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Bernard Michael Bindon — reproductive physiologist, animal scientist, research leader

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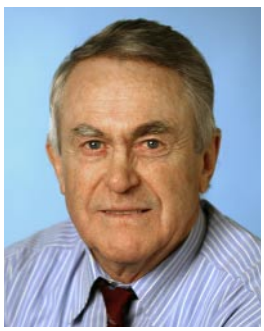

Abstract. This paper is a foreword to a series of papers commissioned on 'the impact of science on the beef industry', where the Beef CRC-related collaborative scientific work of Professor Bernard Michael Bindon will be reviewed. These papers will be presented in March 2006, as part of a 'festschrift' to recognise his wider contributions to the Australian livestock industries for over 40 years. Bindon's career involved basic and applied research in many areas of reproductive physiology, genetics, immunology, nutrition, meat science and more recently genomics, in both sheep and cattle. Together with his collaborators, he made large contributions to animal science by improving the knowledge of mechanisms regulating reproductive functions and in elucidating the physiology and genetics of high fecundity livestock. His collaborative studies with many colleagues of the reproductive biology and genetics of the Booroola Merino were amongst the most extensive ever conducted on domestic livestock. He was instrumental in the development of immunological techniques to control ovulation rate and in examining the application of these and other techniques to increase beef cattle reproductive output. This paper tracks his investigations and achievements both within Australia and internationally. In the later stages of his career he was the major influence in attracting a large investment in Cooperative Research Centres for the Australian cattle industry, in which he directed a multi-disciplinary approach to investigate, develop and disseminate science and technology to improve commercial cattle productivity.

Introduction

Professor Bernard (Bernie) Michael Bindon has dedicated his life's work to animal science and its application. His career path has covered many areas within basic and applied research in reproductive physiology, genetics, immunology, nutrition, meat science and genomics, with associated roles in research leadership, supervision and management. He has been an outstanding mentor and leader to his many postgraduate students and to a very large number of scientific and industry collaborators over many years. Bindon's ability and vision culminated in his inception, direction and leadership of 2 CRCs for the Australian Cattle Industry, and on approaching his retirement, the successful preparation and passing of the

This overview of the career achievements of Professor Bernie Bindon has been compiled by (left to right): Keith Entwistle, Leo Cummins, Michael Hillard, James Kinder, Tim O'Shea, Laurie Piper, Jacques Thimonier and John Wilkins.

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leadership baton for a third term of CRC funded research and education.

Bernie Bindon's colleagues in research, extension and the livestock industries will be gathered for an event following his retirement, to recognise his career achievements, and where a number of authors will be presenting papers on various topics in the animal industries directly involving or influenced by him.

It was, therefore, considered fitting that Bindon's career and achievements be suitably recorded and presented in a way that typifies his collaborative career. The following account attempts to do this as a foreword to the published scientific papers relating to Beef CRC achievements — obviously not in the style of a traditional scientific paper, but as a narrative connecting the many and varied areas in which he has worked with his many scientific and industry colleagues, and which have all impacted on improving the Australian livestock industries. He leaves a deep footprint.

Background to the future scientist

Bernie Bindon came from a pioneering dairy farming family on the Richmond River in northern New South Wales. Following primary schooling in the Lismore area, his secondary schooling was at St Joseph's College in Sydney where he was a good student and became an outstanding rugby player.

He enrolled in 1958 as one of the third intake of students into the Rural Science program at the University of New England (UNE) Armidale, started in 1956 by Professor Bill McClymont. In addition to his studies, as a member of Robb College at UNE, he continued his rugby career with distinction, being selected as a member of the New South Wales team in his final year at UNE. During this time Bernie met his future wife, Robin, who was then a Bachelor of Arts student at UNE.

Early career

Graduating in late 1961, Bindon commenced work with Professor Euan Roberts in the School of Wool and Pastoral Sciences at the University of New South Wales in Sydney. His long-term interests in reproductive physiology were kindled by early collaborative work on progestational control of oestrus and regulation of ovarian activity and of fertility in sheep (Bindon and Roberts 1964; Lamond and Bindon 1962; Roberts and Bindon 1966; Roberts *et al*. 1963). Similar work was being undertaken by Professor Terry Robinson at the University of Sydney who developed the innovative progestagen pessary to synchronise oestrus in sheep, a technique still in widespread use in 2005.

In early 1963, Bindon joined the CSIRO Division of Animal Physiology (Beef Cattle Physiology Unit) in Brisbane led by Dr Don Lamond. This was the first group in Australia to systematically undertake work on the reproductive physiology and reproductive management of beef cattle. During this time, Bindon, stimulated by Lamond's philosophies, commenced an approach which he maintained for the remainder of his research and research management careers — *viz*. of undertaking and facilitating research to determine and understand underlying physiological and biochemical control mechanisms influencing reproduction and productive performance, and of applying these findings to increase livestock productivity. During his time with CSIRO from 1963 to 1966 he also completed a Masters' program on the endocrine control of oestrus and ovarian cycles in sheep and was awarded an MRur Sci from UNE in 1966.

