# A COMPARISON OF SOME CHALLENGES TO GENETIC IMPROVEMENT IN NEW ZEALAND INDUSTRIES

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## SUMMARY
An industry that achieves and benefits from genetic improvement in the long term will have a balance between genetic advance in the breeding sector, gene flows to the commercial sector and cash flows to support infrastructure. In its widest sense, the infrastructure includes producers, breeders, databases, statistical technology to rank individuals, research and extension. These components must be mutually co-ordinated and matched to industry needs. The challenges facing an industry attempting to achieve fine-tuning of existing practice and cost-effective use of new technologies will be determined by the current status of this infrastructure.
**Keywords:** Dairy breeding, beef cattle, tree improvement, technology.

## INTRODUCTION
There are a number of components that are essential for the long-term success of genetic improvement programmes. These components influence the rate of genetic advance in the breeding sector, the gene flow from the breeding to the commercial sector, and cash flow to pay for and reward various industry players. The relative importance of some individual components and the means by which component needs are met varies markedly between different industries. Three N.Z. industry programmes have been chosen for illustration by thumbnail sketch: namely dairy cattle improvement; beef cattle improvement; and *Pinus radiata* tree breeding. This paper serves to: introduce some of the components; compare and contrast current approaches to meet industry needs; and to comment on limitations and opportunities for industry exploitation of emerging technologies and other developments.

## PHYSICAL COMPONENTS OF AN INDUSTRY IMPROVEMENT PROGRAMME
A successful improvement programme has six major components (Garrick *et al.* 1992).

1. **Committed buyers.** Those who make use of genetic material from specialist breeders must demand continued improvement and pay a premium that reflects some of the increased profits derived from use of the improved material.
2. **Motivated breeders.** Breeders need to be sensitive to future production, processing and marketing requirements and to anticipate long-term needs of their industry. They must keep abreast of relevant research and trends in consumption, and must stimulate future research.
3. **Database.** A system is required to collect, receive, validate, correct, manipulate, store and report pedigree and performance records and statistics based thereon. The database structure must link to other computer systems as appropriate (e.g., for BV processing).

4. **Technology to rank individuals.** The technology of genetic evaluation embodies the statistical models, variance components and algorithms used to predict the relative breeding and production worths of candidates available for selection.
5. **Research.** The long-term success of an improvement programme requires a system that evolves and allows breeders to take advantage of new market opportunities and scientific discoveries relating to the identification, multiplication and management of superior individuals. Continuous research is needed to compare alternative selection criteria and selection policies, for example as new measurement and reproductive technologies come to hand. Research needs to be an integral part of the programme to allow results to be available to industry in a timely fashion.
6. **Extension.** Extension organisations and individuals, not the least of which are progressive breeders and buyers themselves, have an important role in ensuring effective two-way communication between the various components in the system. They must be able to demonstrate financial advantage from the use of superior individuals.

The major factors determining the effectiveness of a national genetic improvement scheme are the way that components are mutually co-ordinated and matched to industry needs/wants. An effective scheme will achieve genetic advances in the breeding population, gene flows to the commercial or production populations, and cash flows to support the needs of each component. Balance must be achieved between genetic advance, gene flow and cash flow. Schemes with high rates of progress will not succeed without gene and cash flows. Schemes with good cash flows will not prosper long term unless genetic advance is demonstrably occurring. The next section of this paper will consider some aspects of the breeding goals and structures for three New Zealand industries, along with aspects of genetic progress, gene flows and cash flows.

## DAIRY CATTLE IMPROVEMENT

The N.Z. dairy industry comprises some 3 million dairy cows representing crossbred and straightbred cows from three major breeds (Holstein-Friesian, Jersey and Ayrshire). Holstein-Friesians are the predominant breed with crossbred cows being numerically as important as the Jersey breed. Virtually all animals are voluntarily pedigree and performance recorded. Extensive genetic linkages exist between herds as most cows are sired by artificial insemination from small teams of straightbred bulls (Whittaker 1994). This enables across-breed genetic evaluation of practically all animals in the industry for milk volume, fat and protein production, survival, and liveweight. The inclusion of liveweight (introduced to account for beef returns and maintenance feed intake) facilitates across-breed comparison of animals of markedly different sizes and individual productivities. Breeding values for each of these traits are calculated every three weeks and are combined with economic values to rank animals on profitability per unit of feed intake (known as Breeding Worth BW).

