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Benefits and risks of clonal forestry from a Swedish perspective

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Aims of the clone evaluation

- Initiated by the Berzelii Centre for Forest Biotechnology at UPSC
- Benefits and risks of using clones in Swedish forestry
- Genetic and physiological effects of SE propagation
- Long-term genetic and environmental consequences of clonal forestry
- Management implications of using vegetatively propagated material
- Participants: Richard Bradshaw, Ulrika Egertsdotter, Pär Ingvarsson, Ola Rosvall, Harry Wu





History of vegetative propagation

- Introduction of vegetative propagation in Nordic countries started already in the 1970s
- Well-tested clones were propagated as *rooted cuttings*
- Ageing reduce rooting ability, limiting commercial mass propagation
- ‘*Family forestry*’ from elite crosses also raised interest in clonal propagation
- Recent development in *somatic embryogenesis* (SE) has potential to fulfil commercial scale vegetative propagation

Regulatory landscape

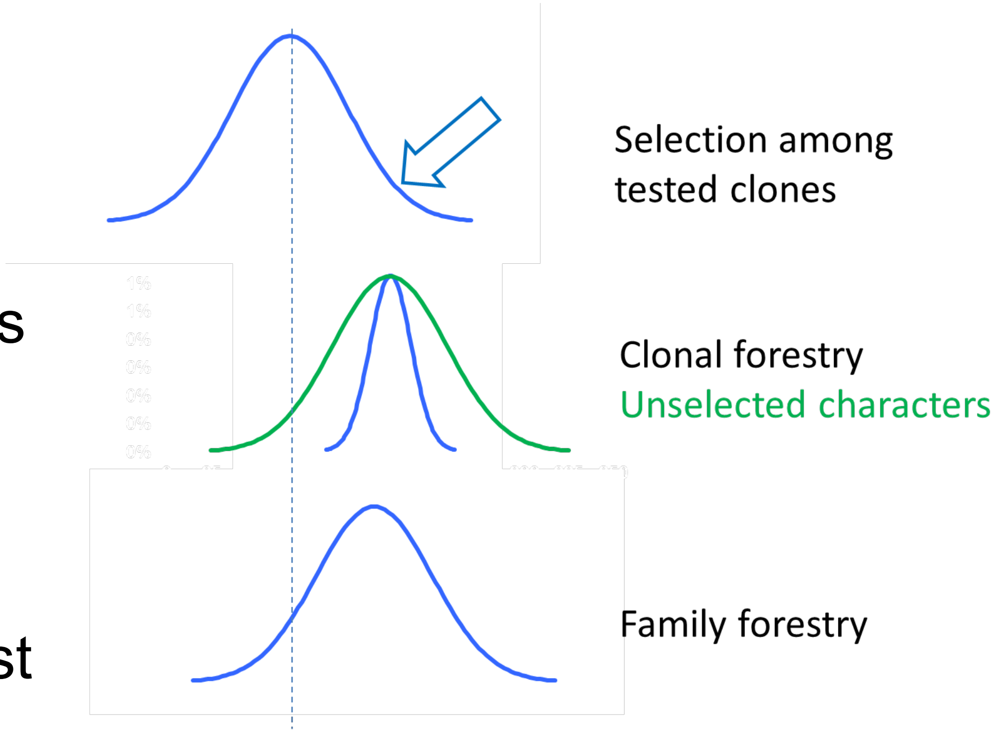
- Vegetatively propagated (VP) material can cover 5% or 20 ha of a land holding
- Areas planted with VP material must be reported and registered
- No rules for:
  - minimum number of clones used
  - maximum number of ramets
  - planting design in the field
- Rules were established when clones were not widely used
- Diversity in clonal forestry practices should allow for more experience and better knowledge to accumulate

Benefits of vegetative propagation

- Vegetative propagation ‘capture’ a larger fraction of the genetic variation - genetic gain increased due to non-additive genetic effects
- Seed orchards are 20-40 years behind current breeding progress
- Gain is diluted by pollen contamination
- Seed orchard crops are unpredictable due to variation in flowering and seed set among clones
- Vegetative propagation combines very well with modern molecular breeding tools (‘*genomic selection*’)

Genetic gain and genetic variance

- Genetic gain in clones is composed of both additive and non-additive genetic effects
- Seed orchards only transmits addictive effects
- Non-selected traits maintain more genetic variation
- Family forestry maintain most of the genetic variation



Introduction of new material from breeding

- Single spruce breeding population operates on ~25 yr cycle
- Different breeding populations are not synchronised
- With 4-5 breeding populations per deployment zone, new, improved trees are available every ~5 yrs
- >1000 are genotypes are available for testing every ~5 yrs

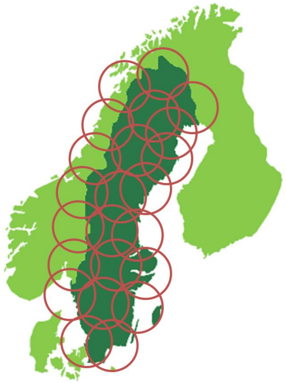


Figure 3-3. The Norway spruce breeding program follows the multiple breeding population system (MBPS) with 22 sub populations (simplified on the map) where 50 selected trees are used for breeding the next-generation recruitment population (after Karlsson and Rosvall 1993).