In addition to his work at that time with cattle and sheep, he and Don Lamond collaborated in some fundamental endocrinological studies, and some elegant and very useful techniques for bioassays of pituitary hormones were developed using hypophysectomised mice as the model (Bindon and Lamond 1966*a*, 1966*b*, 1969; Lamond and Bindon 1966*a*, 1966*b*; Lloyd *et al*. 1968).

It was this area of research that he expanded for his PhD program in the Department of Veterinary Physiology, University of Sydney under the supervision of Professor Cliff Emmens, at that time one of the doyens of reproductive physiology in the world. Bindon was a little unusual as a new PhD student in having had considerable research experience over 5–6 years, with about 8 publications to his credit. The focus of his PhD studies from 1967 to 1970, on an Australian Meat Research Corporation Scholarship, was on pituitary and ovarian regulation of implantation in laboratory rodents and sheep.

This was a period of extraordinary productivity as he collaborated widely with a number of colleagues in the department and in other institutions in Australia and overseas, publishing at least 17 papers on his PhD work. The major outcome was a precise understanding of the endocrine mechanisms that signal the start of pregnancy, involving hypothalamic, pituitary, ovarian and uterine interactions, with considerable work undertaken on hormonal control of implantation in sheep (Bindon 1971*a*, 1971*b*, 1973*a*; Bindon *et al*. 1973).

At that time, there were no suitable assays for sheep or cattle pituitary hormones, and he was instrumental in the development of a successful bioassay for ovine FSH (Bindon 1969*b*; Martin *et al*. 1969) using the hypophysectomised mouse model which was used for a number of other fundamental studies on male and female reproductive activity in mice (Bindon 1969*a*, 1969*b*, 1969*c*, 1969*d*, 1969*e*, 1969*f*; Bindon and Waites 1968) and sheep (Bindon 1969*f*, 1971*a*, 1971*b*; Bindon and Tassell 1969). A colleague, Barrie Restall, who shared a laboratory with Bindon at the time, and collaborated on several projects, recalls the technical skill and speed with which Bindon could hypophysectomise mice, and, given the invasive nature of the technique, his admiration for the very high survival rates and subsequent normal behaviour of these animals.

Despite this prodigious scientific effort over almost 10 years, Bernie found time to marry Robin in 1963, and commence a family, while continuing to indulge in his lifelong passion of Rugby Union football. He achieved fame as a quick and skilful back, either centre or five-eighth, being selected for both New South Wales and Queensland representative teams as well as playing for his clubs in Brisbane (Wests) and Sydney (Drummoyne). His passion for rugby has remained with him, and for many years he coached UNE student College teams, and he continues, while in his mid-1960s, to play Golden Oldies Rugby as a member of the Walcha Baa-Baa's team.

Post doctoral career

In the late 1960s, as a consequence of Don Lamond accepting a senior academic position in the USA, the CSIRO Beef Cattle Unit in Brisbane was wound down, much to Bindon's disappointment, as he had hoped to return there. However, on completion of his PhD studies in 1970, he rejoined CSIRO in the Division of Animal Genetics based at North Ryde, and started to develop an extensive reproductive research program utilising the sheep flocks based at the CSIRO Research Stations Arding and Longford at Armidale. Early work commenced on differences in ovarian activity and endocrine control mechanisms in some of the genetic selection flocks at Armidale (Bindon 1972, 1973*a*, 1973*b*; Bindon *et al*. 1971, 1974).

Understanding the physiological basis for genetic differences in reproductive performance

In 1972, Bindon was joined at CSIRO by Laurie Piper, a former UNE 'student friend' and fellow rugby player, who had just returned from Scotland having completed PhD studies in quantitative genetics. Over the next 2 decades they developed an outstanding collaborative team, which became one of the premier reproductive physiology and genetics research groups in the world, undertaking leading edge research on the physiological mechanisms responsible for genetic differences in fertility in farm livestock, as well as collaborating on a range of other projects.

Booroola Merino research

Bindon and Piper collaborated for many years in their study of the Booroola Merino, commencing with the selection lines for reproduction in sheep established by Turner (1982). This felicitous combination of expertise enabled them to tease out much of our knowledge of this strain of highly prolific Merino sheep, and Turner's account of the origin of the Booroola has been updated by Piper and Bindon (1996).

Their early work showed that, except for the very high prolificacy and the consequences that followed from this, other sheep industry characteristics (wool and carcase attributes) and physiology were similar to those of the parent Merino strain of medium-wooled, non-Peppin sheep (Owens *et al*. 1985*a*; Piper and Bindon 1982).

