INTRODUCTION

Beef breeding programmes have developed significantly in the last 24 years since the 1st WCGALP. Breeding programs as defined here include the definition of breeding objectives, recording and genetic evaluation programs to develop selection criteria and developments in selection and mating technology to optimize genetic progress for the objective. Available today are tools for the implementation of breeding programs, which were at one point only a concept. The objectives of this paper are to review the current state of applied beef cattle breeding programs and related technologies and speculate on future prospects. The emphasis will be on specialized beef breeding programs in the developed world with reference to specific experience in Canada, acknowledging that this is not relevant to beef production in all areas of the world. However, for much of the developed world where specialized beef production is common the following developments and prospects could be valid.

PROGRESS

Breeding Objectives. Although the theory for the development of breeding objectives in beef cattle and their subsequent selection decisions are relatively well developed, their wide spread application in industry are just now emerging. Much of the reasons for unclear definitions of breeding objectives in the past have been blamed on a fragmented industry structure and poor market signals between segments. The industry is best described with separate purebred and commercial sectors and the commercial sector being broken down further into cow-calf / back-grounding and feedlot. This segmentation and lack of clear market signals between sectors has been identified as a major limitation to the development of clear objectives for the industry in the past (Koch et al., 1986; Parnell et al., 1986; Wilton, 1986; Nicoll, 1990). Predictions are made later as to how industry structure is changing to eliminate these traditional problems which have limited the application of breeding objectives on an industry wide basis. Discussed are some of the developments to date and programs in use to implement breeding objectives for selection purposes.

A practical beef-breeding program for purebred cattle in France was described in Phocas et al. (1998). In this case, one overall index was established for the Limousin breed based on a weighted average of the economic weights in different production systems. Similar to Barwick et al. (1994) and MacNeil et al. (1994) the importance of reproductive traits in economic selection criteria was identified. The lack of phenotypic reproductive scores has been cited as a major limitation to breeding objectives (Stewart, 1998).

An overview of the application of a customizable selection index program BreedObject was presented by Ponzoni et al. (1998). BreedObject combines available EBVs from the Australia
Breed Plan system to produce multiple trait selection criteria with consideration of varying markets and productions systems. It was acknowledged that producers appreciated ownership and control over the factors that influenced trait emphasis.

BIO-MATE like BreedObject is a customized selection tool developed to combine genetic evaluations for selection purposes. BIO-MATE is described in Wilton et al. (1998) and is based on a bio-economic model where producers can change such production parameters as genetics of mate (cow), feed costs and replacement structure. The sensitivities of the selection procedure to feed costs and cow genetics are described in Lazenby et al. (1998) and Wilton et al. (2002), respectively. BIO-MATE combines multi-breed evaluations, involving bulls of different breeds and crosses to be compared based on economic merit.

Using BreedObject as a base, a sire selection tool was developed and implemented on the World Wide Web (Charteris et al., 1998). The advantages of this technology and the increased uptake of economically based selection criteria were discussed and outlined. The prediction was made that these multiple-trait selection tools combined with mate selection tools including crossbreeding will become more commonplace and to be successful, these tools will have to be consumer focused. Developments in the last 4 years would support the predictions of Charteris et al. (1998). BIO-MATE moved to the WWW in 1999 and BreedObject is now on the web. BIO-MATE and BreedObject are examples of web based selection and mating tools. Advantages to delivery over the WWW include currency of and access to information, which are important aspects relating to the attributes identified by Charteris et al. (1998).

**Genetic Evaluations.** Of all the technologies reviewed genetic evaluation is the one that has shown the most progress. Reasons for this could simply be industry structure. Where industry did not support establishment of breeding objectives, it did support genetic evaluation.

Although research will continue on improving evaluation methods to make more accurate predictions for use in bio-economic prediction models for selection decisions, genetic evaluations have matured to the point of no longer being a major limitation to progress, at least for the traits that are easily measured. At one point the comparison of animals across herds was a concern (Simm et al., 1990). Now the application of genetic evaluation models has graduated to multi-breed models to compare animals across herds regardless of breed composition. Pollak and Quass (1998) outline the origins and developments of genetic evaluation models used for multi-breed beef cattle populations with a discussion of their own experiences modeling American Simmental data including crossbred records. The first large-scale application of a multi-breed genetic evaluation in beef cattle was reported in Miller et al. (1994). In the time span of two WCGALPs, the idea of multi-breed evaluations has become mainstream. These analyses of multi-breed data will continue to expand as beef breeding programs progress over the next decade as predicted later in this paper.

