Proceedings of the World Congress on Genetics Applied to Livestock Production, 11.375

Tactical desired gains for control of red needle cast in radiata pine under optimal contributions selection

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Summary

Red needle cast (RNC) is the major needle disease of *Pinus radiata* D. Don (radiata pine) in New Zealand, caused by *Phytophthora pluvialis*. The effects of the disease on forest productivity are likely to be large and the loss of volume could be as high as 20%. We used a tactical desired gains approach in which strict control of predicted progeny mean RNC was imposed in an otherwise normal implementation of optimal contributions selection through mate selection. This was tested in a simulated population of radiata pine. The two trait objective included diameter at breast height as an indication of volume growth and modulus of elasticity measuring wood stiffness as an important selection criterion for wood quality. The simulation population consisted of 50 females and 50 males where the long-term response for 50 years on the two trait objective was investigated for 50 cycles of selection while reducing RNC on a defined trajectory, and conserving genetic diversity.

Keywords: Genetic gains, genetic diversity, optimal contribution, red needle cast, radiata pine

Introduction

Red needle cast (RNC) is the most recent needle disease in radiata pine in New Zealand and was first observed in 2007. It is caused by the pathogen *Phytophthora pluvialis* Reeser, Sutton and E Hansen (2013). The disease has become well established in the North Island and has the potential to cause production loss through needle cast and reduced growth (Dungey *et al*., 2014, Ganley *et al*., 2014). Forest management procedures include targeting RNC using chemical control (Rolando *et al*., 2017). Under the changing climate, however, environmentally sustainable methods such as breeding with long-term goals are sought after. Dungey *et al*. (2014) presented moderate estimates of heritability of RNC infection, meaning that selecting for improved RNC resistance can potentially deliver healthier trees for forest deployment. The objective of this paper was to investigate how that might best be achieved, using a tactical desired gains approach with a two trait breeding objective for growth and wood quality as part of full mate selection methodology that can account for all key issues affecting the implementation of the breeding program (Kinghorn, 2011, as implemented in Kinghorn and Kinghorn, 2017). This simulation study compared genetic gains for the breeding objective with different policies on genetic diversity in the population while constraining RNC reduction to a target path.

Material and Methods

Trait and population parameters and methodology for simulation

A breeding population of radiata pine was simulated using the program Popsim (Popsim module of GENUP, http://www-personal.une.edu.au/~bkinghor/genup.htm). The traits simulated were red needle cast (RNC), diameter at breast height (DBH) and modulus of elasticity (MoE) (Table 1). The two-trait breeding objective was equal improvement in genetic standard deviations per year in DBH and MoE. The simulation follows the same structure as was implemented in GENUP (Kinghorn, 1992), but with enhanced functionality including the accommodation of bisexuality for plant breeding, i.e. females can also be males. Breeding decisions at each cycle were made by the program Matesel (Kinghorn and Kinghorn, 2017). This implementation has recently been used by Cowling *et al.* (2017) and Cowling *et al.* (submitted) in crops.

Table 1. Traits used in the simulation.

Trait	**Units**	**SD**	**Mean**
Red Needle Cast (RNC)	%	16.90	41.8
Diameter at breast height (DBH)	mm	47.30	196.7
Modulus of elasticity, wood stiffness (MoE)	GPa	2.3	8.9

Popsim parameterisation: Fifty crossings were made each year for 50 years. Each crossing produced two genotypes that were each available as a male and a female candidate for breeding at the stage of selection and crossing. Each candidate was permitted up to a maximum of 10 matings as a male and 10 matings as a female. Selected plants of both genders were first crossed to produce candidate progeny at 5 years of age, and were available for selection to leave candidate progeny until 8 years of age. This crossing approach reflects a future possibility for genomic selection in radiata pine where a shorter generation interval of 10 years compared to traditional breeding is possible when skipping the time consuming progeny test phase as well using top grafting for an earlier age at flowering (Li and Dungey, 2017, submitted). Mature candidates competed with younger stock to stay in the breeding program each year. Survival rate of mature trees was set at 99% per year. Table 2 shows the phenotypic and genetic parameters assumed for the simulated traits (Suontama *et al.*, 2015).