The increased prolificacy was the result of a very high ovulation rate (Bindon *et al*. 1982; Piper and Bindon 1982) that was the result of a single major gene (FecB) or a closely linked group of genes. By 1992 the ovulation rate had reached a mean of 5.7 in a flock that was virtually homozygous for the FecB gene (Piper and Bindon 1996). Other factors such as fertilisation rates, uterine capacity and embryo losses were not specific to the Booroola (Wilkins *et al*. 1982, 1984). The mechanism of this high ovulation rate was shown to be a longer period of recruitment of ovulatory follicles than in control Merinos. While the ovulatory Booroola follicles were smaller (Driancourt *et al*. 1985*a*, 1985*b*), the resultant corpora lutea (CL) produced a higher plasma progesterone concentration in ewes with 1 or 2 CL compared with control ewes. Progesterone concentration remained similar with further increases in ovulation rate, in contrast with the increasing concentration of progesterone seen with increased ovulation rate induced by PMSG (Bindon *et al*. 1985).

Ovulation was earlier after the onset of oestrus than in control Merinos (Bindon *et al*. 1984*b*), but other characteristics of the oestrous cycle were similar. Booroola ewes had a longer sexual season, with 60 percent ovulating throughout the year (Bindon and Piper 1976*a*). There was no evidence of early postpartum ovarian activity (Bindon *et al*. 1982) in contrast with some other prolific breeds. Higher FSH concentrations were measured in pituitary tissue, jugular plasma across the oestrous cycle, and in ewe urine (McNatty *et al*. 1991).

Although elevated plasma FSH concentrations were seen in Booroola lambs at 30 days of age (Bindon *et al*. 1985), like other statistical differences, this did not provide a selection marker. Booroola ewe lambs had an earlier first ovulation (Bindon *et al*. 1982), albeit in their second year under Australian grazing conditions.

Booroola rams were remarkably similar to the parent strain of Merino (Piper and Bindon 1986), so that selection was based on progeny performance of female relatives.

The seminal insight that the high ovulation rate in the Booroola Merino was the result of a single gene or a closely linked group of genes (Piper and Bindon 1982; Piper *et al*. 1985) has led to a search for other major genes affecting various production traits in farm animals. Since the identification of the Booroola FecB gene, up to 10 major genes have now been described affecting ovulation rate and fecundity in sheep (Davis 2003). What many dismissed initially as a curiosity has had a stimulating influence on genetic research in agriculture, particularly with the development of a range of molecular genetic and biological techniques and approaches.

The FecB gene has been transferred into other sheep breeds such as the Border Leicester (Bindon *et al*. 1984*a*) where it may be of more commercial value than in Merino flocks in which the effect of a single FecB gene is too large

for most producers under Australian conditions (McGuirk *et al*. 1982). However, this may not be the case for sheep under different environmental conditions where the FecB gene has been introduced (Mulsant *et al*. 2003), or perhaps in a future Australian Merino industry geared more towards meat production, where high fecundity would increase economic returns to producers.

Research into the physiology and genetics of the Booroola Merino by Bindon and many others provided an excellent model for the study of ovine reproductive biology in areas related or separate to those discussed above. Interested readers are referred to reports by Bindon (1975, 1984), Bindon and Piper (1976*b*, 1977), Piper *et al*. (1976), Piper and Bindon (1983), Tassell *et al*. (1983), Owens *et al*. (1984), Owens *et al*. (1985*b*), Robertson *et al*. (1984), Bindon *et al*. (1986), Fry *et al*. (1987), Kind *et al*. (1988) and Driancourt *et al*. (1990).

Inhibin and anti-inhibin immunisation

Work on the role of ovarian follicular fluid in regulating ovulation rate in a pregnant mouse bioassay and gonadotrophin secretion and ovulation rate in Booroola and normal sheep led to the finding that the ovary of the Booroola contains less inhibin (Cummins *et al*. 1983; McNatty *et al*. 1991), presumably because of the small size of preovulatory follicles. Together with the greater FSH concentrations in the Booroola, this led to the postulate that immunization of ewes against inhibin (which inhibits release of FSH by the pituitary) would increase plasma FSH concentration and hence increase ovulation rate, thereby mimicking the characteristics of the Booroola. This was first shown with inhibin-enriched ovarian follicular fluid preparations (O'Shea *et al*. 1982) and later by the Armidale group and others with synthetic and recombinant inhibin peptides (reviewed in Bindon *et al*. 1994; O'Shea *et al*. 1994). Although the resultant removal of control of ovulation rate is similar to that seen in the Booroola there are some differences. The ovulation rate is not as repeatable within individual ewes as it is in the Booroola, total luteal tissue weight increases with increasing ovulation rate, and there is no increase in length of the sexual season (Anderson *et al*. 1998; Cummins *et al*. 1986; McNatty *et al*. 1991). One similar result was an earlier onset of puberty in immunised lambs (Bindon *et al*. 1994).