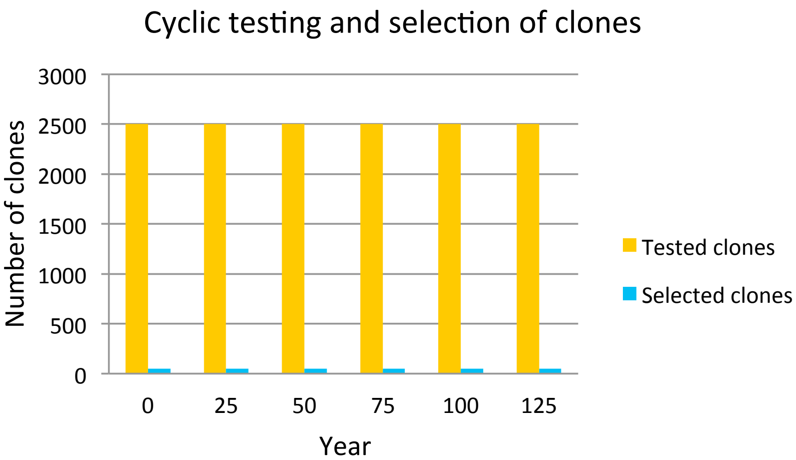


Figure 3-5. Number of clonally replicated genotypes tested per 25-year cycle for a single breeding population. During a 100-year period, 10 000 genotypes are tested per population and in total about 200 000 for the whole meta-population.