Genetic progress is determined by selection imposed in four pathways, namely bulls to breed bulls, cows to breed bulls, bulls to breed cows and cows to breed cows. In theory, farmers "control" the latter two pathways and the artificial breeding (AB) organisations "control" the former two pathways. In practice, the AB companies control three of the four pathways as these organisations determine which bulls are to be made available for farmers to use in their own herds. The dominance of the AB companies in dictating genetic progress will continue as long as farmers use AB, herd test all their cows, and make elite bull calves available to AB companies. Only cows with three generations of AB breeding to the same sire breed have been used as bull mothers. The number of available bull mothers has markedly increased in recent years. As these cows are distributed across 14,500 farms, improvement relies on ranking animals across herds. Across-herd rankings rely on widespread use of AB, high levels of recording and the national database. Selection is on BW with independent culling applied to some other traits, such as milking speed and type. All breeds essentially pursue the same objective.

Genetic progress (potentially $0.25\sigma_g$ per year) is passed on to the production population through the use of AB (up to 400,000 doses per bull per year). As only half of the genes come from the sire, the merit of the production population lags behind that of the bull team by an amount representing progress made over two cow generations (about ten years). Accordingly, the production population lags behind the breeding population by 2-3 $\sigma_g$ (10 years $\times$ $0.25\sigma_g$). In the absence of major advances in cost-effective application of reproductive technologies, there seems little opportunity to markedly reduce this lag.

Cash flows must support the AB companies and the system infrastructure (database, BV processing, research). A major advantage supporting the infrastructure is that almost all producers (not just breeders) are direct users of recording. However, detailed accounting is difficult as farmers herd test for their own culling decisions yet this information assists in the evaluation of all animals, "subsidising" the breeding scheme by identifying superior bull mothers and providing performance information on the offspring of bulls undergoing progeny tests.

## BEEF CATTLE IMPROVEMENT

The N.Z. beef industry comprises some 5 million cattle. Over half of the 2 million animals slaughtered annually are sourced from the dairy industry, including surplus young (bobby) calves, cull cows, Holstein-Friesian bulls and surplus dairy-beef crosses (primarily Hereford-Friesian) finished or mated to terminal sire breeds (e.g., Simmental). Some 165,000 beef inseminations are used in dairy herds, in addition to beef bulls used for natural mating (Charteris and Garrick 1996). Dairy-sourced females comprise 20% of the 1.4 million breeding cows. Unlike the dairy industry, the beef industry has distinct breeding and commercial (production) sectors. The breeding sector comprises 64,000 registered breeding cows half of which are performance recorded. Among performance-recorded cattle, predominant breeds are Angus, Hereford and Simmental. Angus and Hereford cows and their crosses comprise about 70% of the production cow population. Each registered breed has its own separate database. There is no real opportunity for across-breed evaluation until greater numbers of (commercial) crossbred cattle are pedigree and performance recorded. Recorded animals are primarily evaluated for weight traits (recorded at weaning, yearling and 2 yr old). Some carcass assessments are undertaken using independent datasets from registered bulls outcrossed in commercial herds although progeny results have usually been obtained at too late a stage in the bulls life for effective use to be made of this information.

The adherence within the industry to the registered population as the source of sires precludes any contribution from the numerically larger production population. The reliance on weight traits as the dominant selection criteria allows bulls to be selected on individual performance. Accordingly, one might expect improvement would result from two pathways of selection: namely choice of males to use as bulls and females to use as cows. However, analysis of ancestral records demonstrate that far fewer herds supply bull fathers than supply cow fathers. This implies registered herds can be classified into "nucleus" and "multiplier" categories. The nucleus category has major impact on the direction of genetic progress, yet is insulated from some market forces influencing the production sector where the benefits of selection should be accruing. Recent analyses show demonstrable genetic increase in weight traits have occurred within the registered sector, but much of these gains may be attributed to the use of 12,000 doses per year of U.S. semen. Any correlated responses in reproductive and carcass traits are largely unknown (and unassessable with current levels of performance recording), yet these traits are of considerable economic importance to the industry.

Gene flows to the production sector rely largely on the purchase of herd sires for natural mating, since only 25-30,000 beef inseminations are recorded in the entire beef population. Natural mating with low mating ratios (1 bull:50 cows) results in a large annual demand for herd sires. The adoption of widespread artificial insemination would allow more discrimination among sale bulls, but is not practical in production herds given current technology for oestrus detection and given labour constraints on commercial farms.

