Resources required for calf rearing on New Zealand dairy farms when mating programmes are altered to produce less bobby calves: Case study and scenario analyses.

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Abstract

Each year in New Zealand (**NZ**), approximately 2 million calves are slaughtered before 30-days of age. These 'bobby calves' are unsuitable for dairy or beef production due to sex, low-genetic merit, and breed. Growing concern from the public regarding animal welfare is pressuring the NZ dairy industry to reduce bobby calves, to continue to receive a 'social license' to farm. One option to reduce bobby calves is for dairy farmers to utilise more sexed and beef-breed semen in mating programmes. However, changing mating programmes to produce more beef calves, also changes resources required for calf rearing and management decisions, such as shed capacity, milk demand, and labour. These changes need to be quantified to help farmers determine the most appropriate mating programmes.

The objectives of this project were to; 1) identify and quantify the resources required to house and feed calves born on five case-study herds with different mating programmes and, 2) use these data to predict the resources required on an average NZ dairy farm with different mating programmes aiming to reduce bobby calves. Data collected from the farms included calf outcome, birth and exit weights, and age upon exiting the calf shed. These data were then used to calculate calf growth rates and predicted feed and shed capacity requirements for each case-study herd. These data were also used in an analyses to determine the resource requirements of an average NZ dairy farm (444-cow spring-calving herd) if bobby calves were reduced from the national average of ~35% to a target of ~22% or ~0% of calves within the herd. The aim of the scenario analyses was to identify risks and opportunities of different mating programmes implementing strategies (e.g., using sexed semen and more beef-breed semen) aimed at reducing bobby calves.

From the five case-study herds, mating programmes designed to reduce the number of bobbies results in greater calf-rearing resource requirements, particularly calf feed and shed capacity. Outputs from the scenario analyses indicated that a spring-calving herd in NZ produced 40%, 20%, and 7% bobby calves from mating programmes targeting 35%, 22% and 0% bobby calves, respectively. There were greater requirements for milk and shed capacity when bobby calves were reduced to 20% and 7% in Scenarios 2 and 3, respectively, compared to the base Scenario 1 (40% bobby calves). Milk demand increased by 43% when bobby calves decreased from 40% in Scenario 1 to 7% in Scenario 3. Peak shed capacity increased by 11 and 17 calves for Scenarios 2 and 3, respectively, compared with Scenario 1. Peak shed capacity was reached earlier for both Scenarios 2 (day 35) and 3 (day 28), compared with Scenario 1 (day 48). The duration of peak shed capacity increased by 7 days and 12 days, for Scenarios 2 and 3, respectively, when compared to Scenario 1. Before mating programmes are designed to reduce bobby calves, the greater resource requirements and cost of rearing calves must be budgeted for each farm.

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Chapter 1. Review of literature

1.1 Introduction

The world's population is projected to reach almost 10 billion people by 2050, with the population increasing by around 83 million people each year (United Nations, 2022). The growing population's critical need for food security depends on agricultural food production (Malthus, 1798; Reilly & Willenbockel, 2010; MfE, 2022). However, there is increasing pressure from the public and consumers to improve animal welfare, while reducing environmental impacts on water quality, pollution and degradation, and greenhouse gas (**GHG**) emissions (Cone & Ebiquity, 2015; MPI, 2022a), from animal production systems.

The public and environmental pressure places great emphasis on the New Zealand (**NZ**) dairy and meat and wool sectors, which accounts for 41% and 23% of NZ exports, respectively (MPI, 2022). The dairy sector needs to continue implementing strategies to address animal welfare concerns and environmental impact for market transparency (i.e., consumers and industry bodies demand an ethical and transparent supply chain) (DairyNZ et al., 2017; MPI, 2022a). In doing so, the dairy and beef sectors can continue to uphold their international trade reputation by reducing barriers to trade and dairy can continue as NZ's biggest economic exporter earner (MPI, 2022a).

Each year, NZ dairy farms produce around two million calves that are transported and slaughtered before 30 days of age, commonly referred to as 'bobby' calves (Boulton et al., 2020). The intersectionality of greater social, regulatory, and environmental impacts has increased the pressure to reduce the production of bobby calves, and this is a risk to current dairy production systems. There is increased public awareness and concern, internationally and locally, around animal welfare, specifically the handling, transportation, and slaughtering of young calves produced as a by-product of the dairy industry (Haskell et al., 2020; DairyNZ et al., 2017; Ritter et al., 2022). If dairy farm operations are to address bobby calf concerns, a reduction in bobby calf numbers is required and, over time, a farm policy implemented where all calves are reared for a reasonable length of life, (e.g., beyond 30-days of age) (Pike et al., 2019; Ritter et al., 2022).

One necessary and practical solution that can help reduce bobby calves is to utilise more beef-breed semen and sexed semen in mating programmes on NZ dairy farms (Ritter et al., 2019; Haskell et al., 2020; Balzani et al., 2021). Progeny sired by beef breeds crossed with dairy dams are referred to as beef-cross-dairy (beef x dairy) calves (Berry et al., 2018; Wetlesen et al., 2020; Berry, 2021). Sexed semen, that generates predominantly female calves, can be used for producing dairy replacements (Holden and Butler, 2018; Haskell et al., 2020). Using sexed semen can reduce the production of unwanted dairy calves (bobby calves) and allow more cows to be bred with beef-breed semen (Haskell et al., 2020; Brittante et al., 2021). In addition, the increased production of beef x dairy calves instead of beef suckler calves can reduce GHG emissions by 22% while reducing bobby calves and improving public perception of the dairy industry (van Selm et al., 2021; Thomson & Hickson, 2022). Dairy farmers wanting to rear more calves for beef production will need to include sires with better genetics for beef production (elite sires) into their mating programmes.

A mating programme designed to increase beef x dairy calf production to reduce bobby calves could incur both risks and opportunities. Changing mating programmes to produce more beef x dairy calves while aiming to reduce the number of bobby calves will likely change the outcome for the calves born (e.g., bobbied, or reared for meat or dairy production) (Costa et al., 2016; Verdon, 2021; Vicic et al., 2022). The uncertain and different outcomes of calves born from different mating programmes will likely impact the infrastructure and resources required for calf rearing (Costa et al., 2016; Verdon, 2021; Vicic et al., 2022). The current research aims to determine the fate and value of all calves born from different mating programmes and the impact of different calf outcomes on the calf-rearing resources on NZ dairy farms.

1.2 Bobby calves internationally

The bobby calf 'socio-ethical' issue is recognised internationally across Europe, Australia, Canada, and the United States of America. There has been a growing focus on bobby calf welfare that has resulted in the implementation of regulatory change across countries looking to reduce bobby calves and improve calf welfare (Ritter et al., 2019; Haskell, 2020; Wilson et al., 2020; Balzani et al., 2021; Bolton and von Keyserlingk, 2021; Creutzinger et al., 2021; Verdon, 2021; Vicic et al., 2022). Internationally, there is a perception of low value in non-replacement male calves, which impacts market demand (Haskell et al., 2020; Vicic et al., 2022). Rearing more beef x dairy calves and gaining replacements from heifer calves to reduce bobby calves may enhance the value of calves born from these mating programmes (Balzani et al., 2021).

1.2.1 International challenges associated with reducing bobby calves

The minimum age of slaughter of a calf depends on a country's individual regulations. For example, in 2020, Canada introduced new regulations that require calves to be reared till nine days old before being transported off-farm, excluding farm-to-farm sales (Bolton and von Keyserlingk, 2021). Calves born to dairy cattle are usually removed from the dam for artificial rearing (Berry et al., 2018; Wetlesen et al., 2020; Berry, 2021; Martin et al., 2021a). Due to their young age, calves require shelter, high-quality feed (milk and calf/pellets/meal/muesli), and greater attention from staff to minimize the risk of neonatal disease (Vicic et al., 2022). Regulatory changes to on-farm calf requirements before being sold at auction or assembly lines require the current calf rearing system to be reviewed (Creutzinger et al., 2021). On dairy farms, artificially rearing calves that were originally destined for slaughter could increase the requirements for infrastructure, feed, and labour due to lack of sale or rearing options (Costa et al., 2016; Vicic et al., 2022). Improved calf welfare and changes to regulatory requirements for calf rearing produce challenges in on-farm calf rearing.

As young calves are susceptible to illness and stress, traveling to the abattoir for processing poses a risk to their welfare. Canada, Australia, and the European Union either suggest or require calves to be reared for 10 days, 8 days, or 14 days, respectively, before transportation to sale yards or processors due to associated health risks (European Union, 2005; RSPCA, 2018; Canadian Food Inspection Agency, 2019). The older age before travel reduces welfare issues by minimising mortalities and illness associated with long travel times (up to 10 hours) or overnight yard stay before processing (Wilson et al., 2020). If calves were required to be reared beyond four days old in NZ, the requirement for calf-rearing resources would likely increase.

1.3 Bobby calves in New Zealand

New Zealand also faces similar issues regarding the challenges and opportunities around processing young calves. In NZ, bobby calves are sent to slaughter at a minimum of 96 hours old (MPI, 2019). Spring-born bobby calves (July-November) fit into the meat processing calendar, as these calves are processed on the same processing chains as prime lambs. Lambs are predominantly processed between November and June as farmers adjust stocking numbers before winter when pasture quality is low (Morris, 2013). The calves sent for slaughter are those not required for dairy replacements or for rearing for beef production (Jolly, 2016). However, due to uncertain demand for beef x dairy and beef calves, at times of low demand, beef x dairy calves are sometimes sent for slaughter. This highlights the complexity of determining calf outcomes in NZ.

The outcome of calves can vary due to differing breeds, sizes, and ages of calves, and markets (Moran 2002). The calf rearing requirements for these calves are unclear due to low demand and the perception of low-value non-replacement male calves that make it difficult to determine the required shelter and feed requirements (Vicic et al., 2022). The dairy industry has a strategy commitment that ensure all animals have a life worth living and are provided high animal care, this includes bobby calves (DairyNZ et al., 2017). Dairy farmers need to understand the opportunities and risks to meet the needs of changing calf welfare requirements for sustainable calf production and ensure correct resource requirements.

New Zealand dairy farms can implement cross breeding strategies to reduce bobby calves. One method is to utilise artificial breeding for bull nomination to increase beef x dairy calves supplied to the beef industry (Coleman et al., 2016; Hunt et al., 2019; Martin et al., 2020; Brittante et al., 2021). The dairy industry can enhance cattle growth rates and carcass characteristics by selecting specific beef-breed sires for dairy farm mating programmes while maximising the genetic attributes favoured in beef breeds (Dal Zotto et al., 2009; Coleman et al., 2016). Thus, there has been a growing interest in evaluating and comparing carcass characteristics of progeny born to beef, dairy, and beef x dairy cattle over recent years.

Comparing beef and dairy cattle growth rates permits primary meat producers and dairy producers to have a supply chain strategy for producing first-generation beef x dairy. However, inferior meat growth and quality characteristics have been associated with dairy breeds (Coleman et al., 2016). The productivity and profitability of beef animals rely on growth efficiency to reach liveweight targets acceptable to the beef finishing systems (Pettigrew et al., 2016; Berry et al., 2020; Brittante et al., 2021). Furthermore, cattle growth rates can directly affect meat characteristics, finishing age, carcass yield, and meat quality (Martin et al., 2020). New Zealand would profit by breeding for meat growth performance and quality of the beef x dairy cattle.

1.3.1 New Zealand dairy cattle industry

New Zealand's primary export and main agricultural industry is dairy with nearly 6.3 million dairy cattle and of this, 4.9 million are lactating or pregnant in NZ in 2019-2020 (Stats NZ, 2022). The dairy sector produces around 21 billion litres (**L**) of milk annually and exports 95% globally, contributing around 3% of the world's milk supply (Dorigo & Ballingall, 2020). This places NZ as the eighth largest milk producer in the world. The NZ dairy industry is recognised internationally as the most transparent and reputable milk producing country producing milk of high quality with a low carbon footprint and the most emissions efficient producer of milk (Mazzetto et al., 2021; Dorigo & Ballingall, 2020). The dairy sector generates around NZ$20 billion from exports and employs 50,000 people, making dairy one of the biggest contributors to the NZ economy (Dorigo & Ballingall, 2020). Thus, the ability of NZ to uphold its current dairy industry reputation is critical for global exports and the national export economy.

The NZ dairy cow population comprises the following cattle breeds; 50% Holstein-Friesian/Jersey crossbred (**FxJ**), 33% Holstein-Friesian, 8% Jersey, 0.4% Ayrshire, and the remaining 9% are documented as 'other' (LIC & DairyNZ, 2021). The primary product from dairy farming is milk, which reduces the importance of cattle livestock sales (Haskell et al., 2020). Each year, around 4.9 million calves are born on NZ dairy farms, and of these, around two million calves are not used for dairy or beef production due to low demand, sex, low-genetic merit, and breed; these calves are slaughtered under 30-days of age as bobby calves (Hunt et al., 2019; Pike et al., 2019; Haskell, 2020).