Stimulation of ovulation rate in cattle was more difficult. Increased ovulation rate and embryo recovery were seen after immunisation with a native ovine inhibin-enriched preparation (reviewed in Bindon *et al*. 1994). Comparison of a range of antigens confirmed the large increase in ovulation rate on immunisation with a native ovine preparation. Unlike in sheep, immunisation with synthetic inhibin peptides was not successful. Of the recombinant preparations examined, the best was a recombinant ovine inhibin-alpha fusion protein that increased ovulation rate and antibody to inhibin. However, as in the ewe, variability of response was high. Commercial application of inhibin immunisation is hampered by this variability, but another possibility is as an extra stimulus for oocyte collection in young calves (Fry *et al*. 1995)

Following on from the work in developing a better understanding of the physiological and hormonal events related to genetic differences in fertility in sheep, and as a consequence of the appreciation of the role of inhibin in influencing ovarian function, the interests of the Armidale group turned towards the bovine, and in particular to beef cattle.

Manipulating ovulation rate and litter size in the cow

There had been considerable interest for some time in increasing multiple births in cattle by either genetic selection or by using various *in vitro* and embryo transfer procedures, with the aim of improving productivity in beef herds (reviewed by Gordon 1996). In fact, Bindon and Piper established a selection herd during the 1970s by collecting cows from industry with a history of repeated multiple births, and they discussed genetic and other possibilities for utilising twinning in the Australian beef industry (Piper and Bindon 1990).

Bernie Bindon and Laurie Piper (unpublished data) had a concept (not necessarily scientifically valid) that the creator, in designing sheep and cattle, had got it wrong, in that a sheep with 2 mammary glands could rear up to 3 or more lambs, but a cow with 4 mammary glands usually reared only 1 calf. The inferences drawn were that a cow had the capacity to rear more than 1 calf, and that productivity in cattle could be significantly enhanced by increasing the incidence of multiple births.

Increasing the incidence of multiple births by genetic selection is effective but slow owing to low heritability (Gregory *et al*. 1997), and introduces a permanent change to the herd. The genetic gain achieved by Gregory *et al*. of increasing the mean ovulation rate to 1.48 took 18 years (Cushman *et al*. 2005), and required many more resources than were available at the time to the Bindon and Piper team. However, they also made genetic progress and studied some physiological aspects (Owens *et al*. 1985*b*; Piper and Bindon 1990; Thimonier *et al*. 1979), but decided to discontinue this avenue. The alternative of increasing calving rate by embryo transfer is very expensive relative to the value of the extra calves produced, at least in the Australian scene. Thus, when considering a commercially viable system, a low cost and flexible method to increase twin births seemed at least the short term goal. This might be achieved by immunological control of ovulation rate.

The research by Bindon and colleagues during the l980s (described above) into the control of ovulation rate in sheep and cattle using anti-inhibin vaccination (reviewed by O'Shea *et al*. 1994) gave encouraging results, stimulating refinement towards the development of a potentially low cost commercial

vaccine to give a controlled response in the cow. This led to a large collaborative program supported by the Meat Research Corporation, which commenced in 1989. Bindon and his colleagues from CSIRO, Armidale were joined by research teams from NSW Department of Agriculture, Grafton, Victorian Department of Agriculture, Hamilton and Werribee, Monash University, Melbourne and a commercial company, Biotechnology Australia (Cummins 1994).

In retrospect, the formation and operation of this collaborative program could be seen as a model for the structure of the first Beef CRC that Bindon was to establish and lead from 1993 onwards.

The commencement of the 'Cattle Twinning' projects in 1989 allowed the refinement and testing stages of the anti-inhibin vaccination procedure to become part of the overall project aims, incorporating twin induction and twinning herd management and production. The scope of these studies included evaluation of inducing twinning hormonally using FSH, or immunologically using anti-inhibin vaccination (Bindon and Hillard 1992), or by using supplementary embryo transfer (SET; Cummins *et al*. 1992; Guerra-Martinez *et al*. 1990). Although the SET technique was not novel, it was a useful means to an end in studying the management of twinning herds, The anti-inhibin vaccination work, however, was indeed both novel and innovative. Twin compared with single rearing beef production systems were evaluated in 2 different pasture environments (Grafton and Hamilton) to determine the biological and economic advantages of twinning.

A vital part of the project was to establish the management required to realise the potential of the twinning systems examined, since the project team of Bindon and colleagues were very aware of the danger of new technology if not fully supported by a complete management package. A similar immunological approach had previously been used to increase fecundity in sheep (Scaramuzzi *et al*. 1983) that, while achieving its primary goal of delivering more lambs, had mixed success initially in overall productivity owing to variable impacts on the management of dams and survival of progeny.

