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Beef cattle production
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12.1 Introduction
This chapter refers to computer models that simulate beef cattle production. Such models consist of mathematical equations and instructions which mimic the roles, interactions and influences of the various inputs to beef cattle production. The chapter recognises that modelling is a term which refers to both building and using models, and that beef cattle production includes the complex interactions between the physical environment, financial environment, management, feed supply, and animal reproduction and growth. The chapter considers the challenge faced by model builders in dealing with such complexity, overviews possible applications, and gives an example of a simple beef production model.

Pasture and animal scientists started to model beef cattle production after computers first became available for research in the 1960s. A rapid expansion in the range, scope and role of models followed in response to the even more rapid expansions in the power and accessibility of computers. Insight into the progress and philosophy of modelling pasture and animal production are obtained from recent reviews.\textsuperscript{1,2} Models have been a valuable aid to research, extension, and management at the farm, industry or government levels because of the following three attributes.

1. If each equation in a model is regarded as a hypothesis pertaining to a specific process or component, then a model can be regarded as a collection of hypotheses, derived from past research that can be further modified and developed through new research. In this way, a model becomes a repository for past research and a precursor for future research.\textsuperscript{3,4} Model construction is now a common activity that gives research direction and focus.
Models provide a quantitative description of the many interacting components which may have conflicting responses in a beef production system. This is a powerful and unique attribute that greatly exceeds the analytical capacity of the human mind. For example with beef cattle, as stocking rate increases (the number of animals per unit area of land), the liveweight and value per animal decrease, variable costs increase and production per hectare at first increases and then decreases. A manager must balance the trade-offs between profit, risk, pasture degradation and premium prices. Similar trade-offs between productivity, stability and sustainability are common in farming systems and a model allows users to experience 'virtual' reality in managing grazing systems.

Models can give a quantitative extrapolation in space and time of information derived from past research and experiences. For example, by processing historical records of daily weather data, estimates of variability in output can be expressed as probability distributions. Similarly, by processing the historical weather for different land units in a region, and thereby estimating spatial and temporal variations in forage production, estimates of safe stocking rates can be compared against trends in actual regional stocking rates to indicate periods of overgrazing. Further, if the spatial model uses current weather data as input, the output is a near real-time display of pasture and/or animal production that can influence government or industry policies. All of these applications rely on a model’s ability to extrapolate information in temporal and spatial dimensions, and this attribute is fundamental to the role of models in information transfer.

Today a wide range of models on different aspects of plant and animal production are being used as aids to research, farm management, and to determine government or industry policies.

12.2 Elements of beef cattle production

Beef cattle production deals with the conversion of climatic and edaphic inputs into plant products, which are consumed by various classes of animals in a beef cattle herd to give meat for human consumption. This beef production system consists of four interacting biophysical and bioeconomic subsystems, which are manipulated through the management subsystem in response to the climate subsystem (Fig. 12.1). The structure and significance of the various subsystems are described in more detail below.

The climate subsystem is largely outside the management subsystem but it directly affects the four subsystems influenced by a manager. For example, rainfall supplies soil water for plant growth, may cause soil erosion, and influences the rate of waste decomposition in soil. Further, prevailing temperature, humidity and radiation influence plant growth, and the incidence of plant and animal pests and diseases. Climatic inputs also display seasonal and
year-by-year variations and a manager must devise strategies to cope with these variations. Indeed, matching the farming system to the level and variability of climate inputs is a big challenge for a farm manager.\textsuperscript{12} Seasonal variations in climate give rise to seasonal variations in quality and type of forage which may trigger fodder conservation (e.g. hay) to offset periods of forage deficiency. Wide year-by-year variations in climate inputs, often expressed as droughts or floods which lead to major perturbations in forage supply and market prices, need to be handled through skillful and resourceful management.\textsuperscript{13} However, long-term weather forecasts now give managers prior warning of likely climatic extremes. For example, in northern Australia seasonal forecasts indicate the probability of rainfall in the forthcoming three to six months exceeding the historical median value, thereby permitting managers to make an early response to a likely distribution of rainfall.\textsuperscript{14} Also extremely hot or cold temperatures can cause deaths in plants and animals, and computer models such as GRAZPLAN,\textsuperscript{15} coupled to weekly weather forecasts, give early warning of likely mortalities in susceptible classes of animals. In both cases, recent improvements in the reliability and skill of weather forecasting are helping farmers to cope with wide variations in climate.