1.3.2 New Zealand dairy farm production systems

In NZ, dairy farms operate seasonally and are predominantly pasture based. Dairy farms operate by matching feed supply with feed demand to take advantage of seasonal pasture growth rates and quality to be competitive in a global market (Verkerk, 2003). Thus, dairy farming operates seasonally due to profitable low-cost grassland-based dairy cattle grazing, which enables greater pasture utilisation (Roche et al., 2017b; Balzani et al., 2021). The seasonal variation of pasture growth and milk production are illustrated in **Figure 1.**

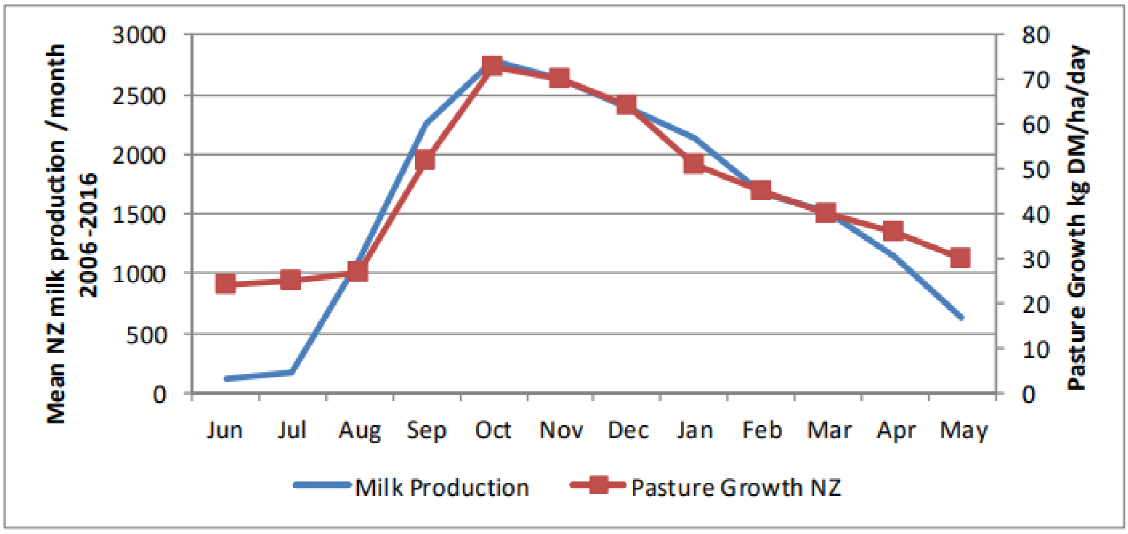


Figure 1.The seasonal variation in pasture growth and mean milk production in New Zealand per month. Figures extrapolated from DairyNZ, Ruakura 16.4 ton dry matter (DM) per ha per year and DCANZ 2006-2016, cited in Shadbolt and Apparao (2016).

In addition, the seasonal variation of NZ dairy farming requires a different calving pattern compared to farms implementing a mixed-feed system with all year-round calving (Veerkamp et al., 2002; Beukes et al., 2010; Roche at al., 2017b). Seasonal pasture management requires compact seasonal calving to begin two months prior to when the herd’s feed demand equals daily pasture growth rates (Dillon et al., 1995; Roche et al., 2017b), where grass productivity can parallel cattle feed efficiency and is utilised by implementing a condensed six-week calving spread (Balzani et al., 2021). The utilisation of pasture growth relies on the calving pattern and requires 90-95% of cows to calve over several weeks (Roche et al., 2017a; Yang et al., 2018). Depending on the regional climate, the seasonal concentration requires calving during late winter and early spring, usually between July and September (Yang et al., 2018; Beef + Lamb NZ, 2022b). Mating programmes influence the calving rate, which is imperative for NZ dairy farming.

1.3.3 New Zealand beef industry

Similar to the dairy sector, the NZ beef industry is export focused and a significant agricultural producer. There are a total of approximately 3.9 million beef cattle in New Zealand and comprising of the national pure beef breeding herd is around 1.1 million cattle that primarily comprises Angus and Hereford breeds (Beef + Lamb NZ, 2021; Stats NZ, 2022). Other breeds include, but are not limited to, Simmental, Belgian Blue, Limousin, and South Devon (Afolayan et al., 2007). The beef industry annually processes approximately 1.6 million beef cattle and of this, approximately 1 million are dairy mixed-aged cattle for meat production (BLNZ, 2021). Each year, around 640,000 dairy-bred calves are supplied from the dairy industry, these calves are born from usually Friesian or crossbreed dams (Morris & Kenyon, 2014; BLNZ, 2021).

In addition, the farming of beef cattle is commonly practiced with sheep farming, and any impacts to beef farming will impact sheep rearing and production (Beef + Lamb NZ, 2021). In NZ, there are approximately 26 million sheep and NZ produces approximately 406,000 tonnes of sheep meat annually contributing $3.9 billion in exports (Beef + Lamb NZ, 2022; MIA, Annual Report 2021; Stats NZ, 2022). Each year, NZ exports around 95% of its beef production, around 480,000 tonnes, to over 70 countries contributing approximately $3.6 billion to the NZ economy (MIA, Annual Report 2021). Like the NZ dairy sector, the NZ beef sector has a global reputation for producing high-quality beef from pasture-based farm systems and is continually aiming to reduce its environmental footprint aligned with governmental regulations and transparency with consumers and the public (MIA, 2021).

1.3.4 New Zealand beef farm production systems

In NZ, beef x dairy cattle are commonly finished on a pasture diet with little supplementary feed and processed around two years of age, but this can range between 18 to 36 months old (Coleman et al., 2016; Addis et al., 2020; Martin et al., 2020). Supplementary feed is introduced when pasture supply does not meet animal feed demand, creating a deficiency that is filled with additional feed, either purchased or homegrown silage, crop, or grain. Beef cattle are faster growing with better carcass characteristics and, for this reason, are processed around 24 months. Finishing cattle before the second summer avoids the period of slow animal growth due to poor feed availability (poor pasture quality and quantity) during hot, dry summer months (Pettigrew et al., 2016). Cattle that attain heavier carcass weights at a younger age can be slaughtered earlier and thus are more profitable in NZ (Martin et al., 2021b).

Cattle growth rates and carcass characteristics are key drivers for NZ beef farmers to remain profitable on a pasture-based system. For example, the Jersey breed has a lower meat yield and slower growth rates when compared to other dairy breeds; however, the lower meat yield can be compensated by utilising a higher stocking rate, stocking rate is the number of animals grazing an area of land (Coleman et al., 2016; Pike et al., 2019). For this reason, the Jersey breed growth and carcass traits are unfavourable among beef breeds (see section 1.8). It has been suggested that the dairy industry can enhance animal growth rates by selecting specific beef-breed sires for dairy farm mating programmes and thereby maximise the genetic attributes favoured in the beef breeds (Dal Zotto et al., 2009; Coleman et al., 2016). Thus, cattle breed is important when considering NZ beef farm production systems and the dairy breeds are less favourable.

1.3.5 New Zealand beef x dairy cattle industry

New Zealand dairy farms can implement crossbreeding strategies as one solution to reduce bobby calves. Each year, the dairy industry contributes beef x dairy cattle for beef production. Beef x dairy calves are beef-sired and dairy-dam progeny, producing beef x dairy progeny (Berry et al., 2018; Wetlesen et al., 2020; Berry, 2021). Beef cattle are supplied from the dairy industry as Friesian bulls, beef x dairy calves, and some dairy cows removed from the herd, also referred to as cow removals or culls (refer to section 1.3.4; Harris, 1989; Morris, 2013). However, beef and sheep farm land and meat processing capabilities limit the increasing production of beef x dairy calves.

1.3.6 Processing bobby calves

The ability to successfully process the young calves is possible due to the alignment of supply chain management across the beef, sheep, and dairy sectors, with farmers, transporters, and meat processors all working together. Currently, NZ abattoirs processes approximately two million calves each year (Boulton et al., 2020). Furthermore, through processing dairy calves, the entire calf is utilised for products distributed around the world, including but not limited to veal production, rennet, hinds, petfood, and the pharmaceutical industry, as illustrated in **Figure 2**. (Haskell, 2020; MIA, 2022). It has been suggested that in NZ, calves could be reared for beef production, either processed around 8-10 months of age (referred to as veal), or until 18 months of age once reaching target slaughter weights (Haskell, 2020; Pike et al., 2019). Despite the success of bobby calf production and appropriate timing of meat processing, these calves are low value, and the return from the product is often less than the cost of production.

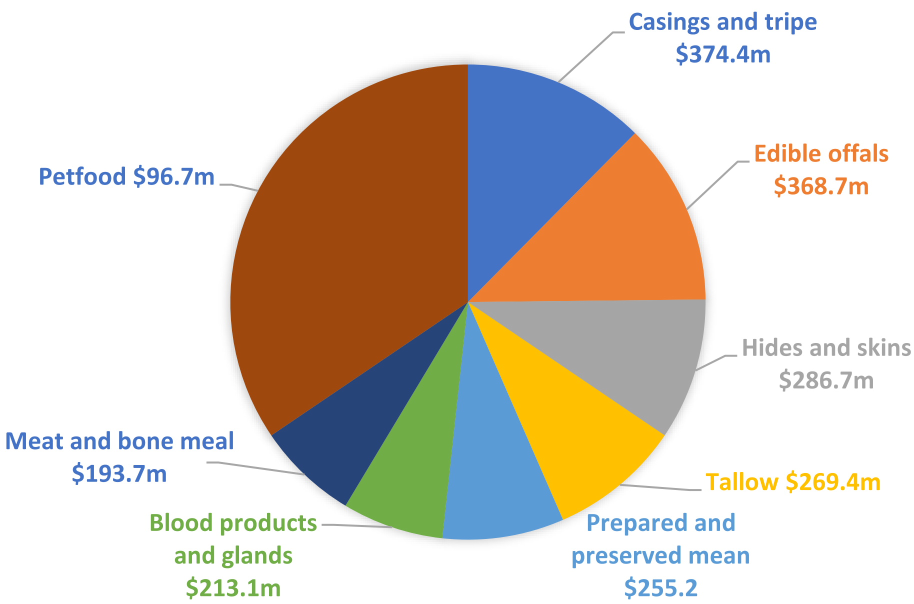


Figure 2. The annual earnings and breakdown of co-products exported from New Zealand month ended 30 June 2022. Adapted from MIA (2022).

1.3.7 Public perception and 'social licence' to farm

Recently, there has been growing concern from consumers, farmers, and the public regarding the animal welfare of the treatment, transportation, and slaughter age of bobby calves (Hunt et al., 2019; Haskell, 2020; van Dyke et al., 2021; Verdon, 2021; DairyNZ et al., 2017). After public outrage of the handling and care of bobby calves in 2014, a review of current cattle standards was conducted, which included public consultation (Guy, 2014). In 2016 and 2017, NZ introduced new bobby calf welfare regulations on the minimum standards for calf management (MPI, 2022e). In 2022, a new cattle code of welfare is currently under review (MPI. 2022b). The growing public concern about bobby calf welfare could require a change in dairy calf rearing practices.

Furthermore, there is increasing pressure on the reduction of bobby calves if dairy farms are to maintain a 'social license to operate' (**SLO**) to avoid economic consequences (Hampton et al., 2020). The SLO is defined by Thomson and Boutilier (2011) as the acceptance from local communities and stakeholders for corporate activities. Essentially, the SLO provides social acceptance, through trust, transparency, and respect, beyond existing legal obligations for industry-wide practice (Morrison, 2014; Edwards & Trafford, 2016). The SLO for dairy calf production has emerged from the bobby calf's welfare and purpose being highly publicised in the media around care and health of calves (Duffield, 2020). Thus, the dairy industry needs to recover its reputation and change current practices if it wishes to continue to receive a SLO.

1.3.8 Government regulations in New Zealand for environmental impacts

In conjunction, there is increasing global recognition of environmental impacts, and this also translates locally within NZ, with pressure coming from the public and government emphasising the importance of global warming, GHG emissions, and freshwater quality and availability (Zonderland-Tomanssen et al., 2013; Cone & Ebiquity, 2015; MPI, 2022a). New Zealand has a target of 10% methane reduction by 2030 and 24-47% reduction by 2050, relative to 2017 levels (MPI, 2022a) To reach these targets, changes in livestock management are needed, to reduce GHG emissions and improve water quality to reduce the agricultural livestock impact across the life cycle from farm production to transport, processing, and consumption (Zonderland-Tomanssen et al., 2013; MPI, 2022a). This global concern regarding livestock environmental impacts is contributing to ongoing reviews.

1.3.9 Government regulations in New Zealand for animal welfare

In NZ, the minimum standards of calf management conditions are set by the NZ Government and issued under the Animal Welfare Act 1990, New Zealand Animal Code of Welfare – Dairy Cattle 2019. In 2016, NZ introduced new regulations to ensure the welfare of calves under 30 days of age, regarding their suitability for transport (MPI, 2022e). The management of calf transport, housing, and feed management is essential in improving animal health and welfare and reducing the risk and death of young calves (Cuttance et al., 2019; Haskell, 2020; Johnson et al., 2021).

The proposed changes to the NZ Code of Welfare: Dairy Cattle (MPI. 2022b), issued by the Minister of Agriculture, recommend that calves are reared daily on milk equating to a minimum of 20% of the calf's liveweight (from the current 10% requirement). Furthermore, within the NZ Code of Welfare: Dairy Cattle proposal, the National Animal Welfare Advisory Committee, an independent advisory committee, is encouraging the use of selecting semen to reduce bobby calves, explicitly encouraging the selection of sexed semen and beef-breed semen (MPI. 2022b). At the time of writing this thesis, the proposed changes to the NZ Animal Code of Welfare – Dairy Cattle (2022d) are being reviewed for public feedback, and are currently being collated, prior to making the final decision (MPI. 2022b; NAWAC, 2022).