Summaries of the results of the 'Cattle Twinning' project were reported in a series of papers by various authors in contract reviews presented to the Australian Society of Animal Production (Cummins 1992, 1994). A suitable prototype recombinant anti-inhibin formulation was not available till the latter stages of the project, when experiments were conducted to determine the optimal timing and dose rate of the vaccine (Hillard *et al*. 1995). Responses were encouraging, but ovulation rates and subsequent numbers of twin calves born did not reach the expected degree of control (Hillard *et al*. 1995; Wilkins *et al*. 1994), indicating the need for further research, which was unfortunately not supported at the time. The matings using SET however, were highly successful in providing the twin calves required to conduct the production and management experiments. The SET matings achieved calving and twinning rates similar to results reported by others (reviewed by Gordon 1996), and the rates of survival and rearing of twin calves gave highly worthwhile gains over single calf systems (Hennessy *et al*. 1994). The experiments also provided information on the survival rates and physiology of twin embryos and foetuses produced by SET or by anti-inhibin vaccination (Wilkins *et al*. 1994). The management requirements of twin rearing herds were described in detail (Cummins 1992, 1994), including twin diagnosis, nutrition and calving, providing a complete package for prospective commercial users.

The 'bottom line' of 50–60% extra weight of calf weaned, for a relatively small increase in cow feed intake (Cummins *et al*. 1994; Hennessy *et al*. 1994) is supported by other studies (Gregory *et al*. 1996). This greatly improves the biological and economic efficiency of twin *v.* single rearing cows, making twinning attractive in appropriate conditions.

Despite some constraints to immediate implementation, the vision of Bindon and colleagues to introduce twin calving systems to improve beef production is still very much alive. Future research to refine the immunological control of ovulation rate or to improve efficiencies in embryo technology is likely to provide the low cost twin calves required for profitable production gains, with genetic lines to increase fecundity also an available option.

Two interesting parallels can be drawn here. The many studies in the highly fecund Booroola, which were conducted or inspired by Bindon and Piper, have provided links through quantitative genetics, physiological control mechanisms and immunological stimulation to the more recent areas of genomic research. A similar thread is also evident from the work on fecundity in the cow, where these scientists were again involved in investigating all physiological control mechanisms. The search for genetic markers now underway (see Reproduction Research Programs at http://www.marc.usda.gov, verified 13 January 2006) in the selection herds referred to by Gregory *et al*. (1997), has been facilitated by the cattle fecundity work undertaken in Australia by Bindon and his colleagues.

International activities

Bindon has also made significant contributions to international animal science research. Resulting from his interests in the physiological mechanisms underlying genetic differences in fertility, he undertook a 6-month study leave program at the INRA Reproductive Physiology Research Centre at Nouzilly, France in 1974–75. The attraction was the quality of work being pursued there especially in relation to the high fecundity Romanov breed that was introduced into France by French geneticists in the 1960s. Knowledge of work in progress on cattle with a history of twinning and selected for fecundity by French geneticists, as well as

discussions with previous Australian visitors to the Centre such as Professors TJ Robinson and DR Lindsay, may have also influenced his decision to work at Nouzilly.

During his time in France, his research (Bindon *et al*. 1975, 1976, 1978, 1979) was focussed on a study of periovulatory gonadotrophin and ovarian steroid secretory patterns in breeds of sheep with differing fecundity (i.e. in the Romanov and Préalpes du Sud breeds, with very different ovulation rates and litter sizes, and in crossbred Romanov × Préalpes du Sud. Females of the Ile de France breed with ovulation rates and litter sizes comparable to the Préalpes du Sud breed were also included in the study). One of the main conclusions was that although breed differences were observed for many features studied, only the interval between oestrus and the LH peak was significantly correlated with ovulation rate. This conclusion was similar to that obtained in other studies comparing several different prolific and non-prolific breeds of sheep.

In contrast, in a subsequent study with one of the French scientists, Jacques Thimonier, who came to work with the Bindon and Piper team in Armidale, the timing of onset of the LH discharge relative to onset of oestrus did not differ between prolific Booroola Merinos and other Merinos of low and medium prolificacy (Bindon *et al*. 1984*b*). Further Australian–French studies revealed differences in terminal follicular growth between these Merinos genotypes (Thimonier *et al*. 1985).

While in France, Bindon was able to visit Morocco and study at first hand the Moroccan D'man breed that had the reputation of being highly prolific, weakly seasonal and able to lamb twice a year. Furthermore, puberty in this breed occurs when females are between 3 and 4 months of age.

During his stay in France and in between periods of intensive work, Bernie also found time for rugby in a University team in Tours, playing with students and other young INRA colleagues. His time in France was much appreciated by his French colleagues and the hospitality enjoyed in France was always generously reciprocated in Australia for short term or sabbatical visitors from France.

Back in Australia, the endoscopic techniques used in France for determination of ovulation rate in sheep and cattle were adapted for Australians conditions (Holland *et al*. 1981). Each step of the technique was modified so that they could be applied to very large numbers of females. They were then used successfully to perform thousands of endoscopic observations of ovulatory activity in ewes and cows.