Breeding improvements

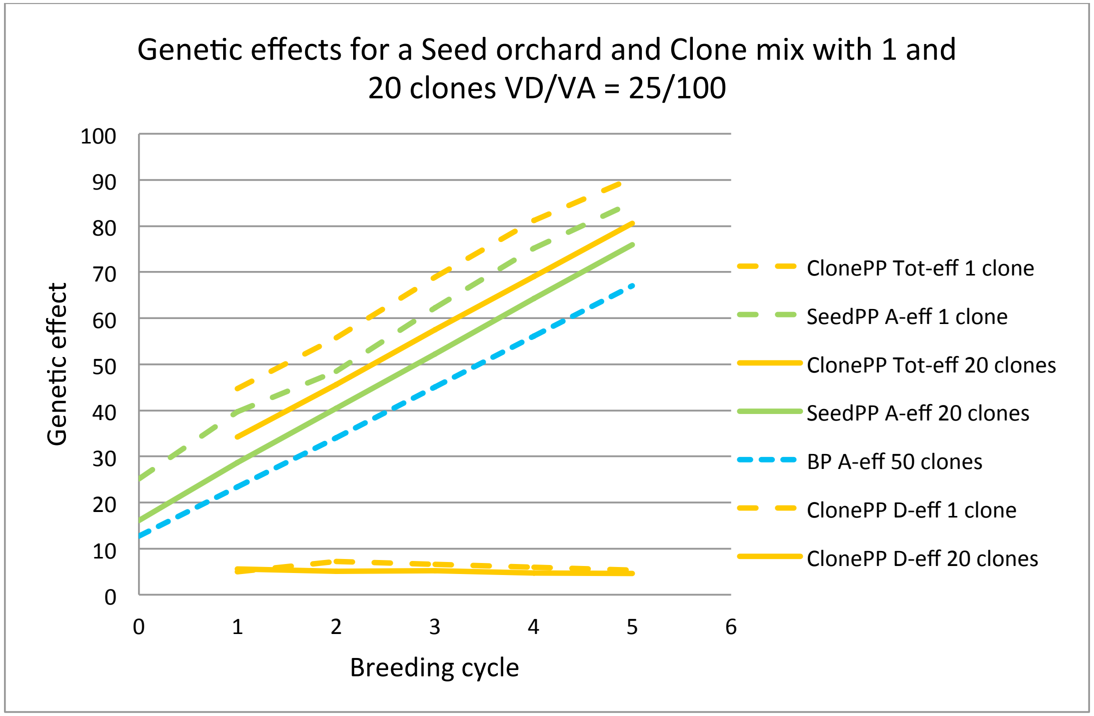
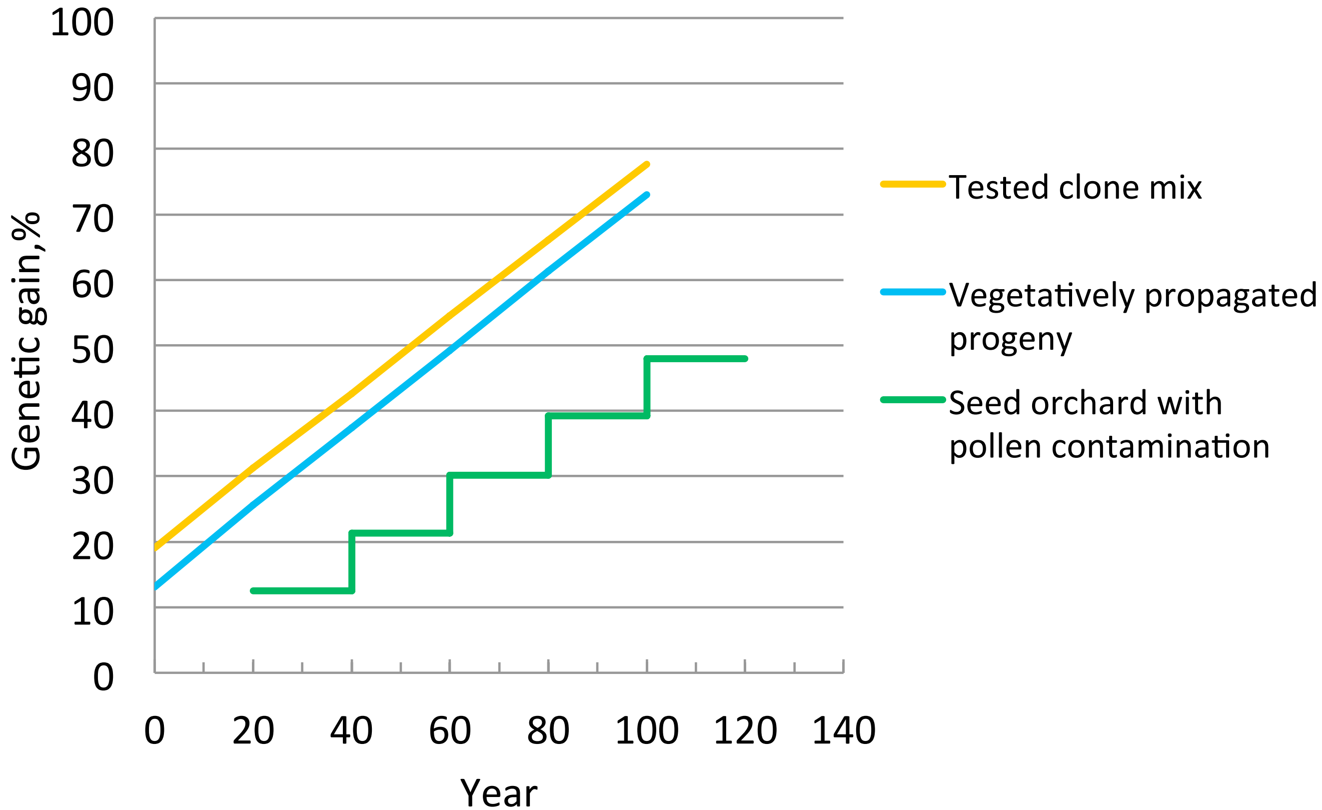


Figure 3-6. Genetic progress for a BP of size 50, and a SeedPP or ClonePP of size 1 and 20 clones for five cycles of breeding. The total genetic effect (Tot-eff) of the ClonePP is composed of the additive genetic effect (A-eff) and the dominance genetic effect (D-eff). The ratio for dominance variance to additive variance is V_D/V_A=0.25.