1.3.10 Milk processors terms and conditions of supply for calf management

Milk supply companies are introducing supply chain requirements to improve cattle welfare for farmers, known as "terms and conditions of supply" policy. The new conditions are aimed to ensure that animal welfare standards are consistent amongst all suppliers (Fonterra, 2022a). For example, Fonterra will require humane reasons for euthanasia of calves on farms from June 1st, 2023, and to ensure all non-replacement calves enter the supply chain. The agriculture sector is currently investing in R&D in the calf opportunities (Fonterra, 2022a), however there are currently limited options for non-replacement dairy calves to enter the supply chain.

The new 'terms of supply' and changing animal welfare requirements is requiring farmers to find strategies to reduce bobby calves. There is a greater emphasis on farmers to use mating programmes to reduce bobby calves and for each calf to enter the supply chain older than four days of age (Ritter et al., 2019; Haskell et al., 2020; Balzani et al., 2021; Fonterra, 2022a; MPI. 2022b). At the same time, farmers need to be able to implement mating programmes to meet these targets and regulations in a cost-effective manner, with minimal effect on farm income and profit, for example, where the value of calves reared beyond four days is greater than the current bobby calf price (Edwards et al., 2021). The low value of bobby calves and the uncertain demand for beef x dairy calves, means calves are not a key driver of profit on dairy farms.

1.3.11 The calf supply chain and young calf opportunities in New Zealand

There is a limited number of options for young dairy calves to enter the supply chain. One outcome is reared on or off-farm for dairy heifer replacement, in which they re-enter the herd as dairy heifer replacements at two years old. Another option for farmers is selling calves to meat processors as bobby calves (Haskell et al., 2020). Calves can be sold to the beef industry for beef rearing, or some calves are euthanised on-farm (Haskell et al., 2020). Each year around 35% of calves born on dairy farms in NZ are bobbied, another 28% of calves are reared for heifer replacement, 27% of calves sold for beef rearing, and 3-12% of calves recorded as mortalities or 'other' (MPI, 2017; Edwards et al., 2021, Cuttance et al., 2019a). Mortality in young calves can occur for several reasons (e.g., premature calves, along with illness such as pneumonia, and euthanasia (Johnson et al., 2021). There is more certainty in the numbers of animals that become dairy heifer replacement calves, along with calves entered into contractual beef rearing agreements, than there is around the other categories. The outcome of calves born in NZ, compared with several regions of Australia, is presented in **Figure 3**.

1.3.12 A comparison of New Zealand and Australia calf outcomes

Calf outcomes in NZ are similar to Australia when averaged over the different states (**Figure 3)**. Approximately 38% of calves born on dairy farms in Australia are bobbied, 37% of calves are reared for heifer replacement, and 16% of calves are sold for beef rearing (Dairy Australia, 2019). The remaining calves are euthanised (7%) or die (2%) due to a number of causes (Dairy Australia, 2019).

However, in Australia, the percentage of calves destined for each outcome varies among states. Western Australia (**WA**) has the lowest percentage of calves bobbied (9%) due to limited bobby calf collection services and fewer dairy farms (Dairy Australia, 2019). As a result, WA produces the highest percentage of calves reared for beef (42%) compared to all other Australian states and NZ (Dairy Australia, 2019). Unlike NZ, all calves reared for beef can be sold and reared by the surrounding beef farms, due to fewer dairy farmers and more beef cattle farms.

Victoria, and more specifically, Western Victoria, is the most consistent with NZ. The region of Western Victoria has the highest percentage of calves bobbied (43%) and the lowest percentage of calves sold for beef rearing (15%) (Dairy Australia, 2019) in Australia. For every region, the outcome of a calf depends on farm management, beef market exports, the scale of the beef and dairy sectors, and consumer preference (Haskell, 2020). Thus, calf demand and the subsequent outcome for calves born are limited by region (demand and scale) and can influence calf outcomes.

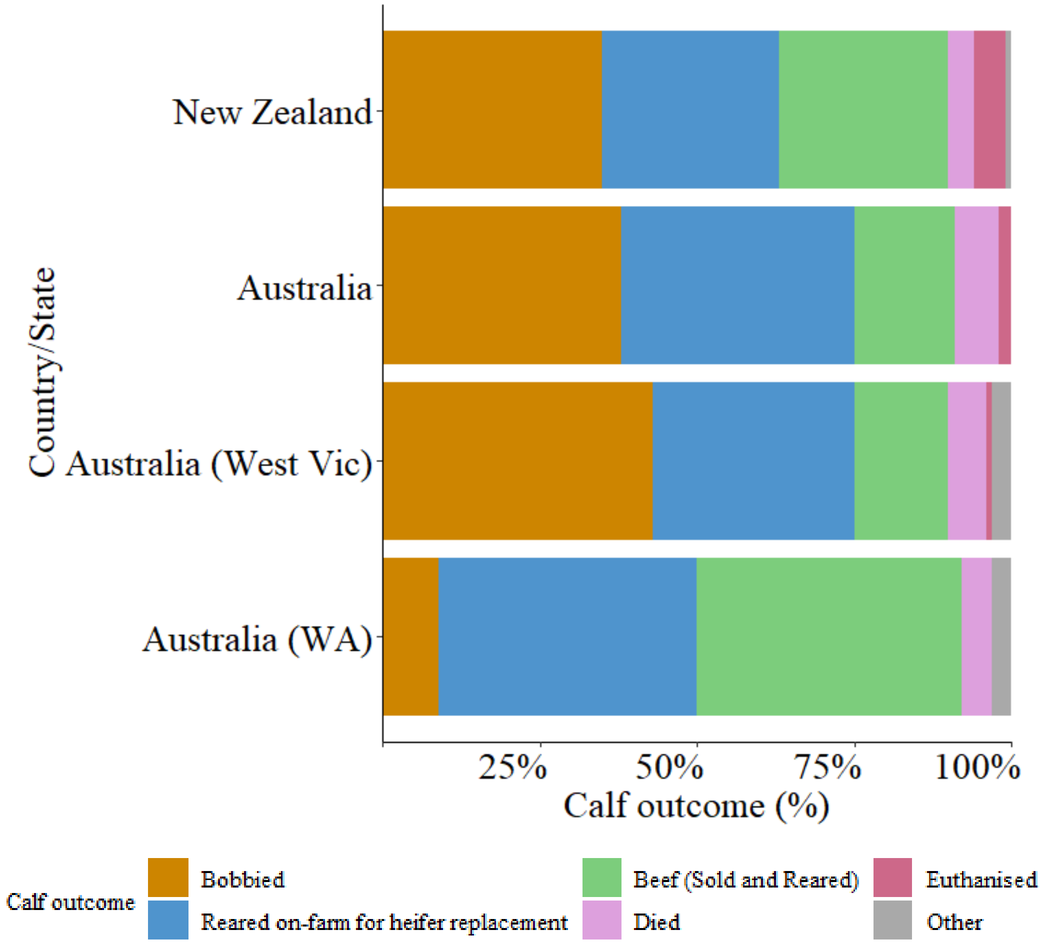


Figure 3. A breakdown of calf outcome by country (New Zealand and Australia). Published data from industry averages recorded in New Zealand (Edwards et al., 2021) and Australia, including a breakdown for Western Australia (WA) and Western Victoria (West Vic) (Dairy Australia, 2019).

1.3.13 *Challenges for reducing bobby calves in New Zealand*

A reduction in bobby calves on NZ farms requires a change to the supply chain management, from the dairy farm to beef contracting sales or direct to meat processing, and this is a problem across the dairy and beef sectors as 'zero-bobbies' requires calves to be reared beyond 30-days of age and would require alternative processing solutions (Pike et al., 2019). However, the challenges around reducing bobby calves in NZ differ to other countries, due to different land availability, export agreements, and national herd population size. The impact on different dairy and beef production depends on production systems, land availability, animal welfare, and environmental impact (MfE & Stats NZ, 2022). The factors influencing land availability in NZ are shown in **Figure 4**.

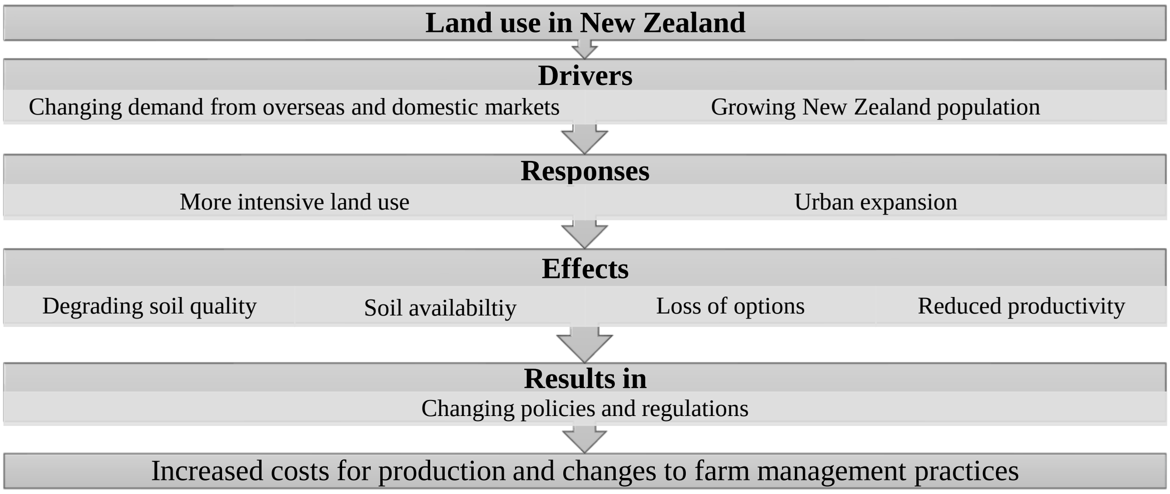


Figure 4. The effects of driving factors on finite land use, land availability, and soil quality in New Zealand. Adapted from Ministry of the Environment, MfE & StatsNZ. (2021).

There are several key physical constraints that affect the ability of the dairy industry to reduce bobby calves. Firstly, there are no live exports available in NZ (O'Conner, 2021); most beef cattle are reared for 18-24 months for maximum profitability before being processed and then exported (see section 1.3.5).

Secondly, land availability is limited in NZ and agriculture already occupies around 48% of the total land area (MfE & StatsNZ, 2021). An additional 1% is occupied for urban living and is likely to expand further onto fertile land as the population continues to increase. The primary use of flat land with generally fertile soil is for cultivating crops (3%) and dairy farming (18%), while NZ hill country is more suited to sheep and beef farming (63%) (Beef + Lamb NZ, 2021; MfE & StatsNZ, 2021; MfE & Stats, 2022a). Dairy farming occupies around 18% total land use, and of this around 15% is flat land and most profitable (MfE & StatsNZ, 2021; MfE & Stats NZ, 2022). However, some dairy farming also occurs on the hill country, which is less profitable in comparison (MfE & StatsNZ, 2021). Furthermore, due to the credits for carbon sequestration, farms are undergoing land use change and converting from livestock farming to forestry (Beef + Lamb NZ, 2022b).

Thirdly, and as a result, there is a limited area of land in NZ to rear more beef cattle without compromising the dairy sector and beef and sheep sector. The beef industry could acquire more stock through selecting to rear more beef x dairy calves as opposed to pure beef breeds, however, approximately 1.1 million pure beef cattle are needed for reproduction to maintain current numbers and breed of animals (Beef + Lamb NZ, 2021). Furthermore, in most hill country beef and sheep are farmed in a complementary system, thus, an impact to beef will likely impact sheep rearing and production (refer to section 1.3.4). Alternatively, the dairy industry could forego land use to rear more beef x dairy calves, or otherwise implement other strategies to reduce bobby calves (Thomson & Hickson, 2022). Furthermore, the dairy and beef sectors require consideration around different genetics suitable for production and rearing (Thomson & Hickson, 2022).

There is currently a limited demand for calves entering the supply chain if reared beyond four days and the complexity of supply chain management is one of the most significant issues in reducing bobby calves (Edwards et al., 2021). However, with increasing regulation and social pressure to reduce bobby calves, farmers must investigate and try alternative mating management decisions, and this is expected to impact on calf-rearing resources.

1.4 Dairy cattle mating programmes

In the NZ pasture-based system cows typically calve every 12 months, so peak feed demand for lactation matches peak pasture production. A fixed mating programme can be implemented to ensure a herd’s feed demand parallels pasture production (Yang et al., 2018). Farmers can select different mating programmes that benefit the individual’s farm and herd management decisions, and the sale opportunities currently available which are ultimately determined by cattle breed. For mating programmes to match seasonal pasture production, NZ dairy farms operate on a concentrated 365-day calving interval (Verkerk, 2003; Roche et al., 2017b; Yang et al., 2018).

The metrics used for mating programmes are planned start of mating (**PSM**), planned start of calving (**PSC**) and calving spread, and these are imperative to understanding the production and management of calves on NZ dairy farms. Dairy farm managers utilise artificial insemination (**AI**), for elite sire and breed selection, along with natural mating practices (i.e., bulls), for greater pregnancy rates and reduced labour, for cow insemination (Yang et al., 2018). Mating and the subsequent calving typically occur over a concentrated 12 weeks (~83 days) to ensure a tight calving spread so that herd feed demand is matched by feed supply (Roche et al., 2017a; Yang et al., 2018). The typical seasonal calving and mating system in NZ has been presented in **Figure 5**.

