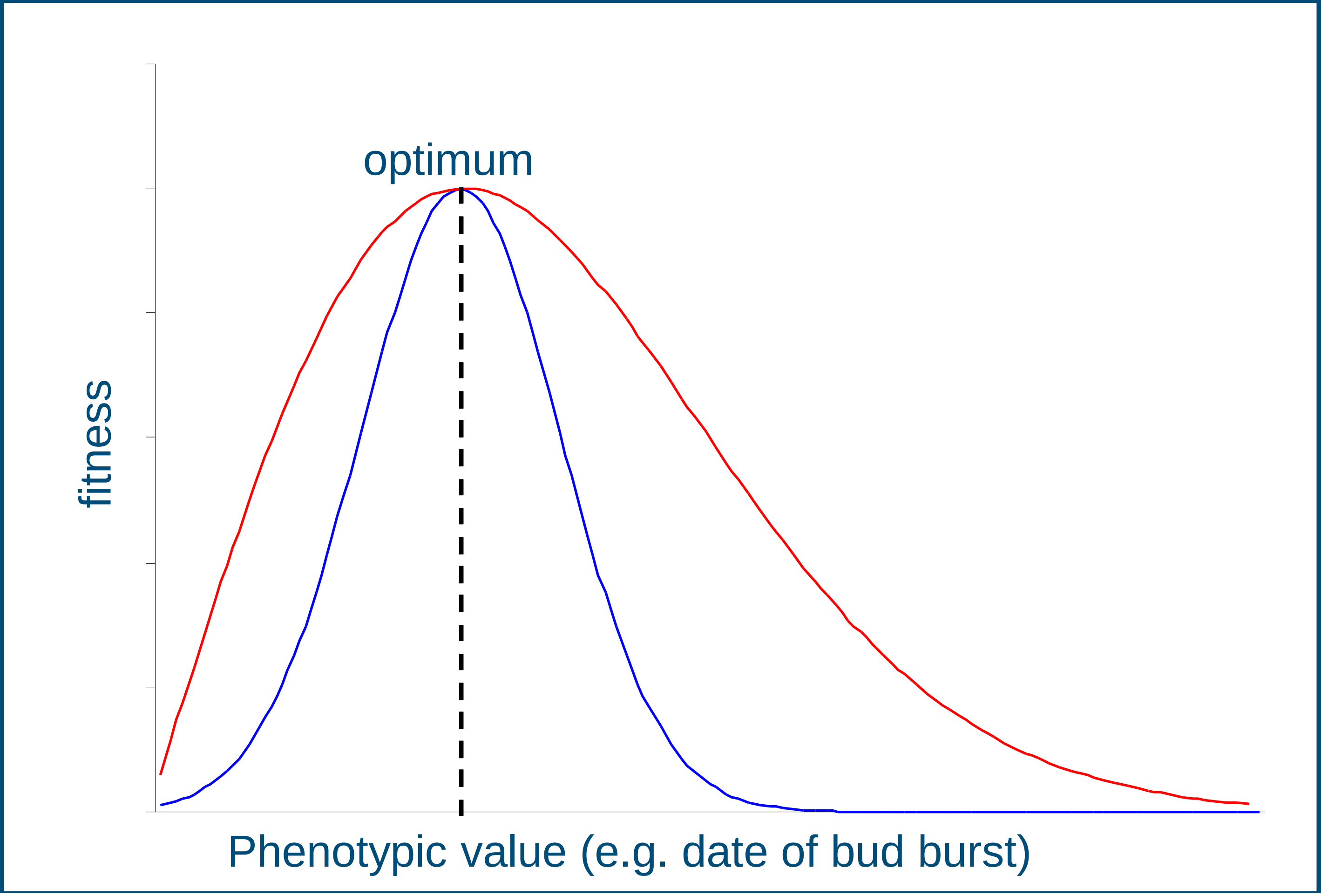




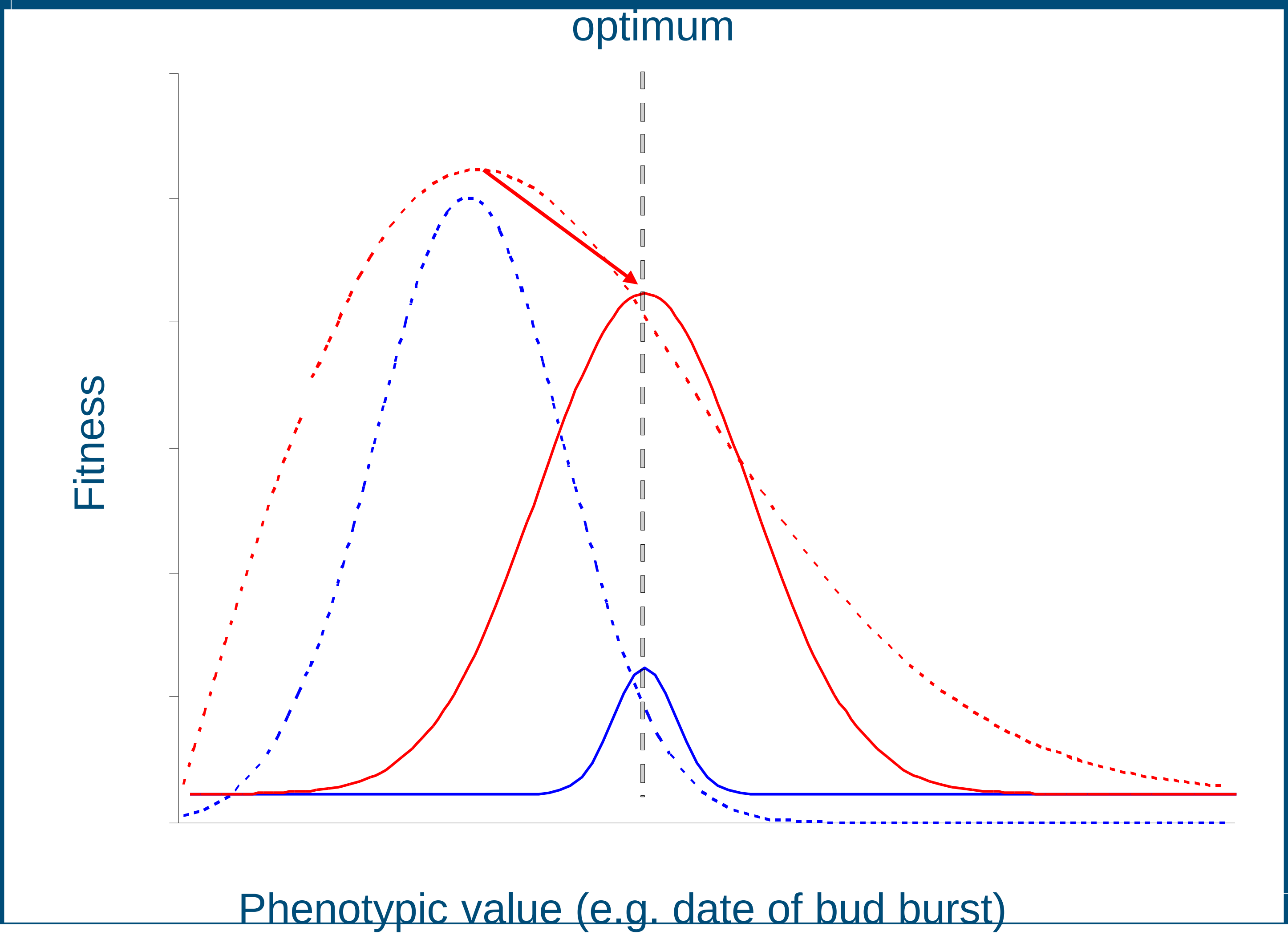
$$N_{t+1} = N_t + r \cdot N \cdot \left(\frac{K - N}{K} \right)$$