The land subsystem supplies water and nutrients for plant growth. Since it includes many of the ecological processes that sustain the whole system, both the manager and interest groups in the wider community are keen to keep the
land subsystem in good condition. Land degradation through soil erosion, desertification, salinisation, acidification and nutrient decline is a major concern in many of the world’s grazing lands and has led to the notion of landscape management. With this approach, managers in a region with a common attribute, such as a river catchment, are encouraged to adopt strategies that enhance sustainable development rather than exploitation of the land subsystem. Landscape management also recognises that grazing lands produce food as well as ecosystem services, such as water and biodiversity that are needed to sustain the cities where most people live. Preferred management strategies for a landscape may arise through different management options being assessed by government agencies or local communities, and computer models are often useful tools in this process.16

Plants within the forage subsystem supply digestible nutrients when grazed by cattle. Forage accumulates through plant growth and forage not eaten, together with faeces and urine from cattle, return to the soil subsystem through the detritus food chain. The quality of forage on offer varies with the growing conditions and type of plant species in the system. New growth is the most digestible and there is a steady decline in quality as plant parts age, die and senesce. Since temperate grasses have a higher digestibility than tropical grasses, grazing systems in temperate zones tend to display higher animal performance than tropical zones, Leguminous species tend to have higher digestibility than gramineous species.17 If a grazing system is based on sown pastures the manager may select to grow a mixed-pasture which usually consists of a few species that are well suited to a particular situation. This contrasts with native rangelands where the system consists of many different species, often including trees. Here a manager aims to keep the pasture in good condition by maintaining adequate plant cover to reduce soil erosion and a predominance of desirable rather than undesirable plant species.18 In both sown pasture production systems and native rangelands, forage condition and animal performance can be manipulated by management options such as the choice of stocking rate, type and amount of fertiliser application, periods of grazing and conservation, level of supplementary feeding, and fire in the case of rangelands.19, 20

The cattle subsystem produces animals for sale through the processes of reproduction and growth within a herd consisting of different animal classes. The number of different animal classes on a farm largely depends on the quality of the pasture subsystem and on the objectives of a manager. In essence, breeding cows produce calves and after weaning these move into different classes as they grow and age (Table 12.1). Usually young female cattle (heifers) are selected to replace aged or culled cows and are mated for the first time when they reach maturity and a specific weight that depends on the breed and prevailing nutrition. Under good nutrition, heifers may be mated first at 15–18 months of age, but with the poorer nutrition in extensive rangelands, mating usually takes place at 24–30 months. Heifers that are not required for replacing cows might be sold for slaughter or for breeding purposes elsewhere. Male cattle are commonly castrated before weaning although a small number of high-
performing males may be retained to replace aged bulls. Depending on the prevailing nutrition and markets, male cattle may be retained for one to three years after weaning, to be sold for slaughter or for finishing elsewhere on another farm or in a feedlot. Thus, which market to target, and how the cattle should be fed to meet the market, are key strategic decisions for a manager. Deciding when to sell specific groups of cattle is a key tactical decision for a manager.

The different classes of cattle in a beef herd have different nutritional requirements because they differ in weight and age. The term adult equivalent \((AE)\) relates the energy requirement of different classes to a common base, the energy requirement for maintenance of an adult animal, such as a non-lactating cow. The \(AEs\) of Table 12.1 can be determined from feeding tables but a first approximation for growing cattle is given by:

\[
AE = LW^{0.75}/105.7
\]  

(12.1)
where \( LW \) and \( LW^{0.75} \) are the liveweight and metabolic weight of animals in a specific class and 105.7 is the metabolic weight of a non-lactating bovine with a liveweight of 500 kg/head. \(^{21}\)

The market subsystem refers to the different markets for beef cattle available to a manager along with the prices and profit margins associated with each market. Specifications for markets vary with location. In an extreme case there is no specification, and all cattle are sold as beef with no separation of cuts at retail outlets. At the other extreme, individual animals are prepared for a specific market and traced through the supply chain, with carcasses being graded for quality and various cuts of meat separated and sold at prices that reflect consumer preferences and the grade. Farmers in countries that export beef, such as USA, Australia, Canada and New Zealand, commonly have a range of market options that are specified in terms of age, gender, weight and fat thickness of a carcass. However, the classification scheme is not standardised internationally, although there is an international trend to reduce the allowable limits for residues of pesticide and growth promotants in export beef. Penalties for farmers in not meeting specifications for chemical residues are usually severe, including condemnation of all meat in the case of excess chemical residues.