Gain using clones vs seed orchards

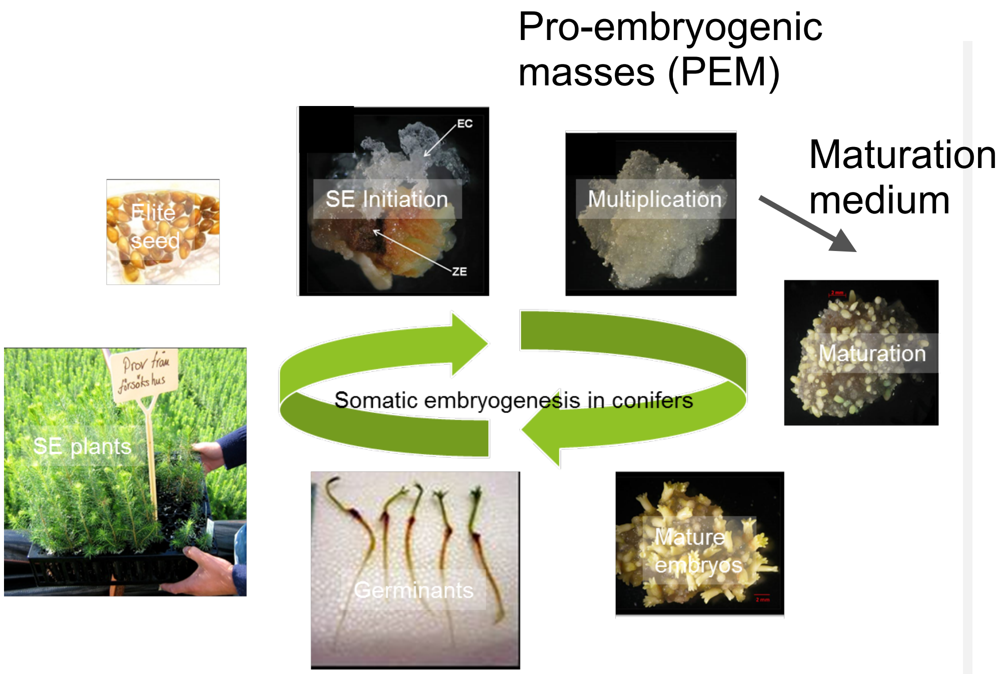


Perceived risks

- Plantation failure
- Diversity loss at the stand or landscape level
- Cost
- Public acceptance

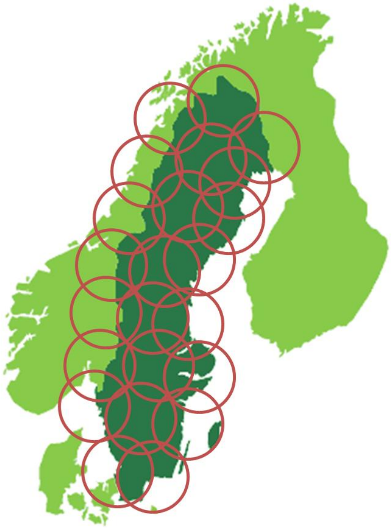
Somatic embryogenesis

- Species difference in initiation success (*Picea* +, *Pinus* -)
- Genotype differences in initiation success
- 15 out of 25 *P. abies* families yielded SE cultures (Högberg et al 1998)
- Genetic instability?



Swedish scenario for SE

- Many breeding zones imply continuous development of new clones
- 200 seeds are needed to achieve 20 cell lines
- Assuming production of 25M seedling per year and a limit of 1M clones per line → 25 new clones needs to be introduced per year (per breeding zone)



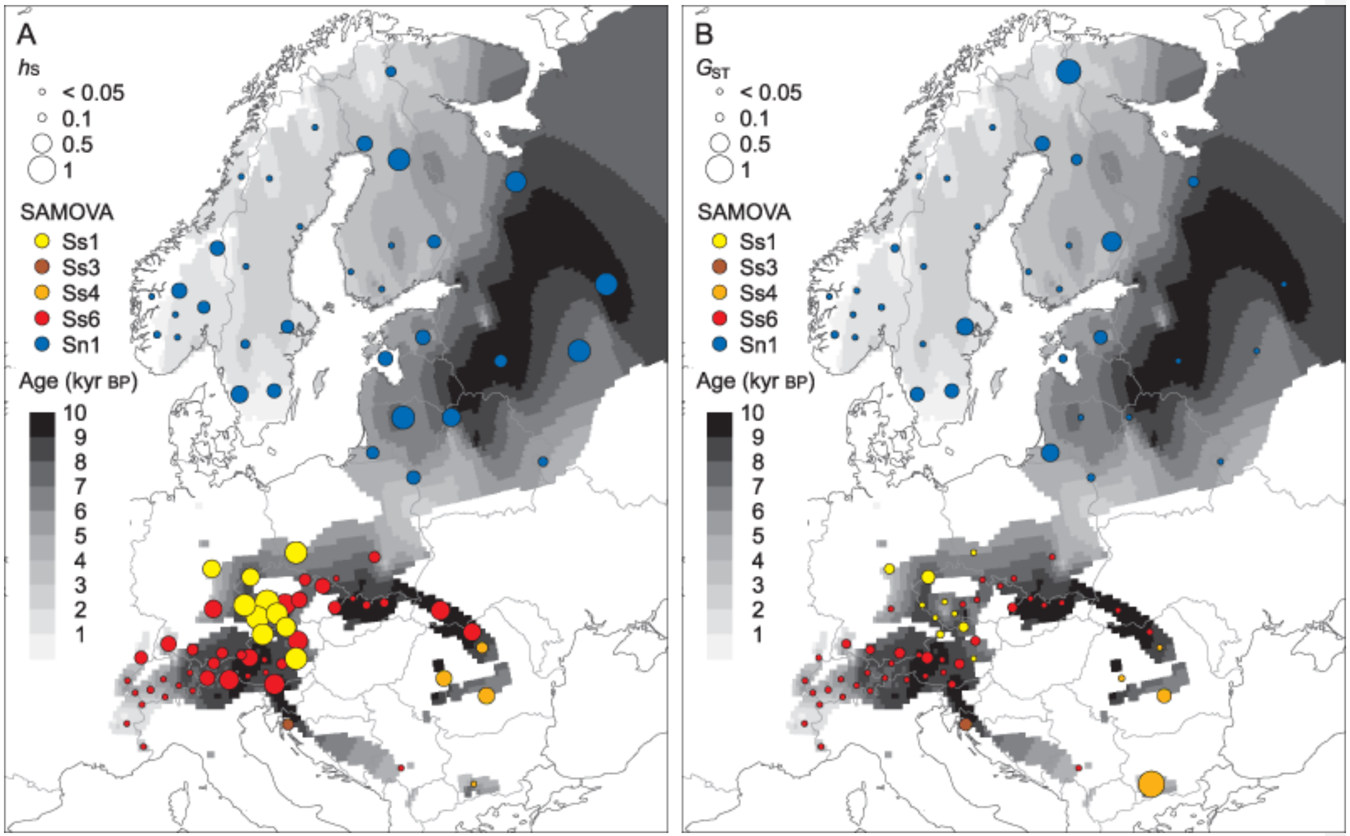
Genetic and ecological consequences of using clones