In cattle, the use of a tractor front-end loader, and subsequently the use of an overhead gantry, to lift anaesthetised animals provided much better visualisation of ovarian structures than the older paralumbar approach to bovine endoscopy. Large numbers of animals could be examined quickly, safely and with minimal stress.

Colleagues would attest that the endoscopy team of Bernie Bindon, Laurie Piper, Bob Nethery and Grant Uphill became legendary, with a 'work hard and play hard' ethic on their missions of gathering the mountains of valuable ovulation rate data for the many research flocks of their collaborators during the late 1970s and 80s — few ovaries escaped their scrutiny!

The adaptations to endoscopy techniques were later re-introduced into France by the French scientists who visited the team at Armidale. Further collaboration between CSIRO and INRA involved the introduction to Australia by an INRA colleague, Claude Cornu, of the French technique for 'artificial' rearing of lambs under an automatic machine with reconstituted milk. In Armidale, this 'artificial' method proved to be a very efficient aid in management of the highly prolific Booroola Merino and significantly increased lamb survival (Cornu *et al*. 1982).

In the early 1980s, when the existence of a major gene affecting litter size and ovulation rate was demonstrated in the Booroola Merino by LR Piper (Piper *et al*. 1985), the CSIRO team was strongly involved in facilitating a gift from CSIRO to INRA of 5 Booroola rams assumed to be carriers (1 or 2 copies) of the major gene. This resulted in a French program on the Booroola gene involving geneticists, reproductive physiologists, and even pathologists.

It has since been shown simultaneously by the French groups and by others in New Zealand and Scotland that a mutation in bone morphogenetic protein receptor-1B is associated with increased ovulation rate in Booroola Merino ewes (Mulsant *et al*. 2001, 2003; Souza *et al*. 2001). This mutation appears to result in advancing the differentiation of granulosa cells and the maturation of ovulatory follicles. Thus, the early work of Bindon and his colleagues on control of ovulation in sheep is continuing, based on other prolific breeds with or without other identified prolificacy genes.

In addition to his increasingly heavy research workload at Armidale during the early 1980s, Bindon was involved in the management of a number of reproductive research projects, supported by the International Atomic Energy Agency, in Latin America, Malaysia, Kenya and North Africa. He also developed and supervised a series of training courses in reproductive endocrinology for United Nations and IAEA staff from Peru and Thailand. As a result of his work with prolific sheep breeds, he also participated in an expert panel commissioned by USAID to study prolific sheep breeds in the Near East and North Africa

His work with IAEA in Peru was notable for several events. The first was his demonstration and application for the first time in *Camelid* species (alpacas) of laparoscopic techniques for studying ovarian function, a technique subsequently used by his Latin American colleagues in ongoing work on reproductive function in this species. The second was the fact that this work was done at extreme altitudes where alpaca were the dominant livestock species, and few other similar studies have been done under these extreme environmental conditions.

The third and more alarming personal event for Bindon during his Peruvian visit was to experience a very severe form of oxygen deprivation (altitude sickness) when at about 4500 m elevation. In the absence of any oxygen supplies, this required a hurried and harrowing descent to lower altitudes for him to recover. While much of his subsequent work has been at the cutting edge of livestock research, as far as is known he has not ventured into the stratosphere again!

Bindon has been a significant contributor to many international conferences and symposia in Australia, the USA and France. More recently, in connection with his CRC role, he has contributed on many occasions as a keynote speaker to meetings in New Zealand, South Africa, Japan and Korea.

Active researcher to research leadership and management

In recognition of his research leadership attributes, Bindon was promoted in 1989 to the position of Assistant Chief of the CSIRO Division of Animal Production based in Armidale. In addition to ongoing leadership of research activities of the Chiswick Laboratory at Armidale, which over that time had up to 30 scientific staff, his wider administrative roles in the Division included research management across several other sites in Australia. Despite this heavy workload he was able to continue his research, particularly in the areas of application of the FecB Booroola gene to the sheep industry, and in his contributions to the anti-inhibin immunisation work and the cattle twinning projects that have been described.

In 1990, the Australian Government established the Cooperative Research Centre (CRC) scheme, designed to support and foster collaboration between research and extension agencies, institutions and industry partners, to facilitate research and the delivery of research outcomes to provide solutions to industry problems. Bindon, with others, was instrumental in developing a submission on a CRC for the Beef Industry, and whilst the first application was unsuccessful, a second application in 1992, of which he was the chief architect, and which had the strong support of the beef production and processing industries, was successful. In early 1993, he was appointed as Director of the first CRC for the Cattle and Beef Industry, a $60 million government and industry funded beef research program which he successfully lead until 2000.

A new application in 1999 for a second term of this CRC, also largely crafted by Bindon, was again successful, and received federal government support of $20 million, in a total budget of $83 million, for ongoing beef research. As Chief Executive Officer of the second CRC for Cattle and Beef Quality, he continued to make very significant contributions in leadership and management to ensure the success of this CRC. Not content with the leadership of these 2 outstandingly successful massive research programs, he was a major force in the submission of a third successful application for CRC funding for the beef industry that commenced in mid-2005.