### 12.3 Challenges for modellers

The above description of beef production is deceptively simple. In practice a model builder is faced with the challenge of expressing the complex interactions between components of the system (Fig. 12.1). Specific challenges include

- how to match the primary purpose of the model to the most appropriate structure
- how to handle natural variability in the biophysical components and the interface between the subsystems, and
- how to validate the completed model.

Answers to these questions are interrelated and reflect back to the history and philosophy of model building.

#### 12.3.1 Matching purpose and structure

Models of beef production systems are commonly built as aids to research, farm management or policy evaluation and their structure may be mechanistic, empirical or a combination of both. \(^1\) Empirical models estimate outputs by empirical equations developed from experimental observation of output in relation to one or more influencing variables, while mechanistic models reflect a theoretical understanding of the factors that control outputs. The relative merits of mechanistic and empirical structures have been hotly debated and the choice of structure is a critical and often difficult decision for a model builder. \(^2\), \(^4\), \(^22\), \(^23\) Mechanistic models, because of their stronger theoretical base, tend to be more
versatile and are more likely to explain responses than empirical models, but they may not be more accurate and often contain parameters that are difficult to determine in practical situations. Conversely, the robustness of an empirical model depends on the range of experimental data used in its derivation, and spurious results might occur if it is applied outside this range. Thus model builders should specify the derivation and application of an empirical model, and users should adhere to these specifications. As a variation on the above distinction, some models combine both empirical and mechanistic elements, such as an empirical model being used to process and interpret the results previously stored from many simulation experiments with a mechanistic model.

Research models are built by researchers to analyse the complex interactions in beef production systems. They can be regarded as a repository for past research since they collate and integrate information from past research. They are also a precursor for future research since gaps in knowledge and understanding are highlighted. Because research models focus on processes and their interactions, they are often mechanistic in structure and have a limited distribution. However, GRAZE is an exception to this statement, being a comprehensive mechanistic model of forage and animal growth that is widely distributed and well documented. Sometimes a research model evolves into a management or policy model, thereby reducing development costs.

Models for farm management are usually designed to evaluate management options pertaining to one or more components of the system. They aid management by evaluating different scenarios thereby allowing preferred strategies to be identified, but importantly, a manager is free to accept or reject the output. Developing this type of model requires considerable time and effort, since to be accepted by potential users, the package needs to operate in a convenient and reliable manner, have a high degree of validity or skill, and have a commercial arrangement for distribution and after-sales service. FEEDMAN is an example of many commercial decision support systems that focus on farm management. However, history suggests that experienced farmers do not readily use such software for common routine decisions unless its use is clearly beneficial and it is promoted by a trusted product champion. On the other hand, professional farm advisors who are paid to recommend preferred management options are likely to use the software to justify a recommendation. Because a farm advisor may have many clients, decision support software that is regularly used by a few farm advisors may still have a big impact on farm management. Both mechanistic and empirical sub-models are widely used in management software.

Policy models serve government or industry leaders by estimating outcomes to possible scenarios and initiatives in policy. Both mechanistic and empirical sub-models are used in policy models dealing with pasture and animal production. Policy models range from those that provide a one-off analysis of a specific problem to those that provide a regular ongoing service. An example of a one-off analysis that influenced policy was the rejection of a plan, based on results from field research over ten years, to construct farm dams and use the stored water to irrigate crops to improve the forage supply in north western Queensland.
Simulation studies based on long-term records of climate showed that the plan was not viable because rainfall was too variable. Apparently the field study that supported the plan coincided with a run of high-rainfall years. An example of a regular ongoing service is the monthly maps of relative pasture yield, adjusted for prevailing stocking rates, which are derived from a pasture production model operating on a $5 \times 5$ km grid for the State of Queensland. The maps provide an objective assessment of drought status for government and industry. Constructing and maintaining a policy model of this scale requires an integrated team of scientists, programmers and support staff. As with management models, a policy model’s credibility depends on its scientific base and validity.