Classical population-genetic models – current situation

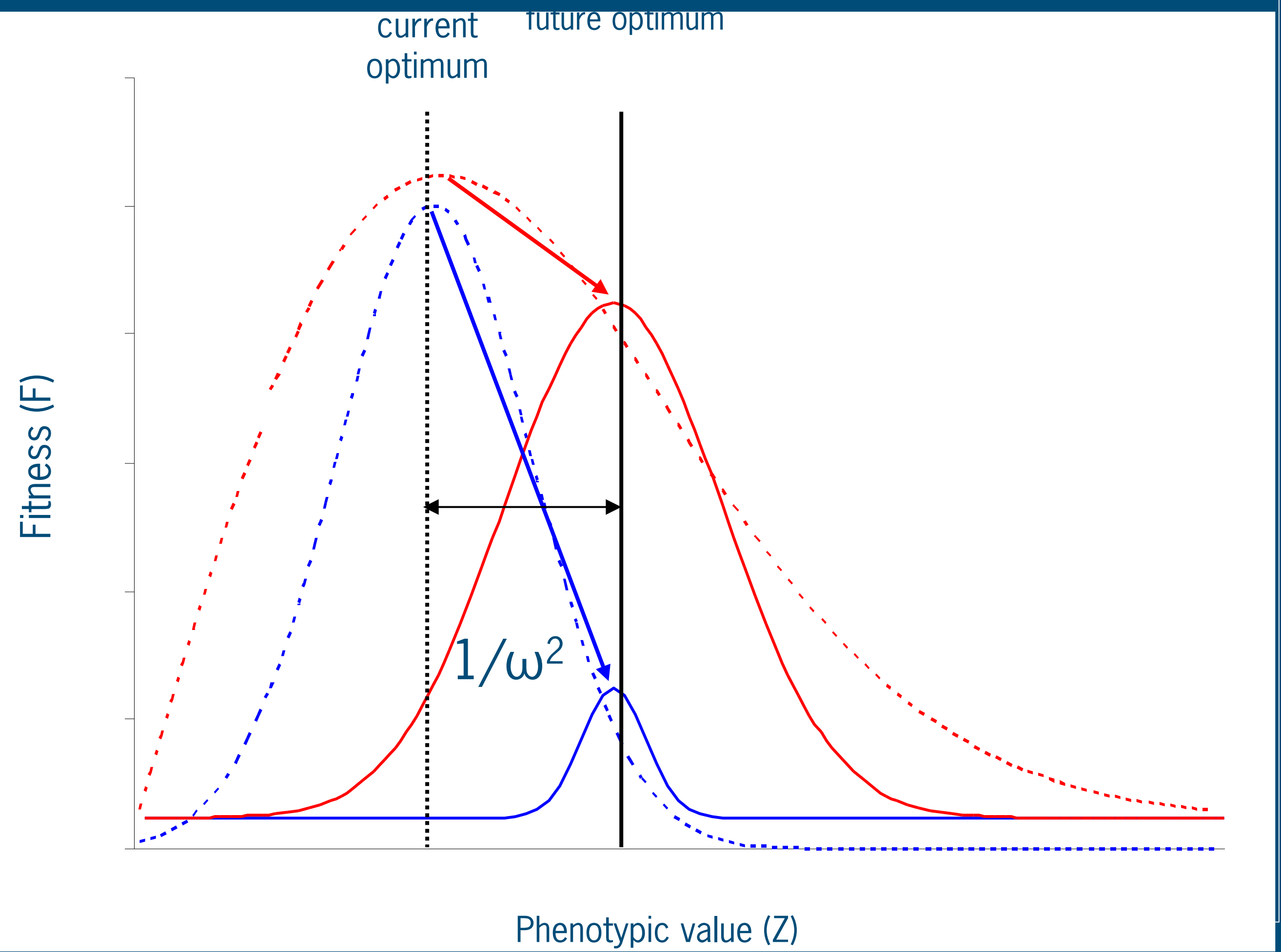
- 2 populations



Classical population-genetic models: future situation



Genetics in equilibrium model



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$$F(Z) = \exp\left(- \frac{(Z - Z_{opt})^2}{2\omega^2} \right)$$