The selection index used was based on the estimated breeding values (EBVs) of DBH and MoE alone, with genetic change in RNC dictated by the tactical desired gains; the starting population mean of RNC was 41.8% and the moving desired gains target was for a linear decrease in RNC to 15% in year 25, then a slower linear decrease from 15% to 5% by year 50. This was implemented as described below.

Table 2. Genetic and phenotypic parameters of the traits. Estimates of heritability on the diagonal, genetic correlations below and phenotypic correlations above the diagonal. RNC=Red needle cast, DBH=Diameter at breast height, MoE=Modulus of elasticity

Trait	**RNC**	**DBH**	**MoE**
RNC	**0.23**	0.06	0.07
DBH	-0.32	**0.17**	-0.34
MoE	-0.05	-0.10	**0.30**

Matesel parameterisation: The only issues that Matesel was asked to manage were genetic gain in the index, genetic diversity (as represented by parental mean coancestry) and the tactical desired gain in RNC. The balance of genetic gain and genetic diversity was set using a fixed target degree line, as in Figure 1. In this example the target for balance of gain and diversity has been set at 25 degrees, where 0 degrees represents full emphasis on genetic gain, and 90 degrees represents full emphasis on genetic diversity. In Figure 1, the converged solution is some distance from the optimal position of the frontier, because another issue has been given some weighting. In the present case the external issue is constraint on the solution to be at or below the prevailing target predicted progeny mean genetic merit for RNC. The constraint on RNC was applied using a penalty on mate selection solutions, as follows:

The penalty was applied to each solution, but with stronger penalties for solutions that do not meet the target RNC:

If pRNC > tRNC then Penalty = W.pRNC
Else Penalty = W.tRNC

where pRNC is predicted progeny genetic merit for RNC for the current selection and mating solution, tRNC is the target RNC for the prevailing year, and W is a weighting factor that is sufficiently large to make uncompetitive those solutions that do not meet tRNC. This approach is not equivalent to independent culling, as the RNC and Index EBVs are considered simultaneously when evaluating each candidate mating set.

Thus, for each mate selection solution, when predicted response in RNC exceeds the desired upper limit, there is a penalty that increases as the unwanted deviation increases. This helps the evolutionary algorithm that drives the method to move in the correct direction – towards compliance with the prevailing RNC target. However, there is no extra reward for solutions that overstep the target. In the case of Cowling *et al* (submitted), who targeted a *minimum* level for heat stress tolerance in the face of increasing global temperatures, this makes sense as excess tolerance provides little or no benefit.

The treatments considered were different settings for target degrees in Matesel, with higher target degrees tending to give better long term response, because of better conservation of genetic diversity.

Results and Discussion

Figure 2 shows that under all treatments, the desired pattern of response in RNC has been achieved. The constraint for RNC reduction was placed on information available, which was the average parental mean of EBV for RNC, and this probably explains small deviations in TBV from the moving target. However, some deviation in the EBV criterion may be due to solutions that are competitive despite not fully meeting the target. The different treatments in balancing genetic gain and genetic diversity had only a small effect on the TBV of RNC over time. The target of 15% of RNC infection when started from the heavily infected parental population was essentially achieved by 2042 with all treatments. In addition, maintaining the genetic variation of the population is possible without losing the desired target in the disease resistance. However, it is likely that genotype by environment interaction may interfere in realized genetic gains when deploying genetic material across different environments in operational forestry and this may need further investigation (Li *et al.*, 2017), but could be incorporated in the mate selection approach.