12.3.2 Coping with linkages between components

With regard to Fig. 12.1, the status of each subsystem is expressed by several different terms, which reflect the purpose of the overall model and the structure of the sub-models that simulate each subsystem. Since the subsystems are interdependent, they need to be linked in an appropriate manner, an issue in model building that is often called the interface problem. As an illustration, simple expressions of the status of each subsystem might be:

1. climate subsystem – inputs of solar radiation and/or temperature on plant growth and rainfall on soil water supply;
2. land subsystem – amount of soil water (mm) available for plant growth in response to daily rainfall runoff, drainage and evapotranspiration;
3. pasture subsystems – yield (kg/ha) of leaf and stem, potentially for each plant species in the pasture, in response to daily plant growth less consumption and senescence;
4. animal subsystem – liveweight (kg/head) of each animal class, in response to an initial liveweight and accumulated daily liveweight gain; and
5. economic subsystem – farm profit ($ or $/ha) in response to value of animals sold less variable costs.

Interface between climate, land and pasture subsystems

Mechanistic models often estimate plant growth as the product of intercepted solar radiation and radiation use efficiency. Intercepted radiation depends on leaf area of the forage, and radiation use efficiency links the soil and climate subsystems, being dependent on prevailing climate, soil nutrient status and soil water supply. In practice, radiation interception and radiation use efficiency are difficult to simulate in pastures in rangelands that are a mixture of C3 and C4 species growing as spaced plants under trees in a semi-arid environment, and are grazed selectively by cattle. Under these complex circumstances an empirical model based on field observations can be a useful tool. For example, pasture growth ($PG$ kg/ha) can be estimated as:

$$PG = WUE \times WU$$  (12.2)
where $WUE$ is water use efficiency, another term that links the two subsystems for a specified site (kg/mm), and $WU$ is water use over a specified time step (e.g. mm/day).

Equation (12.2) avoids the difficulties associated with radiation interception by recognising the strong direct relationship between water use via transpiration and forage growth via photosynthesis, two gaseous transfer processes that are controlled by leaf stomata. It can be applied at different temporal and spatial scales. On a daily time step, $WUE$ becomes transpiration efficiency and $WU$ is daily transpiration estimated by a sub-model of soil water balance, but on monthly or seasonal time step, $WUE$ becomes rainfall use efficiency and effective rainfall (actual rainfall less runoff) is an approximation of $WU$. Although $WUE$ varies with fertility status of the soil, seasonal conditions and the number of trees present, it is a parameter that can be determined simply for a site from measurements of plant growth in relation to $WU$. The FEEDMAN decision support system estimates monthly plant growth through this approach and the default values of $WUE$ for many different soil-forage combinations were either obtained from field experiments or by integrating output from a daily plant growth model. In either case, the default values can be customised to reflect local conditions.

**Interface between pasture and animal subsystems**

This interface must account for nutritional demands of different classes of animals, all of which have the ability to move and select a preferred diet from a pasture that exhibits wide spatial and temporal variation in yield and quality.

In mechanistic terms, animal production is dependent on intake of digestible nutrients, and once the amount and quality of diet is known, models for estimating different forms of production (e.g. liveweight change, milk production, wool growth) in different animal classes already exist. Thus the interface problem becomes how to estimate, either directly or indirectly, two interdependent terms, the amount (intake) and quality (digestibility) of diet. Actual intake is usually less than a potential intake, which depends on the breed and liveweight of animals, due to constraints arising from the amount and quality of forage on offer. Forage digestibility declines with age, is greater in leaf than stem, and varies across species. Mechanistic models commonly simulate diet selection by partitioning the forage on offer into digestibility or age categories with animals then selecting progressively from high to low categories until their appetite is satisfied. Whilst this approach tends to mimic diet selection in temperate pastures reasonably well, the descriptive functions are essentially empirical relationships derived from field experiments. The approach has been less successful in rangelands with a more heterogeneous botanical composition and sward structure. However, a more realistic algorithm for diet selection in heterogeneous forages places plant species into broad preference categories (e.g. preferred, desirable, undesirable, toxic, emergency and non-consumed) and then computes the proportion of each preference class in the
diet. The algorithm assumes that an animal has experience with the vegetation, and has learned to avoid toxic species and non-consumed species. The ‘emergency’ category accounts for species that are only eaten after the preferred, desirable and undesirable species are depleted.

The above ‘mechanistic’ models are essentially based on ‘empirical’ expressions derived from diet selection studies with parameters that are rather abstract and site specific. To avoid these difficulties, the FEEDMAN package used the notion of potential liveweight gain to characterise the seasonal variation quality of different forages. Potential liveweight gain is the monthly liveweight gain of a standard animal (a 200 kg cross-bred steer, Bos taurus by Bos indicus) grazing the forage at a low stocking rate in a good season. It is a bioassay for forage quality that can be measured, but more importantly, it is meaningful to farmers and can be adjusted to reflect local experience and knowledge. With potential liveweight gain for a standard animal given, the energy concentration of the forage can be estimated and applied to different animal classes, after taking account of the impact of high stocking rate on reducing intake and dry conditions reducing forage quality. Because this approach uses a bioassay to characterise forage quality, and a mechanistic model to estimate animal performance, it can be readily adapted to herds of different species, breeds and classes of livestock.