CRC focus and directions

As outlined by Bindon (2001), the focus of the CRCs was to address the emerging beef quality issue facing the Australian cattle industry — demand from domestic and export consumers for beef of consistent eating quality (see also Bindon and Jones 2001; Bindon *et al*. 2001). This required an integrated program of research and education covering growth and nutrition, meat science, and quantitative and molecular genetics. The first stage was to undertake a comprehensive progeny test for beef quality traits — a massive program involving cattle from a large number of breeds and crossbreeds, finished on pasture or in feedlots in southern and northern environments, on which data was obtained from 12 000 carcases. This resulted in Australia having the best ever understanding of genetic and non-genetic factors affecting beef quality, and also established associations between behavioural traits and meat quality. The availability of accurately measured, economically important traits in fully pedigreed cattle on such a large scale produced powerful additions to genetic improvement programs and enabled the discovery of DNA tests for production traits. This work established world leadership in these areas, and gave Australian cattle producers perhaps 6–8 years lead-time on a global level. Additionally, a major component of the CRC program was the integral association with and an important contributing role in the development of Meat Standards Australia (MSA) — Australia's unique beef grading system to guarantee eating quality.

The CRC key research on Net Feed Intake (NFI) of beef cattle, identified animals that 'eat less for the same gain', thereby enabling increased profit on pasture and in feedlots by utilising sires of known genetic merit for this trait. Concurrently, in collaboration with a commercial partner, the IGF-1 blood test was developed — a simple and cheap screening predictor of NFI, and another world first. The impact of disease in breeding herds and feedlots has been greatly reduced by work in the CRC on the development and commercialisation of novel vaccines against Pestivirus and Bovine Respiratory Disease complexes.

The successful third renewal of CRC funding, greatly assisted by Bindon's inputs, was based on the theme of 'Gene Discovery and Expression' with the background of the explosion in knowledge of genomics (evidence — the Human and Bovine Genome Projects), and the prediction of huge increases in future demand for meat in developing countries (the 'Livestock Revolution'). CRC programs will address genetic control of production traits in cattle (growth, meat quality, feed efficiency, disease resistance, reproduction), and the environmental triggers that switch controlling genes on and off. Development of gene marker (DNA) tests for key traits will build on the products

pioneered by the earlier Beef CRC's, to provide management and nutritional strategies to precisely modify the activity of gene networks affecting production. The big picture goal is to help equip the Australian cattle industry into the future for 'Precision Cattle Breeding and Management for Quality, Efficiency and Profit'.

Science relevant to industry

One of the hallmarks of Bindon's career has been his connection with projects that have clear goals of eventual incorporation of biological and physiological principles into practically feasible animal production systems. His individual work and that done in collaboration with others (including his Director's role in 2 CRCs) has always combined scientific excellence with industry relevance. In addition, as a gifted communicator, he has the ability to read an audience and to deliver messages at the appropriate level, a skill that has been greatly valued by many industry people. It is the view point of the authors that there are few scientists who would approach his level of credibility and respect within the arenas of science and industry, with the obvious evidence of his influence on the success of the CRC's described above.

Professional, scientific and industry contributions

In recognition of his contributions to the Australian livestock industries and in particular to the Australian Society of Animal Production from 1962, Bindon was made a Fellow of the Society in 2000. He was a long-standing member of the Australian Society of Reproductive Biology, serving for considerable periods as Secretary and subsequently Chairman, and was the James Goding Memorial Lecturer in 1983. His other professional involvement has included memberships of the Endocrine Society of Australia, International Planned Parenthood Federation and the Australian Association of Animal Breeding and Genetics, to all of which he has contributed significantly. In 2000 he was the recipient of the Howard Yelland Award of the Beef Improvement Association of Australia, in recognition of his contributions to research in the beef industry. He was awarded the RaboBank 2005 Red Meat Innovation Award as the Rural Press Beef Achiever of the Year in August 2005.

An international scientific perspective on Bernie Bindon's career

One of us, J. E. Kinder, was asked by his colleagues for an independent assessment from an international perspective of the scientific, technical and industry contributions made by Bernie Bindon during his career. A synopsis of this assessment follows:

Work before the Beef CRC

After B. M. Bindon commenced research focused on understanding the control of pituitary concentrations of gonadotrophins in laboratory animals (Lloyd *et al*. 1968), he initiated a line of study assessing how blood concentrations of the gonadotrophins, FSH and LH, were regulated in sheep with enhanced fecundity (Bindon 1972; Bindon and Turner 1974; Bindon *et al*. 1971; Findlay and Bindon 1976). There was a growing body of scientific evidence, to which he made significant contributions, that the ovarian factor, inhibin, was a primary regulator of blood concentrations of FSH. This rapidly led to the assessment of the role of inhibin in contributing to the enhanced fecundity rate of Booroola strain Merinos, and subsequently this knowledge was used in attempting to control rate of ovulation in sheep through immunisation against inhibin (Al-Obaidi *et al*. 1986, 1987*a*, 1987*b*; O'Shea *et al*. 1993). This ultimately evolved into a series of studies evaluating use of inhibin immunisation technologies to induce multiple births in cattle (Hillard *et al*. 1995). Thus, the fundamental knowledge that Bindon was able to develop through the early stages of his career was used to establish the sound, scientifically-based understanding and subsequently the technologies that could be used to control the amount of FSH released from the anterior pituitary. This knowledge base was then applied through mission-based research to enhance ovulation rate in both cattle and sheep.