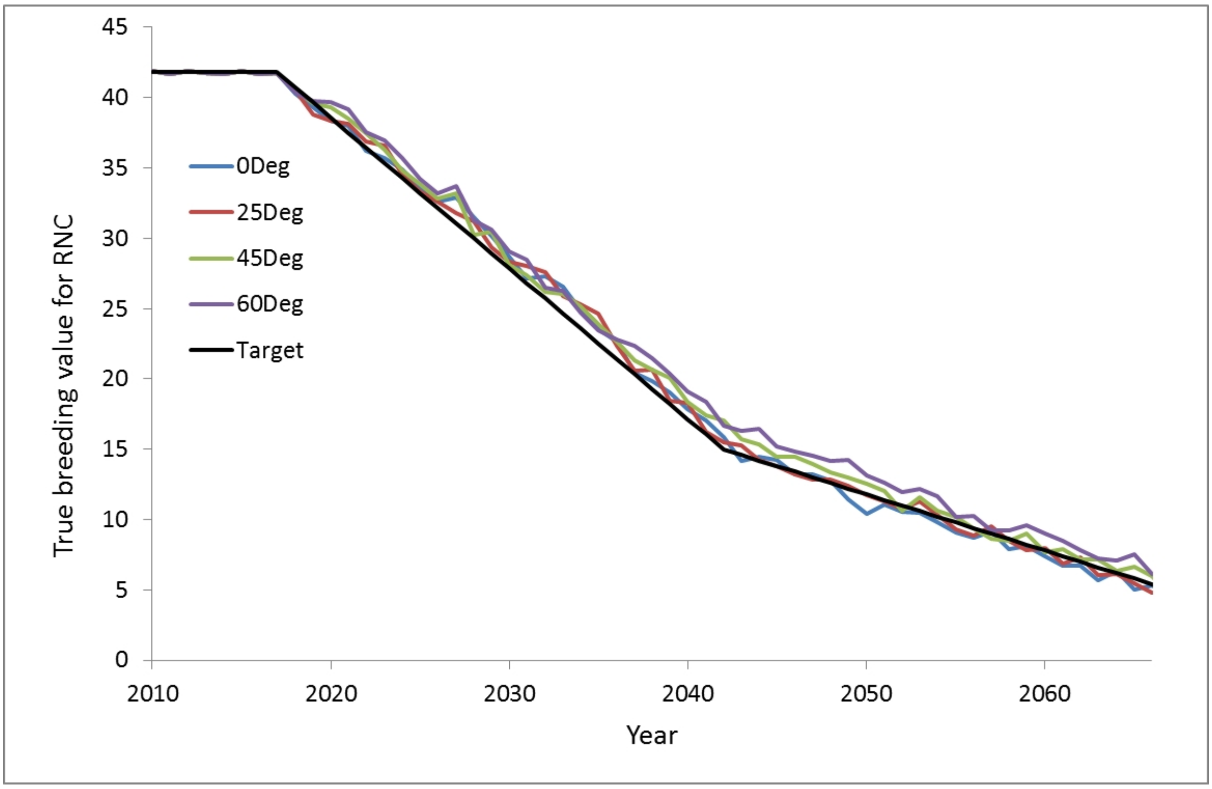

Figure 2. The desired genetic gains pattern in RNC under all treatments.

Differences in the declining trend of genetic diversity along time when using different tactics (degrees) in breeding were large, as expected (Figure 3). This figure shows that parental coancestry becomes dangerously high for the more aggressive (lower weighting on maintaining diversity) breeding policies. This is especially true with the 0 degrees approach where the full emphasis is on genetic gains while paying no attention in genetic diversity. With the mate selection approach targeting only genetic gains, in addition to RNC decline, the mean parental coancestry begun to rise strongly already at the early stages of selection compared to milder approaches. An increase in difference of the mean parental coancestry between different tactics in preserving genetic diversity can be detected already as early as year 2022. This result highlights the importance of optimal contributions methods in balancing genetic gain and genetic variation of the operational breeding population when dealing with a small breeding population of elite individuals and targeting to maximise the genetic gains. Therefore, selecting only for genetic gains is likely not an approach to be used for breeding of a small population in long term but maintaining the balance of genetic diversity and gains.