**Interface between animal and economic subsystems**

Operating profit of a beef cattle enterprise on a farm is given by:

\[
\text{Gross profit} = \text{Number sold} \times (\text{Animal value} - \text{Variable costs}) \tag{12.3}
\]

where \text{Number sold} is the number of animals sold, \text{Animal value} is the average value of sale animals, \text{Variable costs} are average variable or operating costs per animal associated with different management options. Comparison of the gross profit for different management options indicates the relative profitability of the options.

Estimation of \text{Variable costs} is a simple arithmetic exercise, but since there is wide variation in local costs, a model must allow a user to modify and recall this information, and a user must update the information as required. On the other hand, estimation of \text{Animal value} is a two-step process where animals are first allocated to a market category (if more than one exists), each with a corresponding sale price that usually exhibits spatial and temporal variation. Thus, tables of market prices for use in the calculation of \text{Animal value} need to be updated regularly. The determination of market categories is location specific since there is wide national and international variation in the title and specifications for each category. In countries with well developed beef markets, categories may be specified by age, sex and breed of cattle, by weight expressed as liveweight or carcass weight, and by an indication of the degree of ‘finish’ expressed as a condition score in live cattle or fat thickness for carcasses. However, markets are not necessarily mutually exclusive in that while a
premium market may have narrow specifications, cattle suited to a premium market may also be suited to a lower-priced market with wider specifications. Mechanistic models attempt to estimate animal growth and development, and the associated fat deposition.\textsuperscript{37, 38} Condition score has been derived empirically from the history and status of animal performance,\textsuperscript{39} but neither approach has been applied to a full range of market specifications. FEEDMAN uses a simple approach to estimate \textit{Animal\_value} in that the characteristics of each herd are compared against entries in a table of markets, specified in terms of monthly sale price, and breed, age, class and liveweight of cattle. The highest price match is then selected and used to calculate \textit{Animal\_value}.

12.3.3 Coping with natural variability

\textit{On-farm complexity}

Creating a ‘user friendly’ presentation of software that mimics pasture and animal production on a farm is a challenge because a multi-dimensional scenario must be described through a keyboard and monitor. The multi-dimensional scenario might consist of descriptions of fields in the farm, pastures in the fields, number and class of animals in herds, grazing management of herds, and period, type, and amount of supplementary feeding (Fig. 12.1). In addition, potential users commonly prefer the software to have keystrokes and a screen layout similar to other familiar software. Also, outputs must be clear, easily understood, and suitable for further analysis or storage. One approach used by model builders to meet these requirements is to consult with a panel of potential users on a regular basis and progressively modify the software in response to suggestions from the panel.\textsuperscript{11} Such ‘interactive prototyping’ is a time-consuming task that can lead to major changes in the layout of screens for entering data and displaying results, but experience has shown that model builders, who know a package intimately, are not experts in ‘user friendly’ presentations. In practice, there are tradeoffs between the capacity of a decision support package to handle wide variations in farm production systems and the need for the package to be ‘user friendly’. Extensive help notes, default values for input parameters, and training exercises and examples all assist a novice user in mastering a package. In addition to complexity due to on-farm variations mentioned above, climate and prices are off-farm inputs that display wide spatial and temporal variations.

\textit{Climate}

In the case of climate a user may wish to evaluate management options over a range of seasonal conditions contained in historical records of climate. One approach is to use all historical data as an input and then express key outputs, such as farm profit, as a probability distribution. Another approach is to use a probability distribution of historical annual rainfall to establish categories of ‘seasons’ that reflect natural variations, such as:
very dry, rainfall likely to be less than this category in 10% of years;
dry, rainfall likely to be less than this category in 30% of years;
median, rainfall likely to be less than this category in 50% of years;
wet, rainfall likely to be less than this category in 70% of years; and
very wet, rainfall likely to be less than this category in 90% of years.