**Dynamic Mate Selection.** The process of selecting candidates and mating them considering additive and non-additive genetic effects has been merged into a process termed dynamic mate selection. Kinghorn and Shepherd (1990) proposed a unified framework for making breeding
decisions which was to “describe an objective function which describes net economic gain as a function of selections and mate allocations” and then to “develop and implement a mate selection algorithm which maximizes the objective function”. With this approach, the result is a designed breeding program considering selection, crossbreeding and running costs simultaneously (Kinghorn and Shepherd, 1994). The objective then is to maximize genetic merit in some future generation such as grand progeny. In some cases less genetically superior mates are chosen to build connections between fixed effects groups for example, which will enable more accurate evaluations and more progress in the targeted grand-progeny generation. This method has been called the Look Ahead Mate Selection Scheme (LAMS) and was presented by Shepherd and Kinghorn (1998). The efficiency of this approach has been demonstrated by Hayes et al. (1998). The concept of dynamic selection rules where mating and selection decisions change depending on the candidates available for selection was described by Goddard and Howarth (1994).

Selection based on estimated breeding values with an animal model will lead to increased selection of relatives and this will result in an increase in inbreeding levels (Meuwissen, 1998). This phenomenon has been well recognized and the accumulation of inbreeding is accelerated further with advanced reproductive technologies such as MOET that allow for capitalization of elite genetics (Nicolas and Smith, 1983). Considering multiple generations and long-term selection response remains a current issue with details of solutions being presented by Grundy et al. (1998) and Meuwissen (1998).

When considering mate selection strategies in a multi-breed population, the inclusion of additive and non-additive genetic effects between and within breeds may be of interest. Mate selection strategies have been expanded to include non-additive genetic effects between and within breeds implementing the super-breed model including dominance effects (Miller and Goddard, 1998; Hayes and Miller, 2000). Results indicate that full mate selection on total progeny merit, considering non-additive genetic effects between and within breeds is computationally demanding and unlikely to be practical. However, some alternative practical procedures were shown to perform quite well. Despite much research in the area of non-additive genetic effects and their incorporation into genetic evaluation and mating programs, their practical implementation into industry programs remains to be seen.

Genetic Markers / QTL. The implementation of genetic markers and QTL became a practical reality in beef breeding programs in 2000 with the introduction of a marker associated with marbling by Genetic Solutions Pty limited, Australia. This marker will no doubt be followed by more for the same and other traits by various groups working in this area around the world. Primary importance will be traits which are either very difficult to measure or which have low heritability. A number of markers are currently being validated in the USA in a research project termed the Carcass Merit Project (Pollak, 2001).
RETROSPECTIVE ON A PAST PREDICTION
A retrospective on factors affecting future breeding programs in beef cattle improvement as identified by Simm et al. (1990) at the 4th WCGALP is attempted. The progress and prospects of the factors identified by Simm et al. (1990) are discussed here, some twelve years later. Simm et al. (1990) included the following technical factors as affecting the future of genetic improvement programs. 1. Improved statistical methodology, including BLUP evaluations. 2. Improved selection criteria, including wider implementation of technologies to measure live animal body composition, methods to measure food intake on farm and systems to transmit measures from the slaughterhouse back to the cow-calf operator. 3. New reproductive techniques, including MOET as well as embryo sexing and in-vitro embryo production. 4. Gene transfer.

Genetic Evaluations. As described previously, improvements in BLUP evaluations and statistical methodology have been evolving continuously over the last twelve years and have developed to the point where for the most part, evaluation techniques are no longer considered a major barrier to progress.