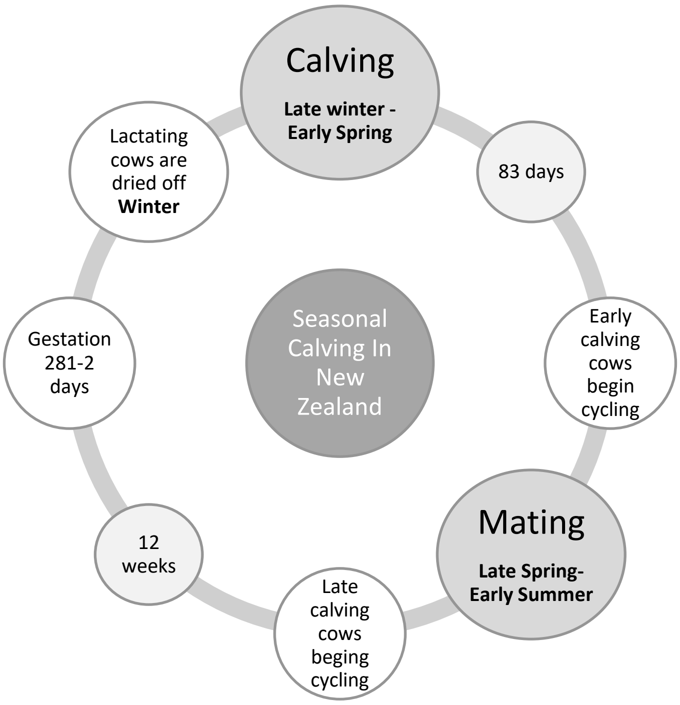


Figure 5. The typical annual cycle for a New Zealand dairy herd from mating through to calving. Early calving cows calved with in the first three weeks of planned start of calving, and late calving cows calved after six weeks of calving. Adapted from LIC. (2013).

Mating programmes can utilise strategies such as sexed semen, and short-gestation semen to condense calving spread and result in more days in milk, and less chance of cows not getting in calf (LIC, 2022b) due to the extended post-partum anoestrus interval (**PPAI**) (see section 1.4.1). The concentrated calving spread means many calves are born in a short time frame, potentially placing pressure on the calf management for farmers (Verdon, 2021). Dairy farmers have finite resources (infrastructure, feed, and labour) to meet the demands of potential increased calf management and resource requirements (Costa et al., 2016; Verdon, 2021; Vicic et al., 2022). These combined factors will influence the calving spread, which in turn could influence the calf-rearing resources required to meet the demands on the mating programmes.

1.4.1 Postpartum anoestrus interval (PPAI) and 'silent' oestrus

After calving, cows usually have a PPAI between 30-60 days, in which the cow does not have an oestrus cycle (Ribeiro et al., 2013; Macmillian et al., 2020). In addition, some cows may ovulate but not displaying visible oestrous behaviour, this is known as a 'silent' oestrus (Sakatani et al., 2016). Silent oestrus and an extended PPAI can impact the farmer's ability to recognise and select cows for AI (Dobson et al. 2010), which in turn can affect the reproduction of the herd.

1.4.2 *Planned start of mating (PSM)*

The PSM (usually considered as the first day that a cow is inseminated during mating) varies across NZ herds and is generally planned to ensure that cows calve prior to the expected peak in pasture growth in the following year. For this reason, 90-95% of NZ herds calve in late winter/early spring just prior to peak pasture production (Roche et al., 2017a; Yang et al., 2018), as presented in **Table 1**. This then defines the mating programme, to ensure that the same outcome occurs in the following year.

Table 1. Reproduction targets and average results for the New Zealand national herd in 2020-2021

Measurements	National targets	National averages (2020-2021)
Duration of mating (weeks)		12 (83 days)
Planned start of calving (date)		21st of July (spring)
Duration of calving (weeks)		12 (83 days)
Cows mated by AI (cows)		3,497,267 (71%)
15-month-old heifers mated by AI		212,639
Mixed age cows 3-week submission rate	90%	81%
Mixed age cows' conception rate		53%
Mixed age cows 3-week pregnant rate	> 60%	
Mixed age cows 6-week pregnant rate	78%	68%
Mixed age cows 12-week non-pregnant rate	< 6%	14%
First calvers pregnant 3 weeks	80%	
First calvers pregnant 6 weeks	95%	
All cows calving pattern 3 weeks	67%*	
All cows calving pattern 6 weeks	88%*	
All cows calving pattern 9 weeks	98%*	

Results derived from Minda Fertility Focus Report (2020), LIC/DairyNZ Statistics 2019-2020.
Administration: AI = Artificial insemination.

1.4.3 *Planned start of calving (PSC)*

The PSM indicates the timing of the PSC and allows the farmer to prepare for the expected calving spread. The aim is for all cows to be submitted for insemination and successfully conceive within 12 weeks of mating (Roche et al., 2017a; Yang et al., 2018). The PSC is approximately 281 days from the first successfully conceived insemination date (confirmed pregnancy diagnosis by a vet). Considering the PPAI, and in order to increase the chance of conception, cows need to calve six weeks before the PSM and heifers need to calve nine weeks before PSM (see section 1.4.1). This requires cows to calve in the first six weeks and heifers in the first three weeks of calving. The PSM, PSC, and calving spread can be used to predict the total number of calves born each day during the calving period, which in turn will impact the resource requirements for calf rearing.

1.5 Cattle reproduction

1.5.1 Oestrus and oestrus detection in cattle

The cow's ability to successfully conceive after insemination is reliant on the cow's oestrus cycle and ovulation. The cow's oestrus cycle determines the time at which insemination occurs. Cattle ovulate on average every 21 days, ranging from 18-24 days, consisting of two-three follicular waves per oestrus cycle (Crowe et al., 2014; Stevenson & Sauls-Hiesterman, 2021). Prior to ovulation, cattle display oestrous behaviour such as, standing when receiving mounting behaviour from other cattle, indicating sexual receptivity (Roelofs et al., 2010; Mayo et al., 2019). A cow in the oestrus period (about to ovulate) is sexually receptive, and semen insemination occurs during mating by the bull or AI (Roelofs et al., 2010; Wiltbank & Pursley, 2014). Farmers can observe cattle behaviour that indicates time of ovulation and use this to determine the optimum time for insemination. Successful selection of animals for insemination by AI requires successful detection of oestrus. If selection for AI is unsuccessful the herd calving spread, and reproduction performance will be compromised.

1.5.2 Artificial insemination

There is a greater emphasis being placed on AI and an increased social expectation of using AI with selected sires (e.g., beef breeds or sexed semen) to reduce bobby calves on NZ dairy farms. For example, the National Animal Welfare Advisory Committee is encouraging more cattle to be mated using AI in order to increase beef x dairy calves and to also utilise sexed semen to decrease bobby calves (MPI. 2022b). However, after using AI for the first six weeks of mating, dairy farmers will often finish the mating period by using a bull to impregnate cows that have failed to cycle, have undergone silent oestrus, or where the farmer has missed observable oestrous behaviour (see section 1.5.1).

Artificial insemination involves the collection of bull semen which is either stored fresh (liquid) or frozen (cryopreserved) and is directly inserted at the cow's cervix by a trained AI technician (Yang et al., 2018). The use of AI increases genetic herd improvement by increasing the genetics of progeny sired by an elite sire (Murphy et al. 2016; Yang et al., 2018; Maicas et al., 2019). In 2021/2022, the use of AI increased from around 3.4 to 3.5 million cows, or 71% of NZ herds, and of these, approximately 200,000 yearlings (5%) received AI (LIC & DairyNZ, 2021). Using AI with a selection of specific semen in mating programmes is a viable option for NZ dairy herds to reduce bobby calves through semen selection.

1.5.3 Natural mating

Natural mating by a bull as part of the mating programme is common practice in NZ dairy herds for multiple reasons. The use of bulls provides the opportunity to reduce labour by eliminating the need for oestrous detection and AI. Using bulls can also achieve greater pregnancy rates due to an increased semen dose per insemination compared to AI and multiple services more often at the correct time for ovulation, although they do not offer short gestation, nor progeny testing to prove the bull's merit easy calving (Thomson & Hickson, 2022). Thomson & Hickson (2022) have documented a small cost advantage when using AI compared to bulls; however, farmers often choose to use bulls after six weeks of AI to reduce the workload after a busy calving and mating period. Virgin bulls (15 months of age) are typically used on NZ farms to reduce the spread of disease (DairyNZ, 2022a). Typically, the farmer will select bull breeds with smaller expected birthweights (e.g., Jersey bulls) for 15-month-old heifers, in order to reduce dystocia (calving difficulties) (Beef + Lamb NZ, 2019; refer to section 1.8.3). Due to these benefits, farmers usually utilise bulls in mating programmes by naturally mating 15-month-old heifers for the whole mating period, and mixed-age cows after six weeks of AI (AgriHealth, n.d.).

However, there are disadvantages and limitations when using bulls in mating programmes. Firstly, the dairy calves sired by bulls have lower genetic merit due to unrecorded sire genetics, or they have not been selected from an elite sire team provided by AI services (Yang et al., 2018). Similarly, the beef calves sired from bulls are of lower genetic merit than those from progeny tested beef-breed sires (Martin et al. 2022b). Bulls also require capital investment, feed, and stock handling and for dairy herds, smaller bulls are required to prevent physical damage to smaller dairy cows (FxJ and Jersey breeds), thus limiting breed selection. Overall, there are advantages, disadvantages, and limitations when using natural bulls in dairy herd mating programmes.

1.5.4 Gestation length

Gestation length plays an important role in breed selection and compact calving, varies among beef and dairy breeds, and is affected by environment and genetics (Winkelman & Spelman, 2001). Dairy-bred cows have an average gestation length of 281-2 days and a PPAI after calving between 30-60 days (Section 1.4.1; LIC, 2022a). The Angus breed has an average gestation length of 280 days, while the Hereford beef breeds have an average gestation length of 284 days, and the Wagyu has an extended gestation period of 286 days (Casas et al., 2012). However, there is a within-breed variation for gestation length. For example, the Hereford breed can vary by 23 days for longer or shorter gestation length (NZ Hereford, 2020). Within the variation, 50% of Herefords vary by two days on either side of the 23 days (NZ Hereford, 2020). A shorter gestation length will reduce the calving interval and create more compact calving.

1.5.5 Short gestation length semen

Utilising short gestation length (**SGL**) semen can reduce gestation length and calving interval. Gestation length is shortened by selecting sires based on gestation length and breed to reduce the number of gestation days of the paternal calf, thus reducing the gestation length of the impregnated dam (Winkelman & Spelman, 2001). Utilising SGL semen can benefit the calving spread, contributing to a more condensed calving compared to using average beef and dairy semen (See section 1.5.4). An advantage is made in milk production if farms reduce the herd's calving spread, as a shorter gestation length equates to more days in milk (Thomson & Hickson, 2022).

In NZ, SGL semen is available in some breeds; for example, Hereford, FxJ, and Jersey. Beef breeds typically have a longer gestation length than the dairy breeds, and SGL semen can reduce the beef gestation length to a similar gestation length of the dairy breed (LIC, 2022a). However, dairy-bred SGL semen can reduce gestation length of the impregnated dam to less than is typically achieved with conventional dairy semen (e.g., from 281 days to 262 days) (LIC 2022).

1.6 Cattle reproduction performance

In NZ, reproduction performance is measured using a three-week and six-week pregnancy rate. Good reproduction results, depend on the fertility of the cow, successful insemination, and conception. The key measures for mating are three-week submission rates, conception rates, six-week in-calf rates (total pregnant cattle within six weeks), and not-in-calf rates (non-pregnant cattle).

1.6.1 Submission rate percentage (%)

The three-week submission rate (percentage of cows submitted for insemination within three weeks of mating) is a comparative analysis to indicate a herd's reproduction performance (Burke and Fowler, 2014). A herd that achieves a greater three-week submission rate reflects a herd of cows that will have a greater pregnancy rate, calve earlier and cycle earlier the following season. The average three-week submission rate in NZ is 81% while the national herd average target is 90% (LIC & DairyNZ, 2021). The three-week submission rate is a good indicator to the farmer of what the remaining mating and calving spread will be.

1.6.2 Conception rate percentage (%)

The conception rate, which is the percentage of pregnant cows divided by the total number of cows submitted (inseminated), is indicative of how many cows were successfully impregnated by insemination (Burke and Fowler, 2014). In NZ, the average conception rate is 53% for dairy herds using AI with conventional semen, with a national target of 60% (LIC & DairyNZ 2022). Conception rates for liquid fresh sexed semen are around 5% lower than conventional semen (Xu., 2014). However, different conception rates have been reported and the conception rates for sexed semen can be up to 10% lower than conventional semen (Maicas et al., 2019). The conception rate is a good indication to the farmer of the total pregnant cows and calving spread.

1.6.3 Mating and calving spread

The submission rates and conception rates contribute to the calving spread. In NZ, on average 68% of the herd (LIC & DairyNZ, 2021), and for some herds up to 90%-95%, are pregnant in the first six weeks from PSM using AI (Roche et al., 2017a; Yang et al., 2018). The mating and calving spread on NZ dairy herds has been presented in **Figure 6**.