In contrast to the dairy industry, improvement programmes must be directly paid for in entirety by bull breeders using performance-recording, with commercial producers rewarding the bull breeders through premiums paid for bulls. High bull prices are primarily the domain of nucleus bull breeders selling to multipliers. Given the current economic situation within the beef industry, there is real risk that the level of recording will further erode as bull breeders seek to reduce costs.

**TREE IMPROVEMENT**

The Radiata pine industry comprises: a breeding population (being re-assembled to include several hundred individuals); orchard populations comprising up to 40 tested parents to multiply improved material; and the production population. The recent domestication and long generation interval of 25-35 years dictates that about half of the current commercial forest is still relatively unimproved, but harvesting and replanting over the next decade will see the entire forest coming from "improved" stocks (Carson, 1992). The breeding population consists of two distinct sublines. Within each subline, subpopulations are maintained for different breeding objectives. All these subpopulations must achieve thresholds for growth and form, and are then classified on the basis of one or more other traits (such as Dothistroma resistance, wood density or high growth rate). These subpopulations overlap such that some individuals could be represented in the elite group for two or more objectives. The breeding population includes individuals maintained for reasons of genetic variation, that are unlikely to contribute directly to the production population. Over the last 50 years, some 4,500 unrelated genotypes have been progeny tested.

The breeding population is an open-nucleus, however the contribution of replacements to this population is increasingly arising from crosses between individuals already in the population, rather than from screening in from land-race and provenance material. A General Combining Ability (GCA) progeny test takes place in and outside the nucleus, in which four superior females from one subline are used to test several hundred males that originate from the other subline. Generations tend not to overlap to the extent that occurs in livestock breeding. The last 50 years of improvement represents several discrete cycles of selection and 2-3 cycles of breeding. Progeny test sites are selected to provide high phenotypic variation, high heritability and to represent most forest regions. Testing of multiple copies (ramets) of a number of (fullsib) clones may in future be used to assess parents. Matings tend to be partial factorials, with cross-classification of parents. Genetic progress in growth rate (wood volume) has been of the order of 1% per year for the last 30 years with additional form and disease resistance gains that are likely to have been of equivalent value.

The production population consists of offspring from matings between males in one subline and females in the other subline, chosen on the basis of prior progeny testing between these sublines. That is, in contrast to the dairy and beef industries, both parents of the production population have been subjected to prior selection and are proven. The availability of clonal copies of the same female allows increased amounts of seed to be created. Tissue culture and nursery propagation techniques allow 1,000s of identical seedlings to be created. The net effect of these technologies is that there is very little lag between the realisation of merit of parents in the breeding population and their offspring in the production population.

The breeding populations are maintained for industry in a co-operative, members of which use individuals from the breeding population both to create their own production populations and to sell material in competition with each other. Cash to maintain the breeding population thus flows from a small number of users who recover these costs from their own plantings and from orchard and nursery sales. In contrast to the dairy and beef industries, there is little competition from foreign breeding companies and the co-operative includes offshore members. The longevity of trees and their immobility makes recordkeeping less dynamic than is the case in livestock industries. Furthermore, the discrete nature of progeny testing on fixed sites and ability to create large, well-designed field trials limits the need for some of the statistical developments that have been crucial to the identification of superior cattle sires. Recording, database and BV technologies are therefore more centralised and on a different scale from livestock breeding, reducing infrastructural costs.

## ISSUES FOR THE FUTURE

The previous sections introduced some characteristics of the N.Z. dairy cattle, beef cattle and tree breeding industries in terms of genetic progress, gene flows and cash flows. This section considers how components of these schemes might be modified to enhance the benefits of the programmes and considers the abilities of the current schemes to exploit some future technological developments.

**Database technology - scope of recorded individuals.** The dairy industry database encompasses both production and breeding sector requirements. Opportunity exists to expand liveweight recording to younger cattle prior to first lactation, and to those individuals that enter the beef industry. In contrast, the beef cattle and forestry databases limit their function to the breeding sector. Since genotypes have been well-characterised before their widespread use there seems little obvious benefit in the forestry industry recording further information from the production sector, although future widespread planting of stands of single clones could lead to review. However, the beef recording industry could increase its user base to the production sector. Such links would be of particular benefit given individual identification will become mandatory from an animal health viewpoint, and meat processors are increasingly providing feedback on individually identified animals. This sector may in future adopt wider parentage recording (using DNA markers) or the capability for widespread use of artificial insemination.