- Perceived risk of using clones include
  - Reduced genetic diversity.
    - What are the possible consequences of low genetic diversity?
    - How many clones are needed to capture ‘adequate’ levels of genetic diversity?
    - Genetic vs genotypic diversity?
  - Loss of adaptation or potential for adaptation
  - Indirect effects on associated communities

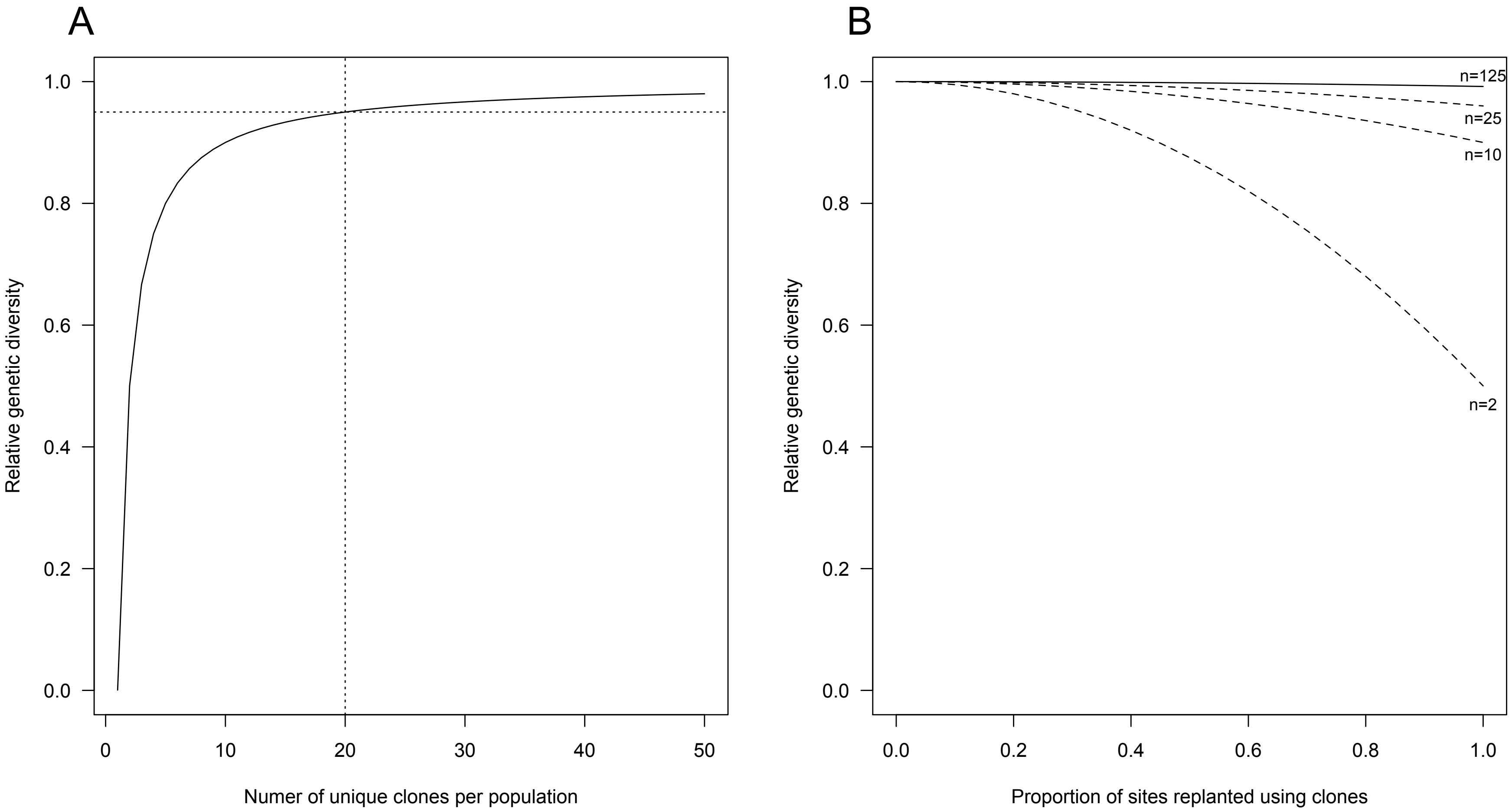
Possible negative effects of low genetic diversity