Selection Criteria. Selection criteria have also improved considerably in the past twelve years. The accuracy and acceptability of ultrasonic measures of body composition for genetic evaluation along with the relationship to carcass traits is reasonably well understood and has been shown to be a valuable tool for genetic improvement of carcass traits (Wilson et al., 1998; Reverter et al., 2000; Devitt and Wilton, 2001a; Crews and Kemp, 2001). Likewise, systems to trace back carcass data from the processing plant to the people making breeding decisions has also seen great developments in the last few years. These developments have been prompted, in many cases for reasons other then genetic improvement such as disease control. Robinson et al. (1998) described the BIO-LINK program in place in Canada, designed to trace carcass data back to the original breeders of cattle and showed favourable relationships between these measures and those predicted based on performance testing of yearling bulls. Devitt and Wilton (2001b) showed the potential value of commercial carcass data through such a program, where with sufficient volumes of data and progeny per sire, these data could be an important aspect of a genetic improvement program. This experience in Canada is likely very similar to other countries, as many countries have or are in the process of developing national identification and trace back mechanisms. Recording of feed intake has seen important developments and is discussed later. Other important developments in selection criteria since the predictions of Simm et al. (1990) have been in the area of calving ease, traits related to female fertility and product quality traits related to tenderness.

Reproductive Technologies. New reproductive technologies, although there have been some developments, are not that different from 12 years ago. As breeders we continue to develop potential plans and use simulation to show advantages of potential structures considering such advancements as in-vitro embryo production, embryo splitting, embryo sexing, cloning, semen sexing and same sex mating. Predictions made here are likely to be similar to those made 12 or is some cases more years ago. Of all the potential reproductive technologies, AI and MOET remain the two techniques that are of practical, though limited, use in beef breeding programs.
today and in probably the near future. Developments in technologies to synchronize ovulation and in turn make AI and ET feasible on a large scale have shown some progress. Considering the previous limitations to beef cattle breeding programs due to low adoption of artificial insemination (Simm et al., 1990), these new advances in synchronized breeding technologies will create opportunities in beef improvement. In addition to technical concerns outlined here, Simm et al. (1990) also outlined structural and social concerns. Of these concerns, consumer interests in methods of production will have the greatest impact on future methods of beef production. These consumer concerns are most likely to have an impact in limiting progress possible through advancements in reproductive technologies such as cloning, but also through concerns over hormone use in widespread commercial AI and ET programs. Simm et al. (1990) were correct in predicting that consumer concerns could influence beef improvement programs and likely this trend will continue.

PROSPECTS

Industry Structure. Bichard (1998) provided an insightful comparison of the structures of both the swine and dairy breeding industries and how although both industries had similar origins with cooperative structures, the swine breeding industry has been much more rapid to evolve a structure based on large international shareholder controlled companies, where as the dairy industry has remained largely cooperative in structure although breeding decisions are likely to move to large AI organizations (Bichard, 1998). In comparison, the beef breeding industry is more like that of dairy breeding than swine with a more cooperative structure then corporate. The origins of beef improvement programs are similar to those of dairy and swine, including the development of breed associations and their respective improvement programs as described for North America by Koch et al. (1986). Impediments to a more corporate structure in beef breeding programs have historically been related to the extensive grazing production system and the unlikely ownership of these resources in a corporate structure (Notter and Hohenboken, 1990).

Despite the impediments, there is a movement in the beef industry towards vertical integration and consolidation into a more corporate structure. Large beef production companies are becoming larger and forming vertical alliances and corporate structures across the production sectors that have divided the industry and historically inhibited progress. These corporations control the cattle and collect or distribute the benefits of improvement at all aspects of the production chain, cow-calf, feedlot, processing and retail.

Green (2001) and Roybal (2001) describe one such vertically integrated beef production enterprise with a corporate structure. This organization described is fundamentally structured around one database system designed to collect and share data at all aspects of the production chain. The supply chain consists of a state of the art packing plant with capacity for 429,000 head per year with one retail customer, 5 feed yards, 20-25 stocker/grower operations, 1000 cow/calf producers and 40-50 seed stock operations. With this model, the development of breeding objectives for those 40-50 seed stock suppliers then becomes much more clear with development of systems to optimize genetic progress for the entire company becoming possible. The benefits of centralized decision-making and rapid implementation with the entire
production chain in mind are described in Nicoll (1990) with the example of Landcorp, New Zealand’s beef breeding enterprise. The results of LandCorp’s implementation of a breeding objective and nucleus-breeding scheme are described in Enns and Nicoll (1997). Landcorp provides an example of a comprehensive genetic improvement structure and complete breeding program which will be demanded and made possible through a more corporate, integrated production environment.