Non-equilibrium approach: individually-based genetic modeling

Non-equilibrium or individualistic approach

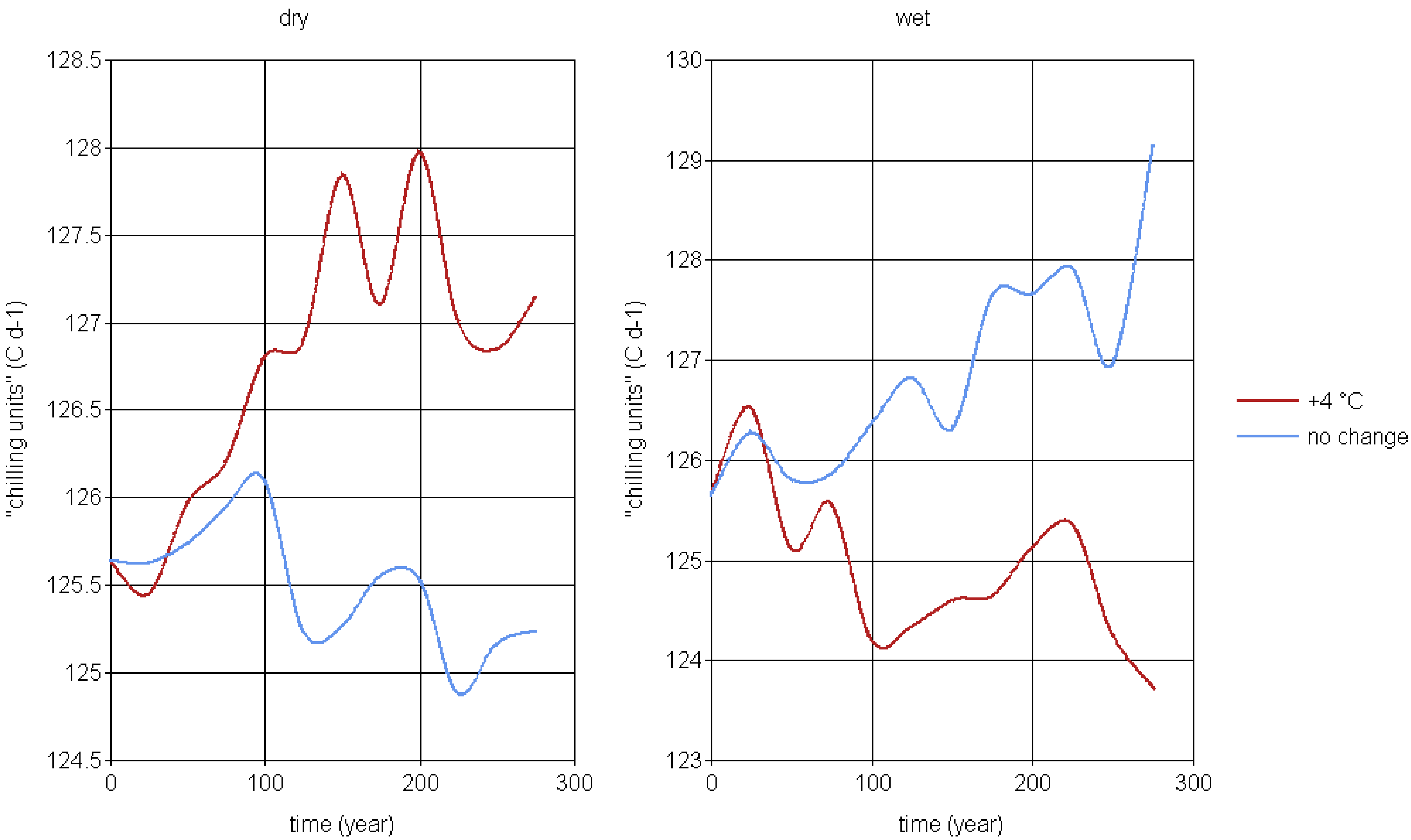
- Assumption:
  - Environment is non-stationary in space and time relative to the rate of adaptation
  - Population is always lagging behind changing biotic and abiotic conditions – both genetic and demographi
  - => History does not provide knowledge on future “stable states”
  - => we have no information on future stable states

- Traits e.g.:
  - Budburst, growth, WUE, NPP, biomass, height

- Model parameters under study e.g:
  - Critical temperature thresholds, sensitivity of process to environmental driver
  - i.e. parameters that determine phenotypic plastic response but are assumed to be invariant with respect to environmental conditions

- Model analyses e.g.:
  - Determine processes and traits that are most under selection
  - Study change in phenotypic plasticity in (future) environmental conditions and assess role of spatial genetic structure, gene flow etc.

E.g. 1. Evolution of critical state of chilling (S_{chl}^*)