Figure 6. Calving and mating spread of New Zealand dairy herds, the weekly number of cows mated by artificial insemination (x 10^3) and calved during June and December, in 2016 (Yang et al., 2018).

1.6.4 Measuring reproduction results

The reproduction results are measured on each herd in the dairy industry and include the submission and conception rates. Typically, for reproduction performance comparison, the dairy industry refers to the six-week in-calf rates, calculated from early pregnancy test results, at least 80% of the herd, and attained from breeding company reports only (LIC & DairyNZ, 2021). The term 'in-calf' refers to cows that have successfully conceived after insemination and are confirmed pregnant. Dairy herds have a range of reproduction results that vary each year. Thus, each herd has a different calving spread depending on the mating success. In NZ, the national targets provide farmers the opportunity to benchmark against averages. The recent 2020-2021 reproduction targets and national herd results have been presented in **Table 1** (page 15).

1.6.5 Dairy calves reared for heifer replacement

Dairy heifer replacements are identified and selected at mating. The outcome of these calves is planned by selecting a sire for mating to a particular dam, and usually selected for breed (usually Jersey, Friesian, or JxF) and the desired genetic traits (see section 1.7.1). Typically, heifer replacement calves are reared on farm until weaning, and then calves are usually sent off farm for grazing and return home prior to calving. Farmers select semen to sire heifer replacements by using, elite sires, daughter-proven semen, or sexed semen (Yang et al., 2018). Factors that determine the outcome of calves reared for heifer replacement include early calving dam, high breeding worth (**BW**) dam, and elite sire selection.

1.6.6 Dairy heifer replacements

Each year a new cohort of animals enter the dairy herd to replace cows that have been removed. Unless the herd has poor genetics, all heifer replacements are born and reared from current stock on the farm, usually in the first 42 days from the actual start of calving (**ASC**) in seasonal calving (Meier et al., 2021). The ASC is the day the first cow calves (not including those that have given birth to premature calves). The 15-month-old heifers are the replacement cattle used to maintain herd size, age profiles, and improved genetic merit. In most cases these are the same cattle reared as dairy calves for heifer replacement. These animals are usually around 15 months old at mating, have never calved (nulliparous) and are referred to in the industry as ‘heifers’, and are typically reared off farm until returning prior to their first calving.

1.6.7 Heifer replacement rate percentage

The importance of heifer replacement rate is that it allows for the removal of aged cows or not in-calf cows, and voluntary culling due to health, poor production, predicted late calving date, or undesirable genetics. This means farmers can maintain a profitable herd by improving their herds genetics and production and reproduction performance (Ingenhoff et al., 2017). Each year a farm manager rears calves for heifer replacements which enter the herd at two years of age after their first calving to replace those cows that have died or have been voluntarily removed. Farmers aim for a replacement rate of 18%, but this can range between 18% and 25% (MPI, 2017) depending on management decisions that year (e.g., yearly cow removal selection and unexpected deaths; LIC & DairyNZ 2022). Thus, in NZ, the annual average replacement rate is 22% (LIC & DairyNZ 2022).

Typically, a farmer would not purchase dairy heifer replacements except for a herd with a season of poor reproduction performance (see section 1.5), in which the number of not in-calf cows is large, and there is little opportunity for voluntary culling of poor performance cows. In which case, a farmer may purchase pregnant cattle, which may be cows, heifers, or carryovers. Carryovers are cows that have failed to fall pregnant during the planned mating period, but with an extended mating period, they eventually fall pregnant the following year and can remain on farm.

1.6.8 Mating dairy heifers

Changes in the mating and management of heifers is needed to help reduce the production of bobby calves. However, there are some benefits and complexities when mating nulliparous 15-month-old heifers. The benefit of mating heifers is the possibility for genetic gain relative to cows already in the herd, as heifers produce genetically superior heifer replacement calves, due to the decrease in generational interval (Ettima et al., 2017). Although, it is important for dairy farmers not to over allocate sexed semen in mating programmes, as this can create a surplus of heifer replacement calves (Ettima et al., 2017). There is typically limited, or no, market for surplus heifer dairy calves in NZ. However, the use of sexed semen can allow more cows to be mated with beef-breed semen, reducing the production of bobby calves (Ritter et al., 2019; Haskell et al., 2020; Balzani et al., 2021). Although there are some benefits for AI heifer replacements, there are plenty of negatives, especially when considering the use of beef-breed semen.

Unlike cows, the heifer’s physiological reproduction system is still developing. The 15-month-old heifers reach puberty (begin the oestrus cycle) around 12-13 months old or once reaching 43-47% of their mature liveweight and should be mated before 16 months old to calve at two years old (24 months) (DairyNZ, 2022a). Once calved, in general, heifers take longer to cycle post-partum, and for this reason are mated earlier then lactating cows (one to two weeks; see section 1.4). By mating heifers earlier than mixed-age cows, the farmer provides sufficient time for the heifer’s oestrus cycle to return before mating begins again in the subsequent season (DairyNZ, 2022a). Consequently, as the 15-month-old primiparous heifers are still maturing, they require different mating strategies on NZ dairy farms.

Typically, in NZ, heifers are serviced by lighter liveweight bulls in the paddock. The selected bulls typically produce on average lighter offspring (i.e., calves sired by Jersey bulls; refer to section 1.8.3). There is the potential to AI heifers during mating in NZ. Currently, the calves of heifers disproportionately contribute to the total calves bobbied due to unrecorded sires and breed selection for light birthweights. Furthermore, research conducted by Coleman et al. (2021) indicates that only a small proportion (5%) of recorded Angus and Hereford bulls could safely be selected to minimise calving difficulties. Evidently, there are currently no safe options for bull selection for mating heifers to reduce bobby calves.

There are also limitations for implementing AI for heifers. Usually, heifers are reared off farm, to decrease the demand for pasture on farm (AgriHealth, n.d.). Often, these off-farm sites have limited or no facilities to support regular monitoring of heifers (e.g., barns, yards), and this has two implications; one, the difficulty to monitor for oestrous behaviour and two, the inability to undertake daily AI (AgriHealth, n.d.). Therefore, heifers present one of the greatest difficulties for reducing bobby calves through changing mating strategies. Successful implementation for changing mating programmes will require changes to current management practices to facilitate AI. Furthermore, beef-breed semen must be selected for traits suitable to both the beef (growth rates and carcass characteristics) and dairy (gestation length and calving ease) sectors when selecting semen for use in mating heifers (refer to section 1.8).

1.6.9 Heifer calving rates

The nulliparous 15-month-old heifers have different submission rates and conception rates compared to lactating cows. The conception rates are typically higher in 15-month-old heifers than multiparous cows; however, this is with hormonal intervention and is disputed (Stevenson et al., 1996; Cartmill et al., 2001; Peters and Pursley, 2002; Tenhagen et al., 2003). Furthermore, heifers are commonly naturally mated earlier than the PSM, contributing to greater submission and pregnancy rates in the first three weeks (DairyNZ, 2022a). For top performing herds, around 82-87% of heifers calve in the first three weeks as mating usually begins 1-2 weeks earlier, thus this is more representative of four to five weeks of mating rather than three weeks (DairyNZ and Dairy Australia, 2017). Thus, the industry calving pattern target for heifers is to aim above 80% in the first three weeks and 95% in the first six weeks, figures from LIC fertility report 2021 (MINDA™, LIC, Hamilton, New Zealand).

1.7 Sire breed and semen selection

1.7.1 Daughter proven semen and sexed semen selection

Daughter-proven semen and sexed semen is produced from elite sires and increases genetic traits. Sexed semen is the sorting of the X chromosome producing approximately 90% female calves and 10% male calves, and daughter-proven semen commonly referred to as conventional semen is non-sorted semen (Ingenhoff et al., 2017). There is a higher purchase price associated with sexed semen when compared to all other semen types and to date, sexed semen produces a 5% lower conception rate than conventional semen (Ingenhoff et al., 2017; Xu., 2014).

The top BW cows are selected to produce heifer replacements sired by daughter-proven semen or sexed semen (Johnson et al., 2018). In NZ, each year most dairy herds have increased FxJ semen usage to produce progeny for heifer replacement, as the crossbred variety is well suited to NZ environmental conditions (LIC & DairyNZ, 2021). In turn, lower BW or late-calving cows are nominated for beef-breed semen due to unsuitable genetics or calving time (e.g., inseminated outside the first six weeks mating period) to produce daughter replacements, as the quickest strategy to improve herd genetics is by excluding low BW cows from heifer replacement breeding (Johnson et al., 2018). Cows which calve early or have high BW are usually mated to produce progeny for heifer replacement.

1.7.2 Individual beef-breed sire selection

Among cattle breeds, sires have different genetics and can be selected through the same process as daughter-proven dairy semen. Selecting the right beef-breed sire and breed is critical to maximising heterosis. For example, growth rates are directly genetically affected by the sire (Martin et al., 2020). There is a difference amongst beef-breed sires and growth weight, and the correct selection can improve the growth rate of beef x dairy cattle (Martin et al., 2020; Pritchard et al., 2021). The sire selection of these breeds needs to be suitable for the NZ market and finishing conditions, primarily being pasture fed. By doing so, farmers can increase the preference and attractiveness of calves born for beef x dairy calves when sold to calf rearers. There is a relationship between different mating programmes that produce different calf breeds and calf traits, and desired calf traits effect the calf outcome. Typically, calves born on dairy farms are usually sold or selected for heifer replacement before 30 days of age. Therefore, the combination of different calf outcomes born from different mating programmes could influence calf outcome and thus the resources required to rear the calves.

Although there is a commonality across dairy mating programmes, there are differences among farms and herds, often due to different breeds (e.g., Friesian, Jersey, and FxJ). Farmers select different sire breeds to produce different calf breeds for different dairy (e.g., Friesian, Jersey, and FxJ) and beef (e.g., Angus and Hereford) enterprises. The differing breeds and sire selections will likely influence the calf outcome, and in turn, the resources required. Mating programmes provide an opportunity for the dairy farmers to reduce the number of bobby calves born through semen selection that optimise calf traits desired in the dairy and beef supply chain markets. In NZ, the calves produced from these mating programmes are ultimately reared for dairy heifer replacement, reared for dairy beef, sold for dairy beef, bobbied, euthanised, or die for various reasons (e.g., still birth, pneumonia, premature).

1.8 Relevant commercial traits

1.8.1 Relevant commercial calving traits required for dairy cattle breeding

The dairy and beef sectors seek a different set of preferable traits relevant to the requirements and outcome of the production and sale of calves.

1.8.2 Gestation length

Gestation length is important when considering different mating programmes. A longer gestation length can influence calving spread and days in milk; for example, cows which have a longer gestation length calve later and, thus, begin lactating later (refer to section 1.5.4. and 1.5.5). The longer gestation length of the beef breeds when compared to the dairy breeds has the potential to extend the mating period and reduce days in milk on dairy farms unless using progeny tested bulls when the merit of the bull is measured (Thomson & Hickson, 2022). For example, progeny tested Angus-sired calves on average can have a 279 day gestation length (Beef + Lamb NZ, 2022a).

1.8.3 Birth weight and calving ease

Birth weight is important for ease of calving amongst dairy cattle, particularly younger, smaller animals. The effect of birth weight on calving ease is dependent on two factors, being the calf size, calving difficulties increase by 2.3% per kilogram increase of birthweight, and the pelvis size of the individual and breed of cow (Oliver and McDermott, 2005). For dairy farmers to select beef breeds for semen, the subsequent beef x dairy calves birth weights need to be comparable to those of dairy farmers, while reaching the minimum 35kg required for beef rearing to ensure calves reach target liveweights (Hickson et al., 2015; Coleman et al., 2022). Generally, beef breeds tend to have heavier birth weights when compared with the lighter dairy breeds (e.g., Jersey); however, this is not the case for all breeds (e.g., Angus). Furthermore, a calf's sire and dam will also determine the birth weight (Greenwood & Cafe, 2007; Coleman et al., 2021). Coleman et al. (2021) has documented an eight-kilogram difference in progeny born from the same breeds from varying sires. Thus, birth weights are critical for both dairy and beef production for different reasons. Average birth weights across dairy and beef cattle breeds are presented in **Table 2**.

Furthermore, calving difficulty is different for 15-month-old heifers when compared to mixed-age cows. Heifers are still growing and as a result, heifers generally have a smaller pelvic area and smaller birth canals. The breeding of larger beef cattle to smaller dairy breeds can cause dystocia, unless sires are carefully selected (Burggraaf, 2016). Calving difficulty for heifers can be minimised by selecting bulls that produce, on average, smaller calves with lighter birthweights, and for this reason, dairy farmers routinely use Jersey two-year old bulls for mating heifers. However, for multiparous cattle beef breeds can be selected for low birthweights, such as Angus, Hereford, and Wagyu, and within breed sire selection for calving ease and birthweight (Oliver and McDermott, 2005). Thus, heifer mating requirements differ to those of mixed-age multiparous cows.

Table 2. Birth weight, weaning weight, and slaughter weight from cattle of different breeds; dairy, beef x dairy, and beef as steers (S), bulls (B) and heifers (H) across different cattle breeds.