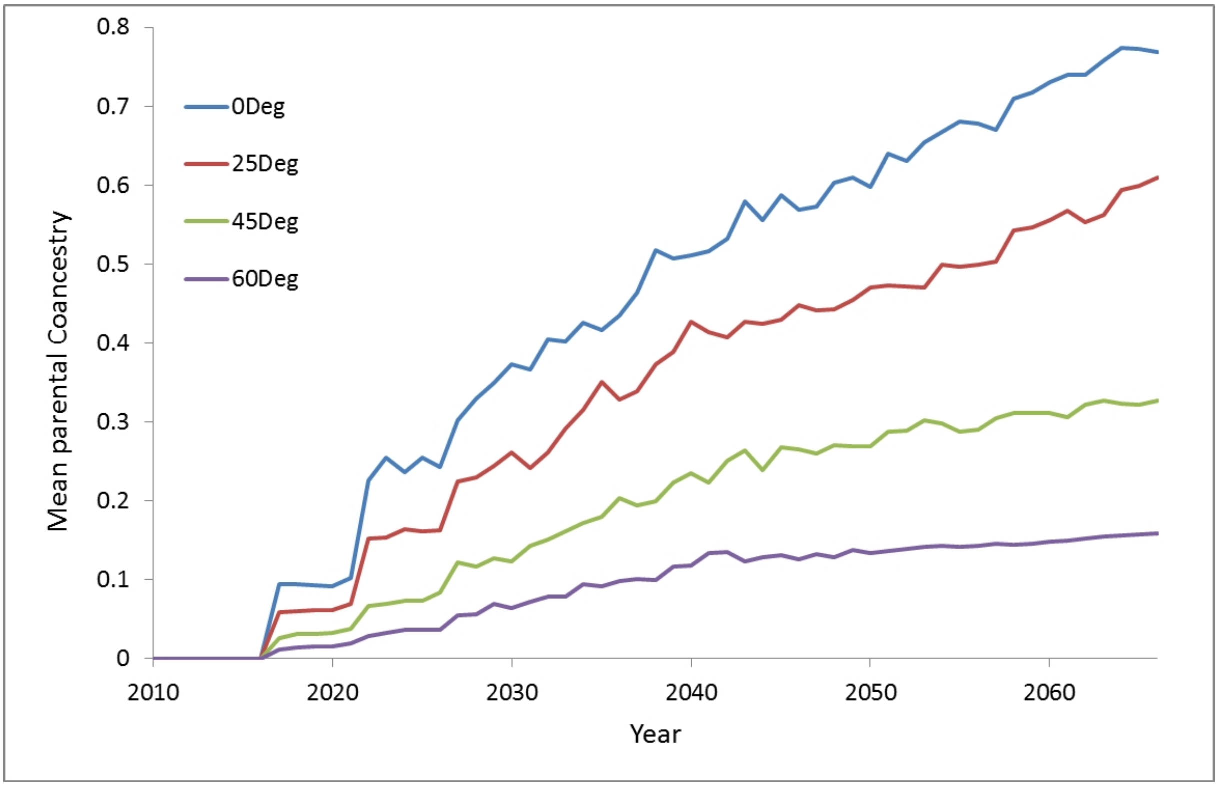

Figure 3. The change in parental coancestry when using different breeding policies.

Figure 4 shows the classical pattern of selection response in the face of different pressures to conserve genetic diversity while seeking selection response in the breeding objective. These results indicate clearly the importance of maintaining genetic diversity in the closed elite population in order to maximise the genetic gains for the breeding objective in the longer term. The 0 target degree approach for genetic diversity demonstrated that the rate of genetic improvement in the longer term will be lower compared with more optimised approaches where conservation of genetic variation is taken into account (25 and 45 degrees). The 0 target degree approach started to lose in genetic gains for the two trait objective already at year 2028 compared with the target degree of 25 that can be considered as a very good compromise in balancing gains and diversity of the breeding population. This is to say that a moderate weighting in favour of maintaining genetic diversity (25 degrees) is sufficient to enable highest rates of genetic gain for the entire period modelled.

A slight increase in rate of response can be detected from year 2042, when the emphasis on genetic change in RNC decreases, however, any such trend will be masked by the fact that the rate of genetic change is being reduced due increases in parental coancestry. This figure also shows a classical pattern of selection response in the face of different attitudes to conserving genetic diversity. For a short term response, the 0 and 25 target degree policies are the best, but in the longer term, the 25 target degrees is best. In the even longer term, 45 degrees could become competitive, because of the loss of genetic diversity seen for the more aggressive strategies, as seen in Figure 3. The 60 target degree policy conserves most diversity, but is probably too conservative, and unlikely to become competitive within any reasonable time frame.