**Database technology - scope of recorded traits.** The dairy industry has the opportunity to increase the scope of milk traits evaluated given that it already receives individual milk samples, and compositional traits are becoming increasingly important. The current recording system can monitor disappearance of animals between birth and first lactation, but information as to the cause of disappearance is not routinely available. This may limit the opportunity for fairly evaluating animals for survival, fertility and perhaps some type traits. A move to include liveweight recording of heifer replacements could considerably improve data quality during these early stages. The beef industry needs to expand its scope of traits evaluated. Current beef cattle recording is limited to traits of moderate heritability that are relatively easily changed with mass selection. Total herd recording would improve the ability to evaluate fertility and longevity traits. The current isolation of the breeding sector from the production sector limits availability of meat and carcass information, as few animals are sold for processing from the breeding sector. Extending the recording scheme to evaluate traits not amenable to direct selection might encourage greater participation in performance recording. Product markets have moved from being entirely price (commodity) driven towards greater sophistication with demand for quality assurance schemes, product tracing with concerns regarding product safety, animal welfare, and animal ethics. These factors may force changes to the database requirements of these industries. The tree breeding industry has total control of their GCA testing and therefore has the opportunity (cost aside) to measure any traits (e.g., wood quality) that are of interest. The advent of clonal forestry would enhance opportunities for utilising non-conventional traits arising from genetic engineering.

**Research - links to breeding.** The dairy industry has reasonably good links between breeding and reproduction researchers and the recording system infrastructure. Links between product quality and processing research and the recording infrastructure could be improved. Research into reproductive technologies have benefited from access to reproductive records on the database. Research in molecular genetics is closely linked to industry such that useful findings will be rapidly available for exploitation within the breeding programme. The beef industry has poor links between the recording infrastructure and researchers which has done little to prevent reductions in research funding. The tree breeding industry is well-linked to research with the main research provider being contracted to run the co-operative breeding programme, and with additional industry/provider ventures covering new applications of molecular biology (including genetic engineering and marker-aided selection).

**Research links to consumers & objectives.** Current dairy price signals are limited to the quantities of fat and protein relative to milk volume, with penalties for some quality attributes including somatic cell counts. In future, it is likely that market signals relating to processing characteristics (e.g., cheese yields) and consumer aspects (e.g., milk colour, butter hardness) will be transmitted to producers. It is not yet clear whether such signals should be interpreted in a breeding context (by directional selection) or by niche production (segregation of cows according to milk characteristics). Preliminary studies indicate considerable opportunity costs are associated with re-directing selection pressure from production and efficiency characteristics to processing aspects. A major dilemma for the beef industry is to decide whether selection pressure should be concentrated on reducing costs of production (e.g., reproductive rate, longevity, growth rate) or on improving product quality (e.g., tenderness, marbling, fat colour, meat colour). It is not clear whether beef producers will ever be properly rewarded for changing meat or carcass quality, or whether it will more effectively be undertaken by processing technologies. In any event, the current carcass classification system does little to assist breeders in identifying market signals. Trees are primarily sold on the commodity market but in recent years log and wood quality is becoming increasingly important. Many investors also have processing interests and are able to communicate signals back to the breeding co-operative. The slow generation interval and the retention of genetic material in archives provides this industry with a unique ability to "mine" their genetic resources for a considerable time period.

**Extension.** The dairy industry funds a national system of consulting officers and invests considerable funds in farmer education. From a breeding perspective, individual farmers have almost no impact on genetic gain, the AB companies having the major impact. One could argue that farmer education is of little value other than from a public relations viewpoint, provided they continue to inseminate their cows using improved semen and to herdtest. The beef industry previously had extension officers available at no charge who raised awareness of the need for, and use of, objective information for breeding decisions. If product quality is to be changed by breeding, then the processing industry must play a greater role in research and extension in this area. If breeding is to be used to reduce costs of production, it might be argued that this is best left to producers and breeders to discover for themselves. However, given much of the country farming beef cattle has alternative land uses including grazing dairy replacements, sheep or forestry, it is more likely that producers will change production systems rather than improve the existing schemes.