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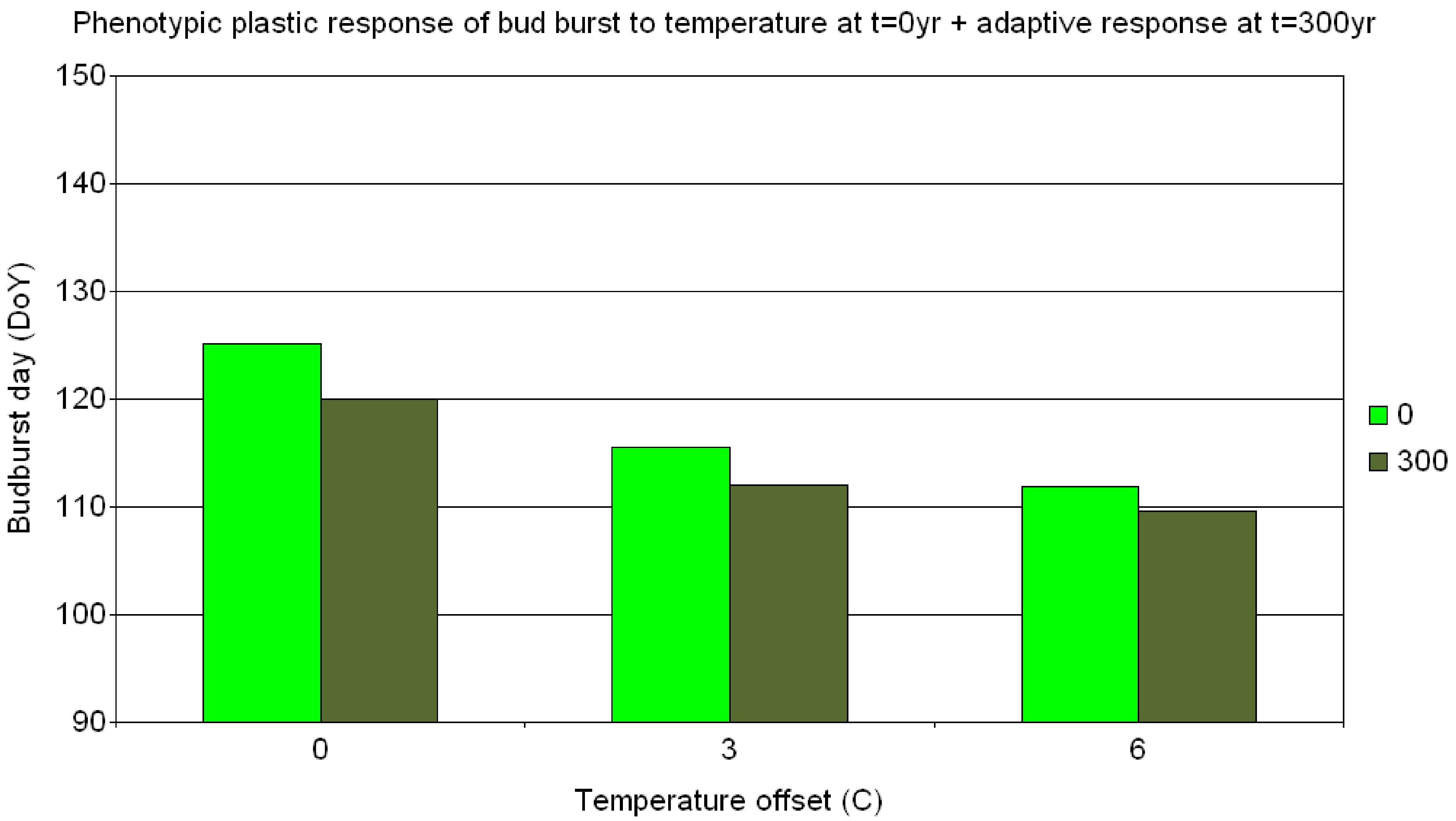
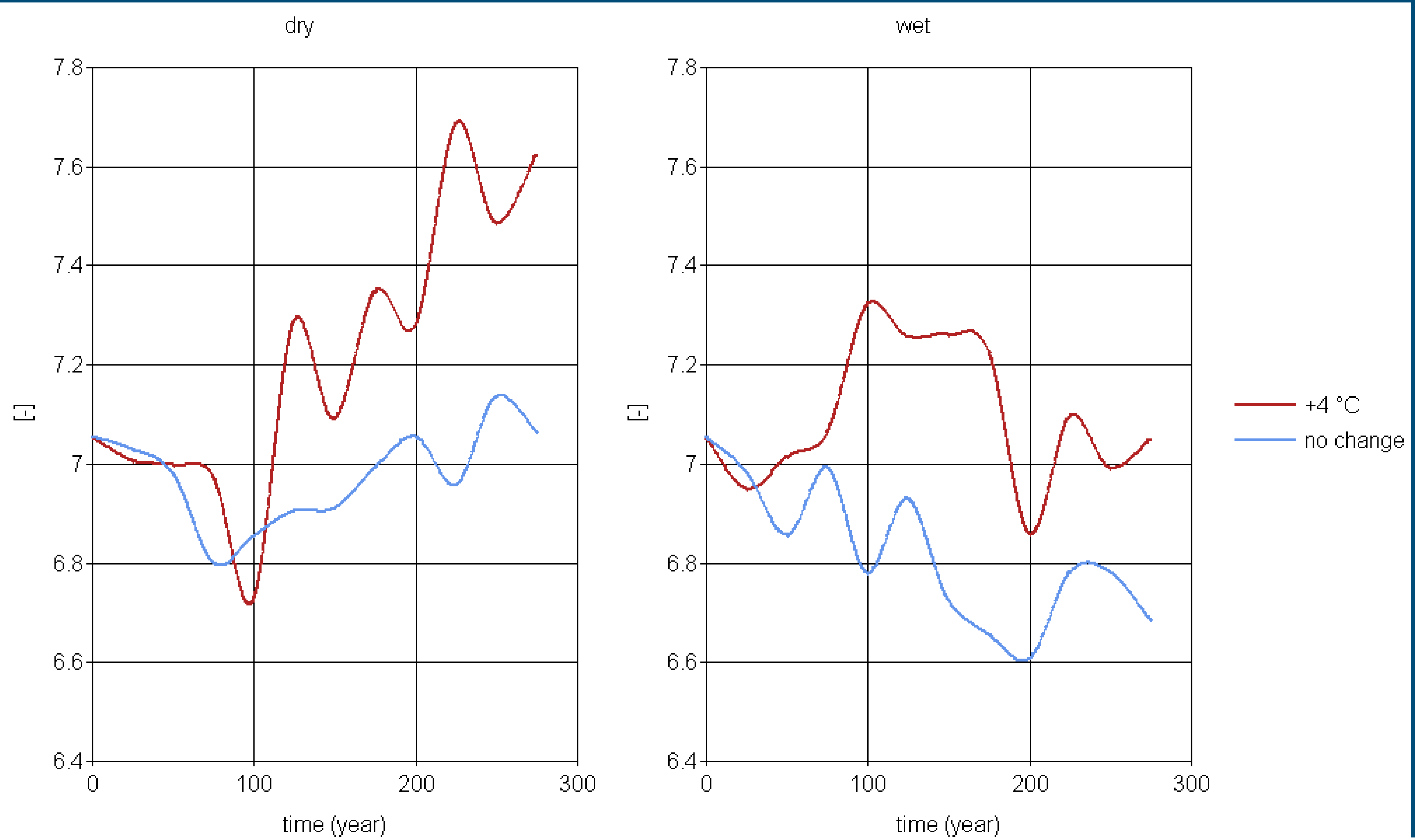
Consequence of change in S_{chl}^* on phenotypic plastic response of bud burst to temperature