- Pests and pathogens may spread more rapidly
- Low genetic diversity may limit productivity due to more intense competitive interactions
- Unpredictable genotype x environment interactions
  - even genetically uniform populations may yield variable end products
  - long rotation times makes predicting future environmental changes hard

Present day genetic diversity

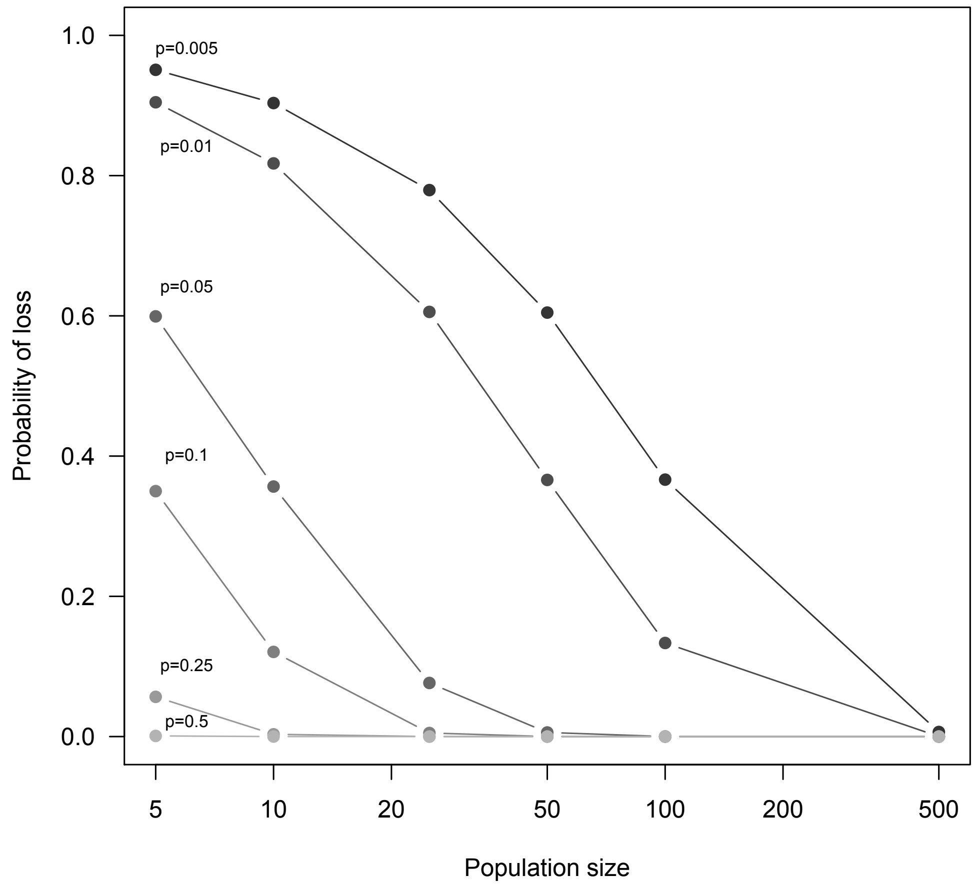


Genetic diversity: how many?