Classification	Breed	Sex	Birth weight (kg)	Weaning weight (kg)	Weaned age (days)	Slaughter weight (kg)	Slaughter age (days)	Author
Dairy	F	B	44.8	100.1		559	870	Muir et al., 2001
	1/4 J 3/4 F	B	42.2	96.3		553	870	Muir et al., 2001
	F	S	42.0	67.6	65	463.3	688	Barton et al., 1994
	J	S	32.4	54.0	67	354.2	691	Barton et al., 1994
	FxJ	S	35.7	63.0	73	432.3	688	Barton et al., 1994
Beef x dairy	H x F[b]	H	40.1	89.3	84	406	577	Burggraaf et al., 2020
	H x F[b]	H	40.1	89.3	84	438	577	Burggraaf et al., 2020
	H x F[a]	H	40.4	96.2	84	414	577	Burggraaf et al., 2020
	H x Fa	H	40.4	96.2	84	455	577	Burggraaf et al., 2020
Beef	A	H, S	36.2		76-88	502.5	850	Martin et al., 2021
	H	H, S	37.3		76-88	505.4	850	Martin et al., 2021
	Beef[b c]	H, S, B	33.1	151	212	368	912	Greenwood & Cafe, 2007
	Beef[a c]	H, S, B	34.2	221	212	393	912	Greenwood & Cafe, 2007
Averages	Dairy		39.4	78.2	68.3	480.6	779.5	
	Beef x dairy		40.3	92.8	84.0	428.3	577.0	
	Beef		35.2	186	212	442.225	881	

Figures compare weights of steers, bulls, and heifers between breeds across all ages and nutrition.
[a] Fed a high energy diet [b] Fed a low energy diet [c] Included a range of beef breeds.
Breed: F = Friesian, J = Jersey, FxJ = Friesian cross Jersey, H = Hereford, A = Angus

1.8.4 Relevant commercial traits required for beef rearing production

The relevant commercial traits for beef cattle differ to those of dairy cattle and are important animal drivers of profit in a beef-finishing system. Understanding growth rate and carcass composition is an important component of the meat supply chain as it ultimately affects feed efficiency which in turn affects economic return (Dal Zotto et al., 2009). Understanding desired carcass characteristics and growth rates is important in evaluating the profitability of different cattle and beef breed semen selection.

If bobby calves are to be reared in the beef systems, farmers need to select and breed for traits desired for beef production. It has been suggested that the dairy industry can enhance animal growth rates and carcass characteristics by selecting specific beef-breed sires for dairy mating programmes that maximise the genetic attributes favoured in the beef breeds (Dal Zotto et al., 2009; Coleman et al., 2016). Cattle carcass characteristics and growth rates are heritable and crossbreeding strategies can improve retail profitability among dairy breeds through beef heterosis (Barton et al., 1994; Wheeler et al., 1997; McIntyre et al., 2009; Wetlesen et al., 2020; Berry, 2021). There is a difference in growth performance and cattle carcass characteristics when comparing dairy, beef x dairy bred cattle, and beef breeds.

1.8.5 *Cattle growth performance*

Cattle growth rates differ among dairy, beef x dairy cattle, and beef cattle. Growth rates can be measured using liveweight, carcass weight, and average daily gain (**ADG**) (Coleman et al., 2016; Berry et al., 2018). Liveweight is the weight of the living animal recorded at any time in its life. The calculation of ADG, is the difference in total bodyweight (live or dead) divided by the number of days between weighing periods (Berry & Crowley, 2013; Pritchard et al., 2021). The mathematical equation for this is:

$$ADG = \frac{End\ weight - Start\ weight}{End\ time - Start\ time}$$

Carcass weight is the weight measured after the animal has been dressed (the head and offal removed) after slaughter. Beef progenies tend to have heavier liveweights and slaughter weight (weight before dressing out), and carcass weights relative to cattle age, compared with dairy or beef x dairy progeny. Generally, heavier liveweights and heavier mature weights are strongly correlated with heavier carcass weights and faster growth rates (Schreurs et al., 2008; Coleman et al., 2016; Pettigrew et al., 2016; Pritchard et al., 2021). In contrast, cattle with lighter liveweights will have slower growth rates relative to age. Regarding carcass weight, beef progenies produce heavier carcass weights and greater ADG, and dairy calves sired by beef breeds produce heavier carcass weights and greater ADG, than dairy calves (Coleman et al., 2016). Beef x dairy calves have faster growth rates, heavier liveweights, and carcass weights compared to dairy calves.

In some cases, beef x dairy calves can produce similar growth performance to beef breeds. Research has documented little compromise of carcass weights among some beef x dairy calves; however, slaughter age may be slightly negatively influenced (Coleman et al., 2016; Muir et al., 2000; Pritchard et al., 2021). The faster growth rates of certain dairy breeds (e.g., Friesian) when crossed with the slower growing beef breeds (e.g., Angus and Hereford) can accelerate growth in beef x dairy calves (Coleman et al., 2016). In contrast, some slower-growing dairy breeds (e.g., Jersey) can negatively impact growth rates among beef x dairy progeny (Barton et al., 1994; Keane & Dreenan, 2008; Williamson et al., 2022). However, of the dairy breeds, Friesian bulls are favoured for beef production due to more suitable growth rates and carcass characteristics than Jersey bulls. Interestingly, the growth rates of dairy calves can be equal to beef calves prior to 12 months of age. This is because growth rates in young cattle are initially high and then slow down as cattle reach maturity (Williamson et al., 2022). The lifetime growth rates of dairy, beef x dairy, and beef breeds have been presented **Table 3.**

Table 3. Weaning weight, liveweights, and finishing weight for cattle of different breeds; dairy, beef x dairy, and beef in steers (S), bulls (B), and heifers (H).

Classification	Breed	Sex	Weaning (kg)	Weaned (days)	150-250 days (kg)	250 days (kg)	400 days (kg)	500-600 days (kg)	700-800 days (kg)	Slaughter weight (kg)	Slaughter age (days)	Author
Dairy	J (1/4) x F (3/4)	B	96.3						553	553	870	Muir et al., 2001
	J x F	B	88.2						522	522	870	Muir et al., 2001
	J	S & H	253.4	250		253.4	319.8	435		435	600	Afolayan et al., 2007
	F	B	100.1						559	559	870	Muir et al., 2001
	F	B	100	84		100			248	248	730	Pettigrew et al., 2016
	FF	S	67.6	65	145.9	175.5	244.3	369.2	463.3	463.3	688	Barton et al., 1994
	JJ	S	54	67	116.5	143	191.2	302	354.2	354.2	691	Barton et al., 1994
	F x J	S	63	73	144.3	178.6	236.7	357.5	432.3	432.3	688	Barton et al., 1994
Beef x dairy	F x A	S	92.9	84	138	201	281	427	572	572	850	Keane & Drennan 2008
	A x FA	S	93.8	84	135	196	272	399	541	541	800	Keane & Drennan 2008
	B x FA	S	99.6	84	151	224	302	429	568	568	800	Keane & Drennan 2008
	H x AF	S	237	168	237				624	624	714	Coleman et al., 2016
	H x AK	S	231	168	231				589	589	709	Coleman et al., 2016
	H x AJ	S	223	168	223				587	587	712	Coleman et al., 2016
	H x K	S	103	90		251				251	250	Hunt et al., 2019
	H x K	S	103	90			349			349	400	Hunt et al., 2019
	H x F [b]	H	89.3	84	107			406		406	577	Burggraaf et al., 2020
	H x F [b]	H	89.3	84	135			438		438	577	Burggraaf et al., 2020
	H x F [a]	H	96.2	84	115			414		414	577	Burggraaf et al., 2020
	H x F [a]	H	96.2	84	148			455		455	577	Burggraaf et al., 2020
Beef	A	H & S	-	76-88	158.4		284.1	425.2	502.5	502.5	850	Martin et al., 2021b
	H	H & S	-	76-88	158.7		283.4	426	505.4	505.4	850	Martin et al., 2021b
	H X A	S	205	168	205				595	595	714	Coleman et al., 2016
	Wagyu	S & H	256.2	250		256.2	320	420.6		420.6	600	Afolayan et al., 2007
	A	S & H	283.9	250		283.9	360.5	486.2		486.2	600	Afolayan et al., 2007
	H	S & H	282.6	250		282.6	352	468.4		468.4	600	Afolayan et al., 2007
	South Devon	S & H	291	250		291	364.7	502.2		502.2	600	Afolayan et al., 2007
	Limousine	S & H	283.3	250		283.3	355.7	485.1		485.1	600	Afolayan et al., 2007
	B	S & H	289.8	250		289.8	365.5	496.5		496.5	600	Afolayan et al., 2007
Averages	Dairy		102.8	107	135.6	170.1	248	365.9	447.4	445.9	750	
	Beef x dairy		147.9	117	185.8	218	301	418.3	580.2	510.1	654	
	Beef		205.7	182	146.7	281.1	335.7	451.9	534.3	475	640	

Figures compare weights of steers, bulls, and heifers between breeds across all ages and nutrition.
[a] Fed a high energy diet. [b] Feed a low energy diet.
Breed: F = Friesian, J = Jersey, K = Friesian cross Jersey, H = Hereford, A = Angus, B = Belgium Blue, C = Charolais

1.8.6 Cattle carcass characteristics

Cattle carcass characteristics are used to grade and value a carcass at slaughter. Carcass characteristics include dressing out percentage (**DO%**), eye muscle area (**EMA**), lean meat yield (**LMY**), muscle to bone ratio (**M:B**), subcutaneous fat, and intramuscular fat (marbling) (Berry et al., 2018; Coleman et al., 2016). The DO% is calculated by the cattle's liveweight divided by the carcass weight, in most cases the 'hot' carcass weight (Coleman et al., 2016; Martín et al., 2020). The 'hot' carcass weight is the weight recorded from the hanging carcass after dressing out and before the carcass is halved (Keane & Drennan, 2008; Coleman et al., 2016; Hunt et al., 2019; Martín et al., 2020). The impact of breed on DO% and carcass weight is highlighted in **Table 4**.

The eye muscle area (**EMA**) is usually measured between the twelfth and thirteenth long rib, called the *M. longissimus thoracis et lumborum* and indicates lean meat, fat, and marbling scores of the carcass, and usually increases with age (Kirton & Morris, 1989; Martín et al., 2020). Lean meat yield is the proportion of lean meat acquired from the carcass (Clarke et al., 2009; Conroy et al., 2010; McPhee et al., 2020). Higher lean meat yields indicate a greater production of saleable product from a given carcass weight. Muscle to bone ratio **(M:B)** is the total lean muscle weight divided by the carcass bone weight expressed as a ratio. A greater ratio, driven by greater muscle to skeletal proportion is desired in meat production.

Overall, dairy progenies have a lighter carcass weight, low M:B ratio due to poor muscularity, lower DO% irrespective of carcass weight, and smaller EMA indicative of lower LMY (Barton et al., 1994; Bown et al., 2016; Coleman et al., 2016; Berry, 2021). Furthermore, dairy breeds produce the least subcutaneous fat, due to less external fat, and lower marbling scores, contributing to a lighter carcass weight and lower LMY (Barton et al., 1994; Bown et al., 2016). Due to these compounding factors, the dairy breed carcasses are often graded below average at slaughter (Barton et al., 1994; Clarke et al., 2009).

In contrast, beef progenies produce heavier carcass weights, have greater LMY, M:B ratio, and greater DO% than dairy and beef x dairy breeds (Arthur et al., 1995; Wheeler et al., 1997; Purchas et al., 2002). Furthermore, beef breeds produce superior subcutaneous fat depths and the highest marbling scores than other breeds, contributing to a heavier carcass weight and greater LMY (Bown et al., 2016; Martín et al., 2020). Meanwhile, beef breeds with a smaller frame and lighter carcass weight still produce more muscle relative to frame size (e.g., Angus) when compared to dairy breeds (Arthur et al., 1995; Coleman et al., 2016; Martín et al., 2020). Overall, the differing beef carcass characteristics result in a superior carcass than dairy breed.

Table 4. Comparison of hot carcass weight (kg) and dressing out percentage (%) for cattle of different breeds; dairy, beef x dairy, and beef in steers and bulls.