E.g. 2: Evolution of sensitivity of stomatal conductance to soil water availability



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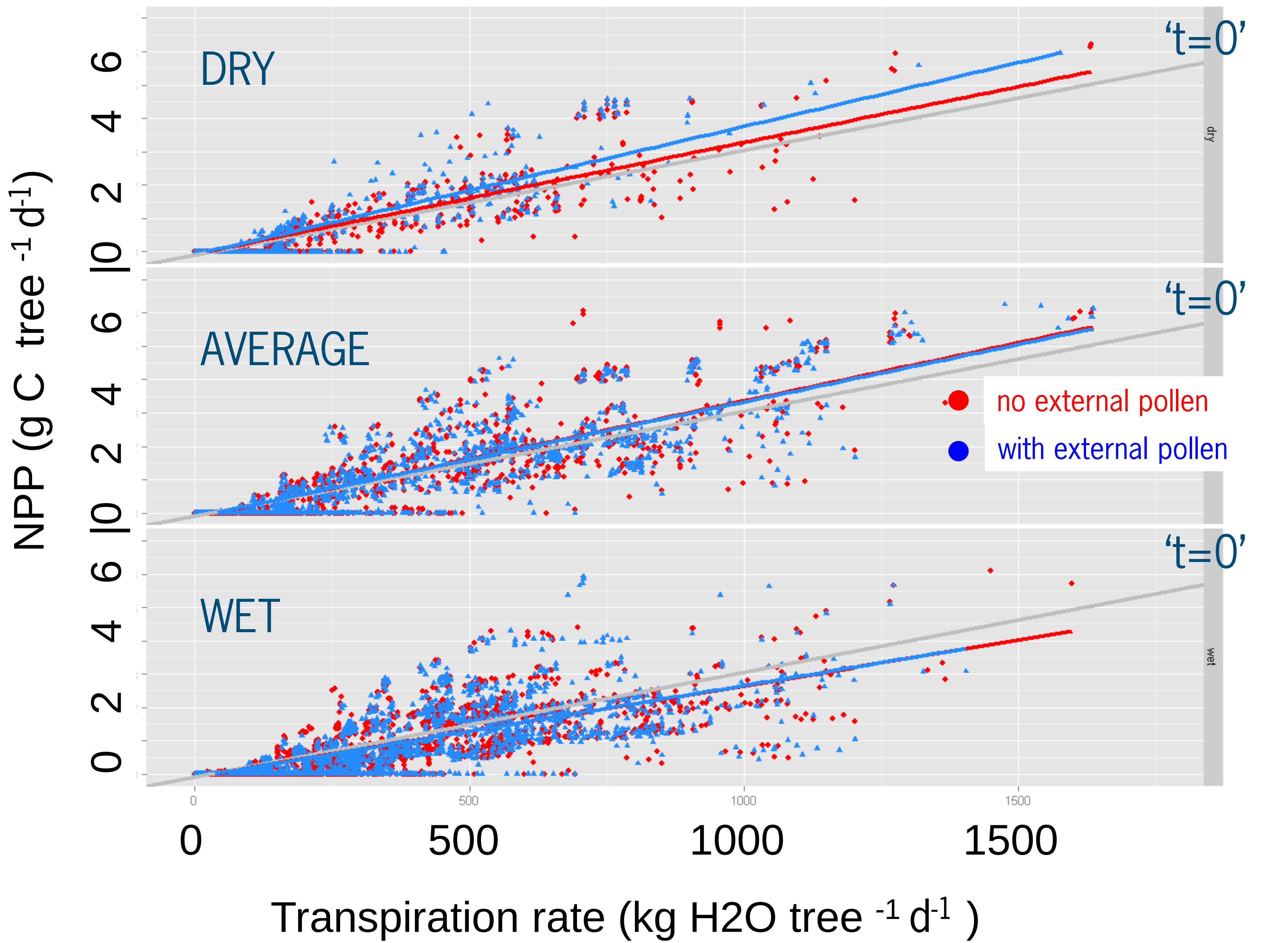
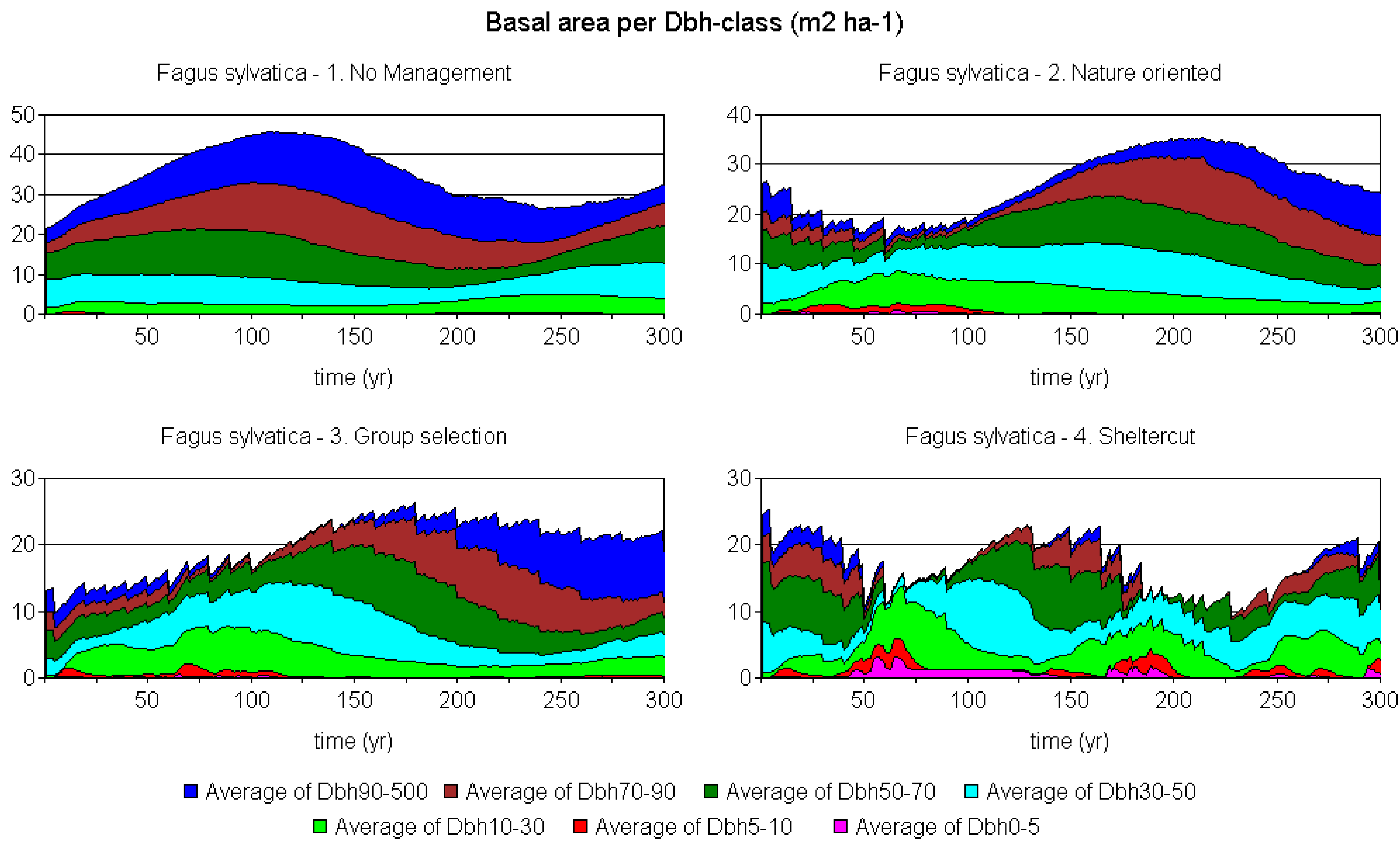

DRY
AVERAGE
WET
't=0'
't=0'
't=0'
no external pollen
with external pollen
NPP (g C tree $^{-1}$ d^{-1})
Transpiration rate (kg H2O tree $^{-1}$ d^{-1})
0
2
4
6
0
500
1000
1500
dry
wet