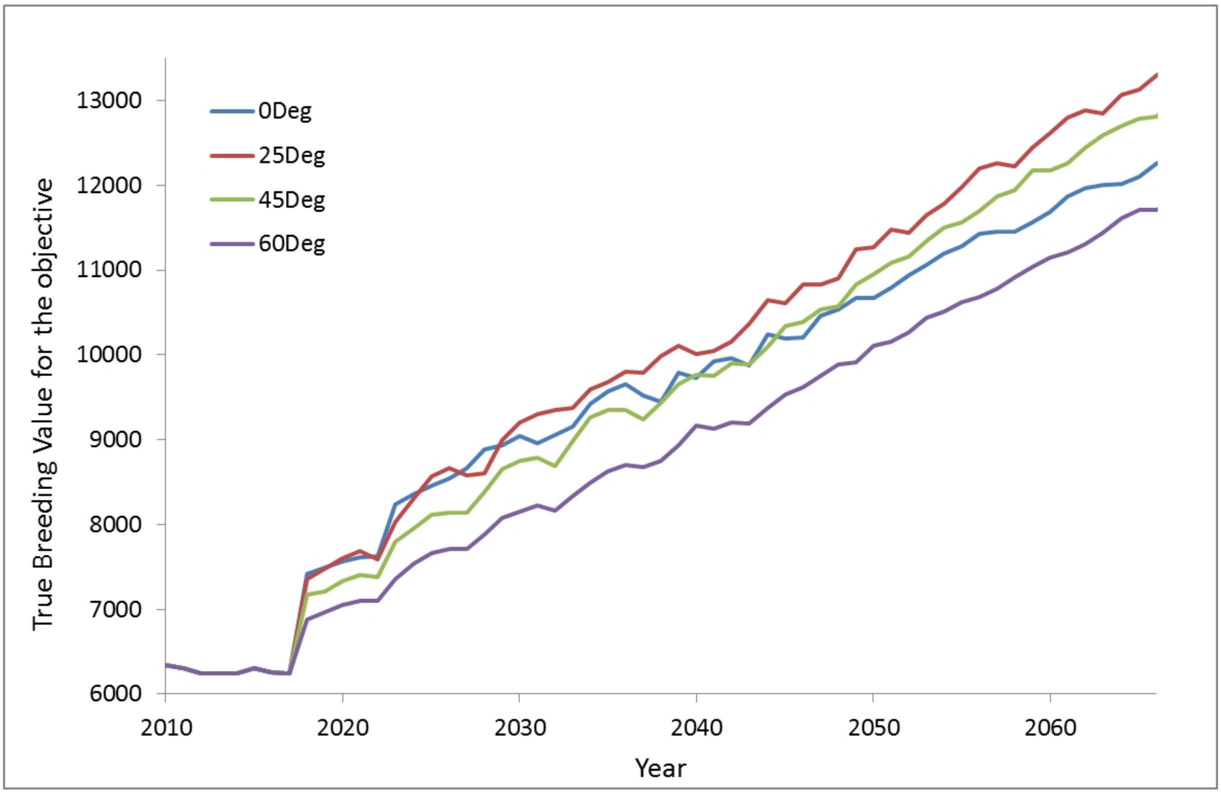

Figure 4. Selection response for the breeding objective when using different approaches to conserve genetic diversity.

Conclusions

A closed population of radiata pine was simulated with the two trait objective for volume growth and wood stiffness in the time frame of 50 years. The tactical desired gains approach was set up to incorporate selection to reduce RNC, which is the most significant current threat to forest resilience in radiata pine in New Zealand. With the long term approach of 50 years the target of 15% of RNC infection was achieved in year 2042 when the parental population was heavily infected with a mean of 41.8%. The most aggressive approach in pursuing only genetic gains would decrease genetic diversity to dangerously low levels and is not beneficial for achieving the maximised genetic gains in the long-term. The 25 target degree policy for maintaining genetic diversity at acceptable levels would be the best approach in optimising genetic improvement and genetic diversity. Applying a genomic selection scenario is also possible for this example by use of the option to use a G matrix or blended H matrix to manage coancestry and inbreeding.

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