Slaughter age	Breed	Category	Hot carcass weight (kg)			Dressing out (%)			Author
			Beef	Dairy	Dairy-Beef	Beef	Dairy	Dairy-Beef	
8 months	H x K	Steer			119				Addis et al., 2020
8 months	H x F	Steer			118			47.3	Hunt et al., 2019
9 months	A	Steer	151.6			55			Arthur et al., 1995
9 months	C	Steer	171.4			56.2			Arthur et al., 1995
9 months	H	Steer	147			55.1			Arthur et al., 1995
10 months	H x F	Steer			146			47.5	Hunt et al., 2019
10 months	H x K	Steer			145.5				Addis et al., 2020
12 months	H x F	Steer			175			50	Hunt et al. 2019
12 months	H x K	Steer			173.9				Addis et al., 2020
12 months	H x A	Steer	302			50.7			Coleman et al., 2016
12 months	H x AF	Steer			312			50.1	Coleman et al., 2016
12 months	H x AK	Steer			293			49.7	Coleman et al., 2016
18 months	H x AJ	Steer			289			49.3	Coleman et al., 2016
15 months	A	Steer	196.7			55.7			Arthur et al., 1995
15 months	C	Steer	216			56.6			Arthur et al., 1995
15 months	H	Steer	195.8			55.6			Arthur et al., 1995
15 months	C x F	Steer [b]			268			57.1	Nogalski et al., 2017
16 months	F	Bull		272 [a]			52		Vestergaard et al., 2019
16 months	F x L	Bull			316**			55.1	Vestergaard et al. 2019
18 months	C x F	Steer [b]			316.7			58.7	Nogalski et al., 2017
23 months	F	Steer		241.5 [a]				52.1	Barton et al., 1994
23 months	J	Steer		181.4 [a]				51.2	Barton et al., 1994
23 months	F x J	Steer		225.6 [a]				52.2	Barton et al., 1994
24 months	F	Steer [b]		287.0 [a]			50.2		Keane and Drennan, 2008
24 months	A	Steer [b]	278.0 [a]			51.4			Keane and Drennan, 2008
24 months	B	Steer [b]	308.0 [a]			54.3			Keane and Drennan, 2008
24 months	F	Bull		340			53.8		Muir et al., 2001
24 months	J x F	Bull		333			54.8		Muir et al., 2001
28 months	F	Steer		323.3					Berry et al., 2018
28 months	J x F	Steer		296.3					Berry et al., 2018
28 months	F x K	Steer		313.2					Berry et al., 2018
28 months	J x K	Steer		285.5					Berry et al., 2018
28 months	F x J	Steer		303					Berry et al., 2018
28 months	J	Steer		277					Berry et al., 2018
28 months	A	Steer	327.4						Berry et al., 2018
28 months	A x FJ (J 33%)	Steer			318.6				Berry et al., 2018
28 months	A x FJ (J 50%)	Steer			314.1				Berry et al., 2018
28 months	A x FJ (J 66%)	Steer			309.7				Berry et al., 2018
28 months	A x JJ	Steer			300.9				Berry et al., 2018
27 months	A	Steer			332			58.7	Arthur et al., 1995
27 months	C	Steer			360.7			59.2	Arthur et al., 1995
27 months	H	Steer			322.3			58.8	Arthur et al., 1995

Figures compare carcass characteristics from pasture-fed steers and bulls between breeds across all ages
[a] Chilled carcass weight recorded
[b] Feed a diet including silage and concentrates, all other animals' pasture and silage
Breed: F = Friesian, J = Jersey, K = Friesian cross Jersey, H = Hereford, A = Angus, B = Belgium Blue, C = Charolais.

In comparison, dairy calves sired by beef breeds tend to produce slightly lighter carcass weights, low M:B ratio, and lower DO% when compared to beef breeds (Bown et al., 2016; Coleman et al., 2016; Berry, 2021). Although when beef-sired dairy calves are compared to dairy breeds, they have heavier carcass weights, greater DO%, greater subcutaneous fat, and marbling (Martín et al., 2020; Berry, 2021). This is due to increased muscularity resulting in a greater DO%, M:B ratio, EMA, and LMY at slaughter, due to the sire beef genetics positively influencing carcass characteristics (Clarke et al., 2009; Martín et al., 2020). Thus, beef x dairy calves produce quality carcasses more suited to the beef industry due to the contribution of beef genetics.

There is an opportunity to improve calf traits suitable for beef production produced from dairy progeny through utilising beef-breed semen. This is because the superior carcass characteristics and improved growth performance found in beef breeds can improve the carcass value of beef x dairy calves when compared to dairy progeny (McIntyre et al., 2009; Bown et al., 2016; Berry & Ring, 2020; Wetlesen et al., 2020). If calves were selected using beef carcass characteristics and growth traits these cattle could be finished earlier and produce a higher LMY resulting in greater economic return (Coleman et al., 2016; Martin et al., 2021b; Pritchard et al., 2021). Calves of Jersey breed produce lighter carcasses and lower economic returns for beef production (Bolton and von Keyserlingk, 2021; Williamson et al., 2022). Thus, the superiority of beef genetics found in beef x dairy progeny increases profitability. However, this requires separate classification at slaughter between 8-12 months and requires a price premium for economic viability (Hunt et al., 2019; Pike et al., 2019). Therefore, selecting sire semen on desired beef cattle growth and carcass characteristics is critical when utilizing more beef-breed semen in mating programmes.

1.9 Desired traits in beef x dairy calves

Most dairy farmers choose to sell beef x dairy calves to external calf rearers instead of rearing the calves on farm. This requires beef x dairy purchasers and rearers to make decisions at the farm gate that determine the fate of those young calves. Calf rearers make calf purchase decisions and decide on the price to pay based on sex, weight, and colour markings as an indicator of breed composition, although there is no universal classification (Thomson & Hickson, 2022). Young dairy and beef x dairy calves can be distinguished on beef characteristics and selected for carcass characteristics best suited for beef production (Coleman et al., 2016; Martin et al., 2021b; Pritchard et al., 2021). In addition, the sire's genetics and breed influences the performance of each animal and progeny born, sires should be selected for desired traits suitable for beef-sired calves to predict progeny performance (Martin et al., 2021a). The calf sire impacts on the predictability of calf growth and carcass characteristics. Thus, the outcome of these calves is usually determined by but not limited to, gender, coat colouring, and frame size.

There are limitations around the possibility of predicting beef traits in young calves. For example, hand-rearing young calves and pasture quantity and quality can influence cattle growth by allowing slower-growing calves more time to reach desired target weights (Irshad et al., 2012; Martin et al., 2021a). Consideration must be given to environmental effects when rearing young calves (e.g., pasture availability and calf rearing).

1.9.1 The importance of sex in beef x dairy calves

Calf sex influences carcass characteristics, and thus the carcass value. Breed, age, and sex influence growth rates, carcass composition, confirmation, and tissue distribution, all of which influence the DO%. For example, a steer has a greater DO% than a heifer (Afolayan et al., 2007; Keane & Drennan, 2008; McIntyre et al., 2009; Coleman et al., 2016; Berry et al., 2018; Martín et al., 2020). Typically, heifers are slower growing compared to males, thus more undesirable for beef rearing, and because of this, many beef x dairy heifer calves are one week old or younger when processed (Boulton et al., 2020). For this reason, female calves are less desirable for beef rearing and are lower in value.

1.9.2 The importance of coat colouring in beef x dairy calves

Due to the complex inheritance of coat colour in cattle, crossbred calves obtain different coat colourings to the pure breed of their dams and sires. Beef x dairy calves with dairy coat colouring are considered to have less desirable sale characteristics for beef production compared to calves with beef coat colouring (Bolton and von Keyserlingk, 2021). The assumption is calves that appear to look more Friesian (e.g., five white points – 4 white socks and a white tail, larger frame and black coat) and less Jersey (e.g., brown coat, smaller frame, and missing or broken white points) will likely have inherited more of the desired Friesian genes from the dam. Calves with Jersey markings tend to produce poorer growth rates and unfavourable yellow carcass fat, and because of this, beef rearers avoid the Jersey traits from entering the beef system (Morgan & Everitt, 1969; Muir et al., 2001; Williamson et al., 2022). Beef rearers expect that calves with favourable coat colouring and markings also have other favourable beef traits (e.g., growth rates and carcass characteristics; refer to section 1.8), although Burggraaf (2016) reported that coat colour has little effect on beef characteristics. Thus, calves with Jersey-marked coat traits are in lower demand than calves with Friesian coat traits.

1.9.3 The importance of frame size in beef x dairy calves

The calf frame size is important for beef rearers when purchasing calves. At two years of age, favourable cattle conformation characteristics for meat production include a full brisket, fat visible around the tail, and a flat back, as these features are graded higher at pre-slaughter (Martín et al., 2020). These traits have not been standardised in young calves and calves with smaller frame sizes of Jersey and Friesian breeds tend to be less favourable among beef rearers and are in lower demand (refer to section 1.8; Thomson and Hickson, 2022).

1.9.4 Reason for bobby calf outcomes

There are several factors that influence the outcome of a bobby calf. Calves are bobbied because they are of undesired breed, sex, or appearance. Bobby calves can be produced from all semen selections and are usually calves with the greatest undesired traits among all calves being born. In NZ, the use of bulls is common among two-year-old heifer replacements (see section 1.6.8), and a high rate of bobby calves are usually sired naturally by unrecorded dairy bulls where genetic markers are not proven. Due to the dam's influence calves sired by beef-breed semen with unfavourable traits to the beef market are also bobbied. Ultimately, there are a range of factors that determine the outcome of a four-day-old calf.

1.10 Calf-rearing resources required for calf rearing in New Zealand

The rearing infrastructure and calf management decisions range across NZ dairy farms. Dairy farm calf-rearing resources include, but are not limited to, feed requirements, infrastructure, and labour, in which, calves require greater care than older cattle (Costa et al., 2016; Verdon, 2021; Vicic et al., 2022). Although no two farms are the same, the ability to address the rearing requirements for all calves is critical if calves are to remain on-farm beyond four days of age, this is consistent with determining the costs for heifer replacements as a necessity to improve operation profitability and associated health issues to improve performance and reduce mortality (Gabler et al., 2000; Johnson et al., 2021; Verdon, 2021). For farmers to be economically viable, the required calf-rearing resources should be quantified before farmers implement strategies to reduce bobby calves, and furthermore, consultations with industry stakeholders (dairy and beef sector, and meat processors) should be undertaken to understand the ramifications of reducing bobby calves in NZ (Verdon, 2021). Thus, calf management and required resources to rear calves born from different mating programmes aiming to reduce bobby calves needs to be quantified across different calf rearing systems.

1.10.1 *Calf feeding demand and management*

The calf feeding management relates to calves being fed adequate liquid and solid feed suitable to their size and age. Calves born on dairy farms and sold for beef production are reared under different conditions compared to calves born on beef farms, as dairy cow-calf separation is common within the first 24 hours of birth (Wetlesen et al., 2020; Martin et al., 2021a). Calves are born with no immune system or antibody response to disease, and calves receive immunoglobulin from colostrum (Cuttance et al., 2019; Barry et al., 2022). Colostrum high in immunoglobulin (>22% on a Brix refractometer) is vital to the health and growth of young calves in providing passive immunity from the first mammary secretion post-calving (Seppa-Lassila et al., 2018; Barry et al., 2022). Insufficient intake of immunoglobulins results in a failure of passive transfer, proven to affect the calf's health and immunity (Cuttance et al., 2019). Calves must be fed between 10% of the calf's liveweight (typically around 2-4L) of colostrum within the first six hours of birth as the quality of colostrum decreases after six hours and after 12 hours the ability for the calf's intestine to absorb immunoglobulin greatly reduces and stops absorbing after 24-48 hours (Wesselink et al., 1999; Cuttance et al., 2019; Barry et al., 2022).

Following the feeding of first-milking colostrum, calves should continue to receive colostrum for the first four days of life and allocated a minimum 10% of the calf's liveweight and feed at least twice a day (Thickett et al., 1986; Jongman and Butler 2013; Phipps et al., 2018; MPI, 2019). Subsequently, calves are to continue to be fed milk or milk replacer for at least the first six weeks of age or until the calf reaches the appropriate minimum weaning weight, 65 kg (Jersey) or 80 kg (Friesian) (MPI, 2019). Thus, the quantity, quality, and timing of colostrum, milk, and milk replacer are important for the overall calf's health, growth, and weaning weight.

Along with a suitable milk or milk replacer diet, calves removed from their dams should be housed and should have access to solid feed within the first week of life and be provided accessible drinking water from the first day (Phipps et al., 2018; MPI, 2019). Introducing water and roughage, calf meal, muesli, pasture, and straw or hay, from a young age is essential for development of rumen papillae necessary for post-weaning growth (Phipps et al., 2018).

Furthermore, calves provided a suitable diet for their size and age can readily reach target weights within the required timeframe. Young calves require high-quality feed to attain a growth rate of 1.0 kg/day ensuring target weights are reached at finishing (Martin et al., 2021b; Pettigrew et al., 2016). The growing calf's energy requirement increases and must be sustained to continue to reach maximum ADG (Pettigrew et al., 2016). However, the strong influence of nutrition and diet on ADG prior to 100 days in calves means ADG is not at an accurate predictor of mature liveweight, or finishing characteristics in mature cattle (Martin et al., 2021b; Pettigrew et al., 2016).

1.10.2 Calf housing infrastructure and management

In the dairy industry, dairy farmers build infrastructure to shelter and house calves during the calving period until they are deemed suitable to go outside (e.g., mild weather, age, health, cohort size) (Boulton et al., 2015). Housed calves must be fed and provided water, bedding, and freedom to express 'normal' calf behaviour (MPI, 2019). Calves as young as three days old require greater lying time than older calves and are more prone to increased muscle bruising and navel infections (Jongman and Butler, 2014; Boulton et al., 2020). The ability for farmers to reduce disease in young calves is through the first colostrum (see section 1.10.1) and offering good housing, as passive transfer from first colostrum cannot always protect calves in unhygienic environments (Johnson et al., 2021). Thus, the number of calves sets the demand for rearing requirements for adequate shelter.

Calves removed from their dams and subsequently housed need a dry, clean, and comfortable environment that protects calves from the natural elements (Phipps et al., 2018). Shelter and housing must provide well-ventilated and clean facilities while protecting calves from adverse weather conditions (MPI, 2019). Housed calves should receive a minimum of 1.5 m^2 per calf, and calves need to be free to express normal cattle behaviour, including standing up and comfortably lying down (MPI, 2019). The calf housing should cater to normal cattle behaviour relevant to their age while ensuring calf health and comfort.