The former approach demands access to a large database of historical records of climate, particularly if a model is to apply to a wide range of locations, each with a different climate history. The second approach, to select from the same comprehensive database a relatively small number of typical climate categories for each location, thereby eliminates the need for regular access to a large database of historical records. Both approaches are an attempt to assess management options simulated by the model in terms of the risk or likelihood of certain outcomes. This is a key attribute of models of beef production in variable climates, which is not obtained by using average or median climate data. Indeed, if only median climate data is used, animal production at high stocking rates is overestimated because year-by-year variations and interactions are ignored.8

In addition to analysing historical records of climate, model users are frequently interested in evaluating management options in relation to the current status of cattle and forage on a farm and future climate scenarios that are based on long-term weather forecasts.13 Currently long-term weather forecasts indicate the probability of rainfall in the next three or six months being above or below median rainfall, and the skill of the forecasts is improving.40 To cater for this requirement, models must allow users to enter potential future rainfall.

12.3.4 Verification and validation

Model verification ensures that the computer programs on which a model is based are free of ‘bugs’ and perform properly within specific limits. Usually a model builder uses special input data and parameters to test components of a model and their interactions under a wide range of operating conditions. The program needs to be corrected if values of the various variables and processes exceed an acceptable range. Problems may arise from a flaw in the algorithm describing a process, particularly as upper or lower limits are approached, or from a typing error in the program code. A sensitivity analysis is another component of verification that indicates the relative importance of accuracy in model inputs. Here a simulation experiment is designed to test the relative sensitivity of inputs and parameters that influence a system. Obviously accuracy is more important with sensitive than with insensitive inputs. The relative sensitivity of different inputs is indicated by comparing the change in output caused by a specific change in the different inputs (e.g. percent change in output after a 5, 10 or 20% change in an input parameter). Whilst verification is primarily the responsibility of model builders, simple exercises on these lines give model users a good appreciation of the operation and limitations of a model.
Model validation refers to how well a model mimics the system it is meant to represent. Validation is commonly demonstrated by first instructing a model to mimic a wide range of scenarios that have been actually observed, and then by comparing predictions from a model against the observations. The validation data should be independent of the data used in developing a model. Linear regressions of observations against predictions are commonly used to make the comparisons. The closer the slope and coefficient of determination for a regression are to unity, and the intercept to zero, the better the validity of a model. However, there are theoretical and practical problems with validation based on regression analysis, and the confidence of the model builders should be recognised as a model undergoes development and modification. Of course, serious users also develop confidence in a model through less formal validations as they compare predictions against their own observations and experiences. In practice, validation is an ongoing activity that warrants considerable effort by the model builders and independent experts, particularly when the model attempts to mimic large variation in production systems and is used as an aid to politically or financially sensitive decisions. In essence a model is ‘valid’ when it sufficiently mimics the real world to fulfill its objectives, and when decisions based on the model are superior to those made without the model.

12.4 Simple model of herd structure

It is obvious from Fig. 12.1 and Table 12.1 that for a given farm, the number and class of cattle in the animal subsystem depends on the amount and quality of growth in the forage subsystem. These interactions are captured in the following simple empirical model of herd structure in relation to broad management options. It also illustrates how a model that incorporates a few basic parameters can be a powerful analytical tool.

The notion of farm carrying capacity (CC) is a good starting point. This is the long-term safe stocking rate for a farm, one that does not cause ecological deterioration of the production system. It is a vital concept for managed grazing systems that incorporate the biological, commercial and social elements pertaining to good land care. It is commonly used to quantify a farm for sale or leasing in Australia and the USA, and because different classes of cattle have different nutritional requirements, it is commonly expressed as adult equivalents (see equation (12.1)).

In rangelands where forage growth is dependent on rainfall, carrying capacity is largely dependent on the amount of forage growth and on the proportion of growth that can be eaten (utilisation, U) without causing degradation of the pasture. Thus, based on the report by Johnston et al. the model for farm carrying capacity is given by

\[ CC = R \times WUE \times A \times U/I \ (AE) \]  

where CC is farm carrying capacity, R is effective rainfall (mm/year, in subtropical climates this is annual rainfall less runoff), WUE is water use efficiency.
efficiency (e.g. 5 kg/ha/mm), A is area of the farm (ha), \( U \) is safe utilisation (e.g. 0.25) and \( I \) is annual intake for an adult animal (e.g. 4000 kg/year). Whilst \( WUE \) varies with the inherent fertility of the soil, fertiliser applications and presence of trees, it is simple to measure. On the other hand \( U \) is not simply measured but studies have shown it ranges from about 0.1 in arid infertile environments to about 0.5 in moist fertile environments. Although equation (12.4) demonstrates the derivation of \( CC \) from first principles, in practice farm \( CC \) is usually determined from local knowledge and experience.\(^{32}\) The next task is to determine herd structure or the distribution of carrying capacity across the various animal classes.