With this change in industry structure the emphasis on tools and the role of the professional beef cattle breeder changes. Emphasis moves from information tools to decision tools. Where genetic evaluations are information, a mating list is a decision. The changing structure will clarify breeding objectives and provide data systems to capture information, including DNA perhaps, throughout the production chain. The challenge is then placed on the professional beef breeder to use, and further develop, all available technologies to improve the competitiveness of the production company.

**Novel Traits.** With the change to more integrated production systems, in which the company benefits from all phases of production, the emphasis on traits may also change. Once it is identified that a trait can be improved in a cost effective manner to benefit the company, it will be incorporated into the breeding objective. Examples of such traits that will see increased attention in the near future include traits related to feed intake recording and feed efficiency (Archer et al., 1998; Basarab et al., 2001). Interesting developments will include the use of infrared technology to better understand energetic efficiencies (Tong et al., 2001). As well technologies to improve end product traits such as tenderness will become more important under this structure. An important area that is now just emerging is that of environmental sustainability. Methane gas and ground water quality will continue to be major issues. A company could benefit from not only consumer marketing but also perhaps from such monetary benefits as carbon credits from other industries in the adoption of technologies such as improved feed utilization to reduce the impact on the environment of their beef production enterprise (Okine et al., 2001). Advancements in these novel traits are more likely to be expedited through the corporate system proposed here than through the current more cooperative system.

**Genetic Evaluation and Mating.** Genetic evaluation models will continue to develop, likely to match demands of implemented technology. More intensive data collection through electronic devices such as feed intake recording, repeated ultrasound and thermal imaging will provide repeated observation on animals which can be analyzed with random regression models which are now being implemented in beef improvement (Meyer, 1999; Schenkel et al., 2002). Through consideration of changes in these different biological parameters, the implication for interaction with management and marketing systems can be modelled. Similar to the example program of increasing twinning rates below, genetic evaluations will have to consider additional information made available through genetic markers and optimally incorporate these into mating plans.
Prospects for mating plans lie in the ultimate application at this point. Look Ahead Mate Selection schemes, as their developments have been described here, offer an opportunity to optimize both selection and mating strategies as well as population structure for optimum progress over a specified time horizon. Application of these technologies will coincide with current selection tools such as BreedObject or BIOMATE. An example of such a development is the current offering of the web based Total Genetics Resource Management (TGRM), University of New England, Australia.

Example. The twinning line at the Meat Animal Research Centre, USA could be held as a practical example of a success story in beef cattle breeding. Faced with tremendous challenges, such as low heritability, sex-limited expression, and difficulty of measurement as well as a categorical trait, excellent progress was made. Increasing the rate of twinning at a rate of 3 percent per year to a level of around 50 percent has been accomplished through a program of intensive breeding (Echternkamp and Gregory, 2001). This intensive selection program was based on evaluating two traits, ovulation rate and twinning rate, each with a low heritability (.10 and .09, respectively) (Thallman and Gregory, 2001). The trait ovulation rate allowed selection of heifers and repeated observations. Three QTL accounting for 15 percent of the genetic variation were identified which were combined with polygenic effects to compute marker adjusted predictions of breeding value (Thallman and Gregory, 2001). It is likely that similar practical breeding challenges will be faced in the future and similar strategies required.

CONCLUSION
Although the tools for the development of sound beef breeding programs are relatively well developed and much progress has been made, application has been limited due to a segmented industry with lack of vertical integration. The future will see a more corporate, vertically integrated structure to the beef industry that will create opportunities for genetic improvement. This changing structure will create demand for the practical implementation of theories and tools developed, which may not have been implemented on a commercial basis to date.

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Communication No 02-18

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