**Prediction technology - international comparisons.** It is somewhat ironic that the dairy industry also evaluates cattle for liveweight, across-breed and is using more weight records than are available for beef breed evaluations. International comparisons via Interbull, are increasingly important as the industry seeks to exploit any genetic material that might benefit profitability. The commercial beef industry could benefit from across-breed comparison but data to achieve this end is currently unavailable, except perhaps via the dairy industry. The breeding sector is unlikely to benefit from across-breed evaluations. International comparisons are increasingly becoming of interest, quite rightly so given the impact that foreign semen has had on our breeds. However, these comparisons have been primarily with Australia, which has not been the source of significant quantities of semen (compared to U.S. and Canada, for example). In contrast to international dairy evaluations, where performance in each country is treated as a different trait (e.g., MACE, Schaeffer 1994), the beef approach has been to pool data from different countries and process in a single evaluation. Approaches akin to MACE will be more rewarding in the long-term, as these allow for different units of measurement and expression in different countries, and for non-unit genetic correlations between countries, as well as allowing inclusion of progressively more and more international partners. The tree breeding industry comprises genetically-indistinct breeds for a small number of breeding goals, duplicated across the two sublines. Any desired production population can be formed from crosses within and between these breeds. Parallel breeding populations (for example, in Australia and Chile) can provide future sources of material, and appropriate benchmarking trials have been established for international comparisons.

**Breeding objectives.** Existing selection objectives are often narrowly focussed, and show little variation both locally and internationally. There could be undesirable correlated responses that have yet to be identified. New traits may prove to be important in future and useful variation in these characteristics may have already been eroded. The dairy industry has the recorded production population as a resource, which although sired by few bulls has many dams, such that genes of low frequency should remain in the population for some time before extinction. The beef industry has not historically made much use of the commercial population for breed improvement, and limits its gene base to the registered sector. However, the wide use of natural mating within this sector will have reduced the chance genes will be lost. Furthermore, the lack of an objective has resulted in animals being selected for any number of a range of traits. The tree breeding industry has been more careful to maintain diversity, with retention of sublines and the use of multiple (different) objectives within each of the sublines. The "open" status of the nucleus population allows for new material to be screened in. However, the production forests may not offer much scope for new material as both parents of these trees will have been sourced from the breeding sector.

**New reproductive technologies.** These provide options for greater genetic advance and improved gene flow. It is likely that the benefits will be greater in gene flow (reducing genetic lag) than in increasing genetic advance within the breeding sector. Possible animal technologies include long-life (e.g., encapsulated) semen, clones, embryos from pre-pubertal calves, in-vitro maturation and fertilisation, semen sexing, twinning. Some of these technologies are being researched, but most have been studied for many years and chances of breakthroughs seem little closer than they were a decade or more ago. The beef industry is likely to benefit from any such developments in the dairy industry. The tree industry is much further advanced in this regard, developing effective controlled pollination and early flowering techniques, using clones both for testing parents and to produce production forests, with tissue culture and nursery propagation techniques allowing many identical copies of the same genotype.

**Benefits of new genetic techniques.** These include marker-assisted introgression (MAI), marker-assisted selection (MAS) (Mackinnon 1992), gene transfer and fine-mapping. The dairy industry is well-positioned to exploit marker-assisted selection should this prove to be a viable option. A joint venture with European interests has determined some interesting chromosomal regions. However, the means of exploiting these within the context of the breeding industry structure is not straightforward. The time-frame for receiving financial benefits from improved production is beyond the investment horizon used by most companies. An AB company could benefit in a shorter time frame through international semen sales of an improved bull. The dairy industry is not currently undertaking research that might identify genes useful for MAI. The beef industry does not have the funding or the infrastructure to research or exploit marker-assisted selection. This industry could possibly benefit from MAI, provided it was prepared to make use of crossbred animals. The tree industry is well-structured to research these molecular technologies, and their propagation techniques give this industry the best chance of utilising any findings. Existing plantations and field trials allow for independent verification of any major genes in material outside that used to detect gene using MAS. This verification may not be so easily achieved within the beef and dairy industries. Transgenic opportunities and other ethical issues are likely to be of far less concern in (corporate) tree breeding than is the case with animals.

## DISCUSSION

For a variety of reasons, every breeding industry has developed in a unique manner, although many share common characteristics. These similarities and differences must be accounted for when considering the challenges facing these industries both in fine-tuning existing practice and in making cost-effective use of new technologies. A considerable amount of current research seems to be undertaken with little regard for the limitations that might exist in the transfer and exploitation of these findings to the benefit of the industry. There are opportunities for mutually beneficial collaboration both between different industries within a country and between the same industries in different countries. Political and other reasons have often ensured that such collaboration does not take place. In relation to the dairy breeding and tree improvement industries, the beef breeding industry is not as well placed to take advantage of many current and future opportunities.

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