When all cattle on a farm originate from the breeding cows (i.e. no off-farm purchases) the system is characterised by three performance indicators, which underpin a simple but versatile mathematical model of herd structure.

(1) Weaning rates refer to the number of calves weaned per hundred cows mated. This key indicator depends on the nutritional health status of cows and on the number and fertility of bulls. It commonly ranges from 95% in high-performing herds to less than 50% in herds of poor performance, a value that will not sustain the herd in the long term.

(2) Survival rates refer to the proportion of each class of cattle that survive a year. Mortality from poor health, accident or predators is common, particularly in extensively-managed beef production systems. The animal classes most prone to mortality are breeding cows and calves soon after weaning. Clearly high survival rates are desirable and susceptible classes of cattle commonly receive special feeding to avoid mortality from poor nutrition.

(3) Culling rates refer to the proportion of breeding cows culled annually for age, infertility, or other imperfections. Hence, if the effective breeding life of a beef cow is about ten years, culling helps to maintain high weaning rates. The rate of culling, plus the mortality of breeding cows defines the number of replacement heifers required to maintain a constant number of breeding cows.

The following model, which is suitable for a spreadsheet, provides a ‘steady state’ estimate of number in the various classes of cattle in a herd (herd structure, Table 12.1), in response to a few key assumptions and parameters, and local knowledge of performance criteria. The model depends on four assumptions.\(^{46}\) First, all animal classes on a farm with breeding and growing cattle can be specified by a manager, and are related numerically to the number of cows mated, provided extra animals are not purchased. Second, the overall carrying capacity (\( CC \)) of a farm, in terms of number of adult equivalents, is either known or can be estimated by equation (12.4). Third, for simplicity, cows and calves are regarded as a single animal class until the calves are weaned. Fourth, the number of cows mated (\( CM \)) is fixed for each situation because if one dies or is culled from the breeding herd it is replaced with a heifer. Thus the ‘\( n \)’ classes of cattle on a farm can be represented as
An 12

and after collection of terms and simplification

\[
CM = \frac{CC}{\sum Ai}
\]  

(12.6)

where \( Ai \) is a coefficient that relates the number of animals in the \( i \)th class of cattle to \( CM \), the numbers of cows mated. \( Ai \) is the product of four factors:

\[
Ai = PFi \times CFi \times SRi \times BRi
\]  

(12.7)

where \( PFi \) is a flag to indicate if the \( i \)th class of animal is present (1, present; 0, absent); \( CFi \) is a factor to convert the \( i \)th class of animal to adult equivalents (Table 12.1); \( SRi \) is the proportion of the original number surviving in the \( i \)th class; and \( BRi \) is the ratio of the number of animals in the \( i \)th class to the number of breeders when survival in the class is 100%.

\( WR \) is weaning rate, expressed as a percentage of the number of calves weaned to number of cows mated. If half the weaners are assumed to be female, it follows that \( BRi = \frac{WR}{2} \) for each class of steers in the herd, and for heifer cattle \( BRi \) is similar to steers until replacement heifers enter the breeding herd.

Replacement heifers enter the breeding herd when two or three years of age by adjusting \( PFi \) accordingly. First dead cows are replaced (\( DEATHS = \) percentage of \( CM \) dying each year), then culled cows are replaced according to a specified culling policy (\( CULL = \) preferred percentage of \( CM \) replaced each year). If there are too few heifers for the culling policy, all available heifers are used as replacements and the shortfall is noted by the lack of surplus heifers for subsequent sale and a reduced ratio for culling. If there are too few heifers to replace the dead cows the herd cannot be sustained. Thus for culled cows:

\[
BR_{\text{cull cows}} = \text{MAX} (0, \text{MIN}(CULL, \frac{WR}{2} - DEATHS)/100)
\]  

(12.8)

and for any surplus females

\[
BR_{\text{surplus females}} = \text{MAX} (0, (\frac{WR}{2} - CULL - DEATHS)/100)
\]  

(12.9)

Once the number of cows mated have been calculated using equation (12.6), the number of cattle in the remaining animal classes is given by

\[
Ni = CM * PFi * SFi * Bri
\]  

(12.10)

where \( i > 1 \) since for cows, being class 1, \( Ni = CM \).