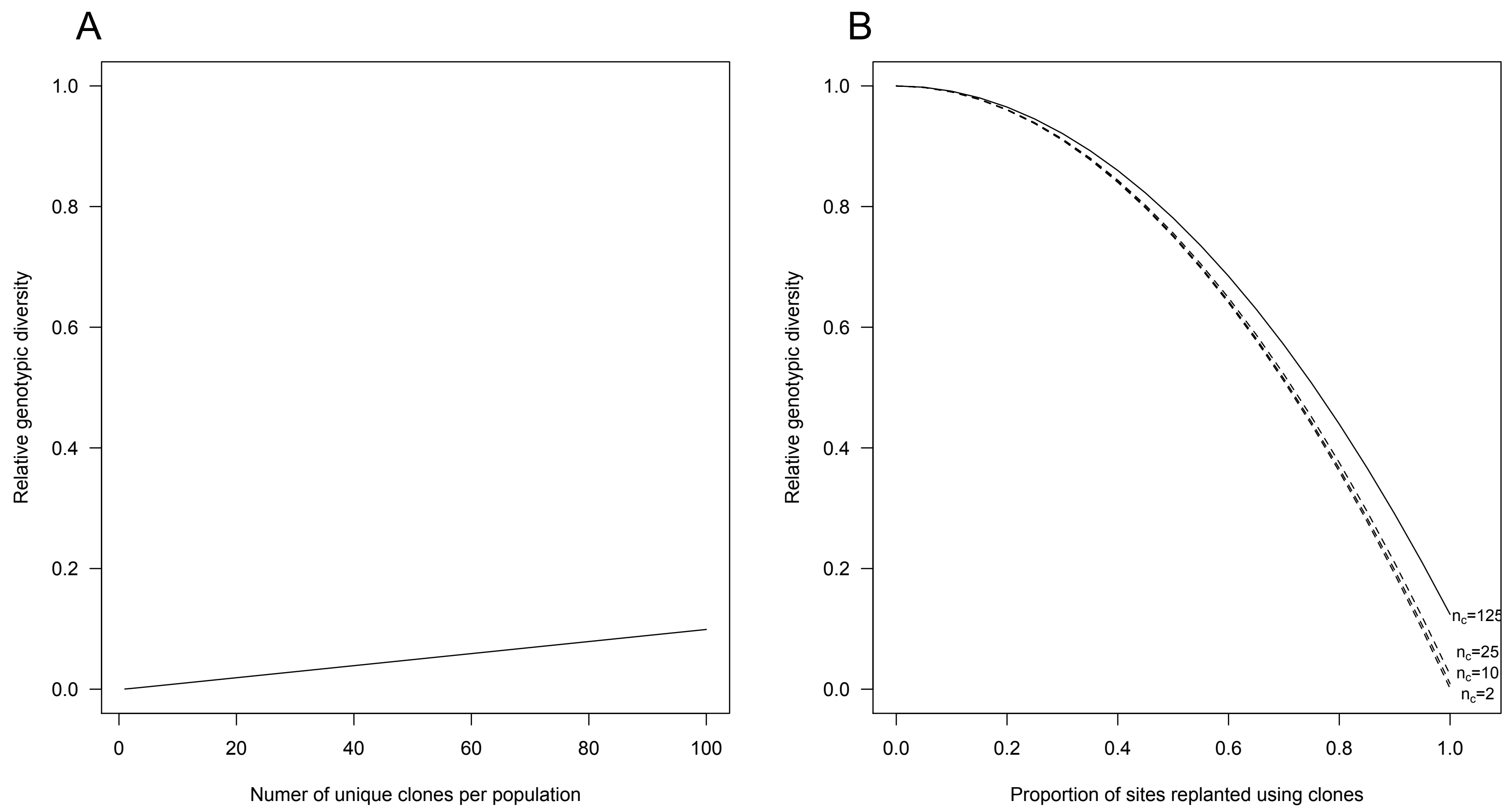


Probability of loss of alleles

- Rare alleles more likely to be lost
- More individuals are needed to ensure retention of rare alleles