Example output ForGEM - Basal area



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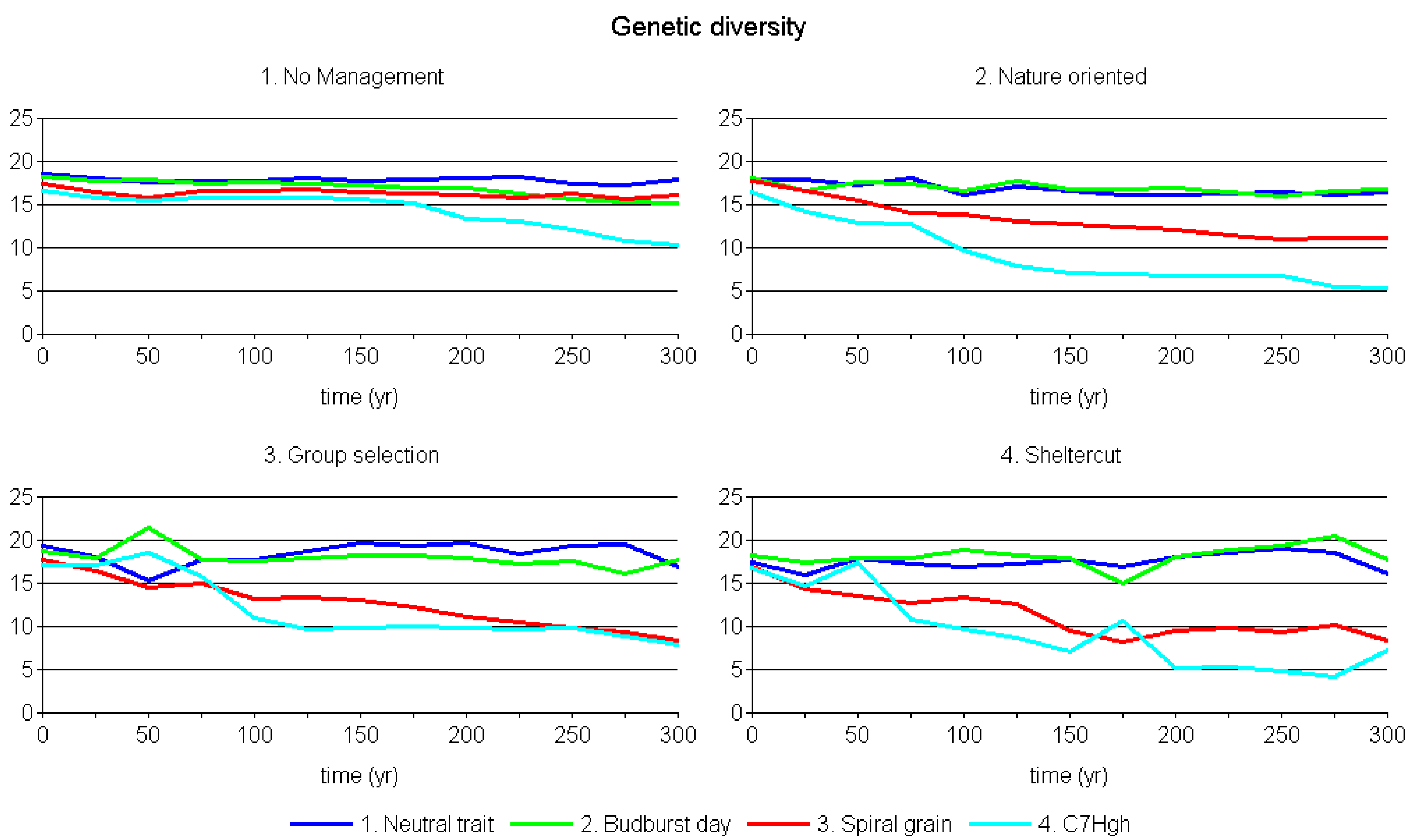
Example output ForGEM: Genetic diversity



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Pros and cons of eq. and non-eq. genetic modeling

- Eq.:
  - Generic, suitable for analysis of past, long-term evolutionary processes
  - Abstract traits related to whole tree fitness function
  - Not suitable for short-term future assessment because equilibrium states and selection pressure are input to the model
- Non-eq.:
  - Realistic, suitable for prediction at short-term, also for future equilibriums
  - Traits that have trade-off in resource use and fitness, that results in phenotypic plastic responses (morphological / physiological)
  - Not suitable for long-term (>10s generations) evolutionary processes

Conclusions on adding a genetic model to existing forest model

- Don’t add an equilibrium genetic model to a process-based forest models
- Don’t add phenotypic traits with partial fitness effect in equilibrium model