Table 12.2 illustrates the application of this model to four scenarios pertaining to breeding and growing beef cattle on extensive rangelands. Case 1 represents a herd where disease and/or poor nutrition severely restricts performance of the breeding herd and this limitation is removed in Case 2. Case 3 is similar to Case 2 except for a 50% increase in farm carrying capacity, which might occur through farm development options such as buying more land, controlling woody weeds or sowing improved pasture. Case 4 illustrates the effects on herd structure of a further improvement in performance of breeding cows along with a reduction in age of selling steers and mating heifers, as might
occur from a further improvement in herd nutrition and management. Whilst Table 12.2 is a static representation that ignores the transitional states that would occur when changing from Case 1 to Case 4, it shows the broad implications of management options on herd structure and number of cattle for sale. It also illustrates that simple ‘spreadsheet’ models can be a useful first step in selecting broad management options that warrant a more detailed evaluation.

### Table 12.2 Herd structures generated by the simple model given above in response to changes in key parameters that might occur as health, nutrition and management improves in a ‘closed’ herd consisting of breeding and growing cattle on extensive rangeland.

<table>
<thead>
<tr>
<th>Key parameters</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm carrying capacity (CC) adult equivalents</td>
<td>1000</td>
<td>1000</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Weaning ratio (WR) (% of cows mated)</td>
<td>50</td>
<td>80</td>
<td>80</td>
<td>90</td>
</tr>
<tr>
<td>Cow mortality rate (DEATHS) (%)</td>
<td>15</td>
<td>5</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Ideal culling ratio for cows (CULL) (%)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Age of steers at sale: years</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Age of surplus heifers at sale: years</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

**Simulated results**

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of cattle in herd</td>
<td>1088</td>
<td>1121</td>
<td>1682</td>
<td>1700</td>
</tr>
<tr>
<td>Number of breeding cows</td>
<td>421</td>
<td>303</td>
<td>455</td>
<td>532</td>
</tr>
<tr>
<td>Proportion of herd as breeding cows (%)</td>
<td>39</td>
<td>27</td>
<td>27</td>
<td>31</td>
</tr>
<tr>
<td>Number of culled cows</td>
<td>42</td>
<td>61</td>
<td>91</td>
<td>106</td>
</tr>
<tr>
<td>Proportion of breeding cows culled (%)</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Number of surplus heifers sold</td>
<td>0</td>
<td>44</td>
<td>66</td>
<td>112</td>
</tr>
<tr>
<td>Number of steers sold</td>
<td>99</td>
<td>114</td>
<td>171</td>
<td>227</td>
</tr>
<tr>
<td>Total number of cattle sold</td>
<td>141</td>
<td>219</td>
<td>328</td>
<td>446</td>
</tr>
<tr>
<td>Proportion of sale cattle in herd (%)</td>
<td>13</td>
<td>20</td>
<td>20</td>
<td>26</td>
</tr>
</tbody>
</table>

12.5 Future developments

Modelling pasture and animal production has come a long way in three decades. Its future as an aid to research is assured since it provides direction and context to research programs.

While farmers have been slow to adopt decision support packages that aid routine decisions, professional advisors who need to give good advice to many clients are more receptive to new tools that assist in evaluating management options within complex systems across a wide range of environments. Future developers of farm management models will probably regard farm advisors or service agencies rather than farmers as the primary customers. Also, the models will be more user-friendly through the use of improved graphics and visualisation techniques, and the provision of support and upgrades via the World Wide Web.

The scope and range of policy models are expanding rapidly because they provide policy makers with an objective assessment of complex problems. This
trend will continue, but policy models are likely to expand from the traditional biophysical base to include socioeconomic components and estimates of the impact of policies on the ‘triple bottom line’ – ecological sustainability, profitability and social acceptability.\textsuperscript{47–49} Indeed, a future challenge will be how to better integrate the technologies pertaining to hard and soft systems, such as pasture and animal production models being part of participatory action research, and thereby involving stakeholders in defining and evaluating policies.\textsuperscript{16, 50}

A global network of information for model development and proven software modules is expanding through the World Wide Web. Model developers will have increasing access to libraries of algorithms, and computer operating environments which will encourage more rapid development of new models and a rich set of shared applications and experiences. However, since models are repositories for information and results from past research, there remains a global need for scientists and government agencies to organise creditable databases of information, which are critical to the future development of decision support systems and integrated policy models.\textsuperscript{51}

12.6 References


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