In cattle, Bindon was the leader in the research programme that resulted in development of a prototype vaccine based on small doses of recombinant inhibin-α protein. This resulted in increased concentrations of FSH in blood and enhanced ovulation rates after booster vaccinations (O'Shea *et al*. 1994). This work indicated that inhibin immunisation should result in lesser needs for exogenous FSH in embryo transfer programs for cattle compared with conventional FSH protocols (O'Shea *et al*. 1994).

The development and direction of the Beef Cooperative Research Centres

The vision of Bindon and others of the need to integrate the sciences of quantitative and molecular genetics, meat science, and growth biology to enhance the status of the cattle industry of Australia led to the development of a proposal focused on high quality beef production for the original Cooperative Research Centre (Beef CRC). This was ultimately funded by the Australian Federal government, state governments, and the private sector with Bindon as the foundation Director of the original CRC and continuing his leadership as Director of the second Beef CRC.

The initial programs of the CRC involved both temperate and tropically adapted cattle breeds; grain- compared with grass-finishing environments, and domestic compared with Korean/Japanese-market end-points. The CRC research program focused on beef quality traits as well as efficiency of feed utilisation to market end points. Research scientists aligned with the CRC pioneered the search for gene markers and candidate genes for beef quality traits in cattle assembled through the CRC program.

Since 1993, when he became the CRC Director, Bindon has continued to publish and communicate research results (23 refereed journal papers and book chapters and about 70 conference papers) on all aspects of CRC outcomes and has continued to make valued scientific and technical contributions of great value to the Australian beef industry.

Through CRC-based research, phenotypic correlations between carcass and meat quality were found to be low, indicating that there are few phenotypic predictors of meat quality traits (Reverter *et al*. 2003). Genetic correlations, however, indicate that animal and meat traits can be of use as indirect measures of meat quality in multiple trait evaluation programs (Reverter *et al*. 2003). Genome-wide screening of DNA markers has provided a number of putative Quantitative Trait Loci (QTL) associated with meat quality through CRC-focused research endeavours. The breadth and depth of the CRC-supported research led by Bindon has allowed for an enhanced understanding of the genetic and environmental factors that are important in impacting quality and eating characteristics of beef.

The Australia Beef CRC program has also facilitated the conduct of several other research projects outside of the focus of the CRC that impact on beef production in Australia, South Africa, Korea, Japan and New Zealand. These projects would not have been conducted in the comprehensive manner that has occurred without such a research infrastructure in place. The manner in which Bindon has continued to focus on applied reproduction problems while providing leadership for the Beef CRC program is also evident by publications such as the one focused on applied oestrous synchronisation programs that resulted from research with the CRC cattle that were used for the genetic-based studies (Corbet *et al*. 1999).

The research and scholastic leadership that Bindon provided from his earliest work on the fundamental aspects of gonadotrophin synthesis in the anterior pituitary, continued with his subsequent work on how gonadotrophin release varied between genetically different fecundity lines, and the physiological differences in these genetic lines. These approaches laid the strong scientific foundation for him to provide the leadership in the genetic- and physiological-based studies that have occurred with the Beef CRC Program. The depth and breadth of these research endeavours over the 40 years of BM Bindon's career distinguish him as an eminent scholar in the area of research with food and fibre producing animals.

What does 'retirement' hold for Bernie Bindon?

In addition to his prodigious scientific, managerial and leadership achievements, Bernie Bindon and his family have, since moving to Armidale in 1975, operated a sheep and beef cattle enterprise on the New England Tableland. In this setting he was able to put in place some of the technologies to enhance animal productivity that he was instrumental in developing.

He will undoubtedly enjoy the opportunities to spend more time on his farm, but for those who know him, 'retirement', as such, is an unlikely option. The high degree of respect in which he is held by his scientific colleagues and by the beef industry, suggest that his advice in these arenas will continue to be widely sought. There is little doubt that he will enjoy continuing to make valued contributions to science and to the beef industry, and the best wishes of his many colleagues and friends will go with him in the next stages of his career.

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An electronic version containing a full list of the 280 plus publications of Bernie Bindon is currently being prepared and will be available from the Beef CRC in the near future. The following references are those quoted in this Foreword.

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