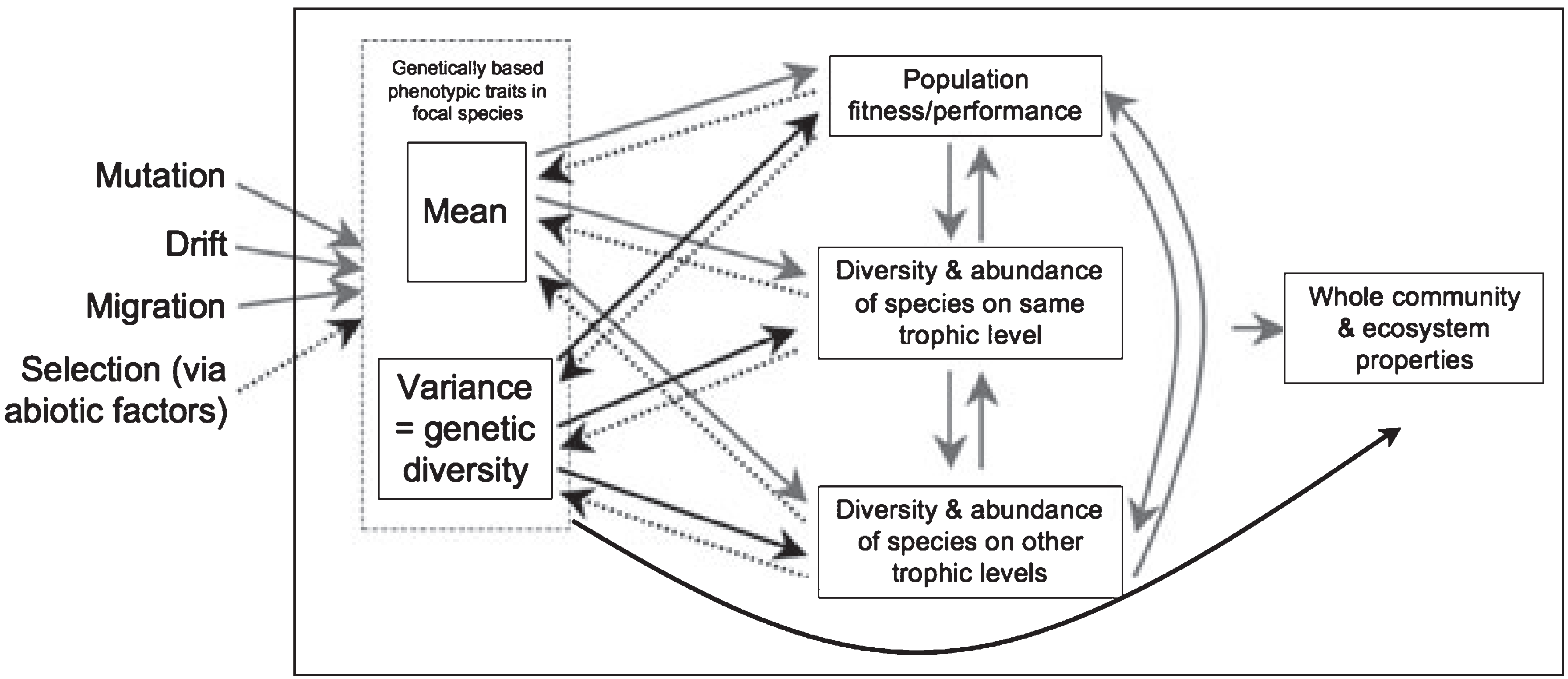
Genotypic diversity



Effects of genetic diversity on adaptation

- Loss of genetic diversity could prevent adaptation to future climate change.
- Likely stronger effects at range margins
- More likely with negative effects at lagging edge (as opposed to leading edge)

Direct and indirect effects of genetic diversity



Genetic diversity: summary

Origin of new material	Genetic diversity		Genotypic diversity	
	Local	**Regional**	**Local**	**Regional**
Natural regeneration	low	high	high	high
Seed orchards	high	high	medium	high
Few unique clones	low-medium	low	low	very low
Many unique clones	medium-high	medium	medium	low

Management implications

Method	Number of ramets or progeny per clone	5% (1)	10% (2)	20% (4)	40% (8)
		Planted spruce forest land of total productive forest land % (million ha)			
		Annual planting (million trees)			
		25	50	100	200
		New clones per year			
Clone mix	10 000	2500	5 000	10 000	20 000
Clone mix	100 000	250	500	1000	2000
Clone mix	1 000 000	25	50	100	200
Clone mix	5 000 000	5	10	20	40
Seed orchard	10 000 000	2.5	5	10	20

Public perception

- Clonal forestry and SE may impose a negative public perception since they combine intensive silvicultural techniques with ‘manipulation’ of genetic diversity.
  - What constitutes a ‘natural’ forest in terms of genetic diversity?
- Intensification of silviculture associated with use of clones
  - Forest production likely to become focused on a smaller land area
  - Potentially releasing forest land for other purposes, including maintenance of ecosystem services

Operational guidelines

- Stand-level genetic diversity should be monitored and maintained at ~90% of natural populations
- Landscape-level genetic and genotypic diversity should be maintained by subdividing breeding programs
- Ensure adequate genetic diversity in cell lines used for SE propagation
- Confine plantation forestry to existing intensively managed forest land or former agricultural land to retain the ecological benefits associated with semi-natural and natural forest areas.
- Support basic and applied research on clones in silviculture

Publication of the report

- The report will be published as a special issue of *Scandinavian Journal of Forest Research*

- Thus far two papers are available:
  - Egersdotter "*Plant physiological and genetical aspects of the somatic embryogenesis process in conifers*" https://doi.org/10.1080/02827581.2018.1441433
  - Ingvarsson & Dahlberg "*The effects of clonal forestry on genetic diversity in wild and domesticated stands of forest trees*" https://doi.org/10.1080/02827581.2018.1469665