1.10.3 Calf transport and collection

Calf transport management refers to the handling conditions required for calves to travel to and from locations, usually because of sale. The requirement for young animal transportation is prevalent in dairy supply chain management (Boulton et al., 2020). The dairy industry transports calves under 30 days due to calves sold as bobby calves or for beef production (Boulton et al., 2020). In New Zealand, calves must be a minimum of 96 hours old before transportation for sale or slaughter (MPI, 2019). Haskell (2020) suggests that calves sold for beef rearing are commonly transported to calf rearers around eight days of age and Wilson (2020) suggests calves are commonly transported between 3-7 days of age. The calf outcome could influence the age at which calves are transported and the accumulative calf-rearing requirements on farm.

1.10.4 Bobby calf collection

The availability of abattoirs to collect bobby calves ranges across the individual company and processing standards. Each abattoir has set days allocated for bobby calf collection which can range from daily to once every ten days. The regularity of bobby calf collection depends on the abattoirs' processing capacity and availability over the year (Beef + Lamb NZ, 2019a). However, some processors cannot always take on new farmers as they are at maximum processing capacity. The unprecedented and unexpected impacts of Covid-19 on labour shortages have impacted the agriculture sector (Piddock, 2022). In 2022, the Covid-19 pandemic left abattoirs short-staffed, impacting processing capacity and, at times, reducing calf processing and delaying bobby calf collection, highlighting the volatility of bobby calf collection services (Piddock, 2022). The abattoirs determine bobby calf collection and are also susceptible to external pressures.

Ultimately, dairy farmers are responsible for calf rearing and outcome, and are susceptible to external market conditions. Dairy farmers have little control over the collection of bobby calves and are at risk of having to rear calves for longer if the service changes. Dairy farmers should be aware, if regulations or services change, that rearing requirements and resources could also change. Using mating programmes to produce more beef x dairy calves can help mitigate some risks. However, the demand for beef calves is not guaranteed, then the requirement to rear more calves is expected to increase calf-rearing resources. Thus, to our knowledge, the current calf-rearing resources for different mating programmes and different calf outcomes is not determined.

1.11 Conclusion

Calves born to different mating programmes have different outcomes depending on breed, sex, and age. The outcome of calves in terms of heifer replacement, reared for beef, sold for beef rearing, bobbied, euthanised, or dead are determined by several factors which ultimately influence the demand for these calves at a young age. The uncertainty of demand and the economic values of calves disenables farmers from making certain decisions when selecting semen for mating programmes. The uncertainty in the supply chains prevents farmers from predicting the calves' outcome and the calf-rearing resources required. Farmers could be provided insight into the expectation of calves and their subsequent outcomes during calving through mating programmes and the required calf-rearing resources.

To our knowledge, the impact of different mating programmes aimed to reduce bobby calves (through utilising more sexed semen and beef-breed semen) on calf-rearing resources (shed infrastructure, feed demand, and labour) before calves exit the calf shed has not been measured. Therefore, the objective of the present study is to compare and analyse different mating programmes aiming to reduce bobby calves and evaluate the risks and opportunities of calf-rearing resources from subsequent mating programmes.

Chapter 2. Research questions and objectives

New animal welfare regulations from government and dairy supply companies are consistently under review and changing. If dairy farmers are to continue to farm, they need to meet potential regulatory constraints, and maintain the publics' 'social licence' to farm. To do this, farmers must address the bobby calf 'issue'. One way to reduce bobby calves is through utilising more sexed semen and beef-breed semen in NZ mating programmes. The subsequent calves sired by different breeds and semen selection could result in different calf outcomes and demand different calf rearing resource requirements (e.g., infrastructure, feed demand, and labour). These changes will impact farm practices and the management of calves and could ultimately affect the required calf-rearing resources.

The current research project aimed to determine the fate and value of all calves born from different mating programmes and the impact of different calf outcomes on the calf-rearing resources. The objectives of this project were to; 1) identify and quantify the resources required to house and feed calves born on five case-study herds with different mating programmes and, 2) use these data to predict the resources required on an average NZ dairy farm with different mating programmes aiming to reduce bobby calves.

Data were collected from five herds on three research farms in Taranaki (an autumn-calving Jersey herd, a spring- and autumn-calving Friesian herd, and a spring-calving Friesian herd). The mating programmes were individual to each herd and used a range of sire breeds (e.g., Friesian, Jersey, Hereford, Wagyu to name a few) and semen types (conventional and sexed semen, and natural mating), and were aimed at reducing bobby calves. Quantitative and qualitative data were collected and analysed to determine calf performance and the minimum infrastructure and resource requirements needed to meet calves' ethical and welfare needs during rearing. The data were then used in a modelling exercise to predict the impact (on shed infrastructure, feed, and labour) and feasibility of three stimulated mating programmes (industry average; reduced bobby calves; zero bobby calves) on an average NZ farm (based on NZ dairy industry statistics).

The research questions were:

- Using five case-study herds, what were the effects of mating programmes aimed at reducing bobby calves (industry average; reduced bobby calves; zero bobby calves) on:
    - Calf performance (time in the calf shed, exit age, birth and exit liveweight, growth rate, and outcome) and how these compared with national averages?
    - Calf rearing resource requirements (infrastructure, labour, and feed consumption)?

- The predicted changes in calf-rearing resource requirements and the potential impact on revenue for a NZ dairy farm (444 spring-calving crossbred cows; based on NZ averages)?

It is hypothesised that case study and simulated herds with different management systems (e.g., breed and calving date), and mating programmes aimed at reducing bobby calves (industry average; reduced bobby calves; zero bobby calves) will have increased calf performances (e.g., calf growth rate, age, and weight at leaving the calf rearing shed, and outcomes) and increased calf-rearing resources requirements (e.g., infrastructure, feed, and labour).

Chapter 3. Materials and methods

3.1 Case-study herds

An embedded multiple-observational case study research approach was used with five selected case-study herds from three research farms to create a real-life comparative analyses (Yin, 2014). As these were commercial dairy farms, there were variations within the herds, for example: cow breed and calving date, and thus there were no control herds, nor were there any replications of the herds.

Data were collected during the 2021 calving period from the three research dairy farms that are owned and operated by Dairy Trust Taranaki (**DTT**) (**Table 5**). The five case-study herds were selected on the basis that they had implemented different mating programmes in 2020 aimed to generate dairy heifer replacements while reducing the number of bobby calves. The mating programmes were unique to each herd and included a range of sexed and daughter-proven bull semen for heifer replacement, beef breeds for beef x dairy production (Wagyu and Speckle Park semen), and SGL FxJ and SGL Hereford semen. Bull semen was purchased through Livestock Improvement Corporation, NZ (**LIC**) and sire selection was independent to each case study and depended on availability.

The five case-study herds were selected from three pasture-based research farms located in the Taranaki region of NZ. Briefly, the farms were:

1) Farm one (DTT Waimate West Demonstration Farm), an autumn-calving herd (case study 1) with 119 Jersey cows
2) Farm two (DTT Kavanagh Farm), a spring-calving herd with 302 FxJ cows (case study 2a) and an autumn-calving herd with 307 FxJ cows (case study 2b)
3) Farm three (DTT Gibson Farm), two spring-calving herds; one herd with 206 FxJ cows (case study 3a) and one herd with 169 FxJ cows (case study 3b).

Case study 1

Case study 1 was an autumn-calving Jersey herd (94% recorded ancestry) from the Waimate West Demonstration Farm located in Waimate West in Taranaki (latitude 35.52°S, longitude 174.14° E). Data were collected from February 2021 to May 2021. The herd consisted of mixed-age cows (n=102) and primiparous heifers (n=17). The cows were managed in one herd on 34 ha effective milking area and milk production was 413 kg milk solid (MS)/cow/year. Case study 1 has one calf shed facility for housing all calves (total area 104 m^2). Labour during the calving period include one manager and a part-time calf rearer to assist in feeding the calves morning and afternoon.

Table 5. Three Dairy Trust Taranaki (DTT) research farms from which the five case-study herds (cows managed in their herds under rotational grazing with some imported feed) were selected for having implemented different mating programmes in 2020 aiming to generate heifer replacements and reduce bobby calves.

Case-study herd	Dairy Trust Taranaki Farm	Breed	Calving Season	Farm size (ha)	Peak cows	Other stock	Per cow (kg MS)	Milking frequency*	Production system	Labour (people)
1	Waimate West Demonstration Farm	Jersey	Autumn	34	119		413	TAD	System 3[2]	1.5
2a	Kavanagh	FxJ	Autumn	104	302	10	413	TAD	System 3[2]	4
2b	Kavanagh	FxJ	Spring		307		439	TAD	System 2[3]	
3a	Gibson	FxJ	Spring	110	206		356	TAD	System 2[3]	5
3b	Gibson	FxJ	Spring		169			TAD	System 2[3]	

* TAD: Cows were milked twice a day morning (~6:00) and afternoon (~14:00)
[1] System 2 = Feed imported, either supplement or grazing off, fed to dry cows, approximately 4 - 14% of total feed is imported (DairyNZ, 2022b).
[2] System 3 = Feed imported to extend lactation (typically autumn feed) and for dry cows, approximately 10-20% of total feed is imported (DairyNZ, 2022b).
MS = Milksolids

Case studies 2a and 2b

Case studies 2a and 2b were autumn- and spring-calving herds, respectively from the Kavanagh farm located in Hawera in Taranaki (latitude 39.61°S, longitude 174.29° E). The herd was FxJ (100% recorded ancestry) and included mixed-age cows (n=459), and primiparous heifers (n=150). The split-calving herd, autumn, and spring, operated on a total 213 ha effective milking area, generating an average milk production of 426 kg MS/cow/year. Case studies 2a and 2b share a calving shed facility (area 392m^2) designed to house all calves born in the spring-calving herd (n=607). In 2017, the farm moved to two split-calving herds (spring and autumn), thus the large calving shed afforded the luxury of more extensive housing facilities for a split-calving herd. Farm labour across both herds included three full-time employees and one full-time primary calf rearer.

Case study 2a

Case study 2a was an autumn-calving herd from the Kavanagh farm and included mixed-age cows (n=234) and primiparous heifers (n=68). Data were collected between February 2021 and May 2021. All autumn-calving cows were managed as one herd on 104 ha effective milking area, produced an average milk production of 413 kg MS/cow/year.

Case study 2b

Case study 2b was a spring-calving herd from the Kavanagh farm and included mixed-age cows (n=225) and primiparous heifers (n=82). Data were collected between July 2021 and September 2021. The spring herd was managed in one herd on 104 ha effective milking area, producing an average production of 439 kg MS/cow/year.

Case studies 3a and 3b

Case studies 3a and 3b were two herds from Gibson farm located in coastal south Hawera in Taranaki (latitude 39.62°S, longitude 174.30° E). Data were collected from July 2021 to September 2021. The spring-calving herds were FxJ (99% recorded ancestry) mixed-age cows (n=239), and primiparous heifers (n=68). All cows were managed on a total of 110 ha effective milking area, with an average milk production of 356 kg MS/cow/year. On this farm, cows were managed in two separate herds due to trial protocols not related to this project (Step Change project; DairyNZ), but because the two herds had different mating programmes they were identified as **case study 3a** (n= 130 mixed-age cows and n=38 primiparous heifers) and **case study 3b** (n=109 mixed-age cows and n=30 primiparous heifers) and analysed separately.

In total, case studies 3a and 3b had three separate calf-rearing sheds; one bobby calf shed (area $38m^2$), one calf shed for heifer replacements and beef x dairy calves (area $146m^2$), and one overflow calf shed (area $77m^2$). Labour included four full-time employees and one primary full-time calf rearer. All calves from both case studies 3a and 3b were reared in the same facilities. For retrospective analyses, the shed area was proportionally allocated to each case-study herd to highlight individual case study mating programme calf outcomes and calf rearing requirements.

All farms were pasture based, using rotational grazing and supplementary feed during times of feed deficit. Calves were born to both multiparous and primiparous dairy cows in 2021. All protocols were conducted in accordance with, and approved by, AgResearch Animal Ethics Committee, application number 15343. All cows and calves were managed adhering to best practice management and New Zealand Animal Code–of Welfare - Dairy Cattle 2019. All cows across the five herds received the rotavirus vaccine four weeks before the PSC for the herd.

3.1.1 Mating programmes

In all the case studies, the multiparous mixed-age cows were artificially inseminated over twelve weeks in 2020; either in autumn (case studies 1 and 2a; June 2020 – August 2020) or spring (case studies 2b, 3a and 3b; October 2020 – December 2020). Artificial inseminations were conducted by trained commercial technicians and documented in herd management software (MINDA™, LIC, Hamilton, New Zealand). The primiparous 15-month-old heifers were mated in 2020; either in autumn (case studies 1 and 2a; June 2020 – August 2020) or spring (case studies 2b, 3a and 3b; October 2020 – December 2020), and were naturally mated with a Jersey bull for six weeks, from the 5th of October for spring herds and the 2nd of June for autumn herds.

Artificial insemination mating programme and cow selection criteria for multiparous mixed-age cows

For all case studies, a pre-determined mating criterion was used to identify each dam with the appropriate semen selection. The sire breed was selected in relation to mating decision rules, allocation, and dates which were then matched to cows displaying oestrous that day. Once the sire breed and dam were determined, cows were randomly nominated to a sire, depending on the sire availability on the day. Cows displaying a returning oestrus were mated to the nominated bull breed allocated on the day and per the time interval of the mating programme. Fresh semen, as opposed to frozen semen, was used for AI for all animals. The mating programmes are presented in **Table 6.** Each herd manager implemented a specific mating programme designed to utilise beef- and sexed semen to demonstrate mating programmes aiming to reduce bobby calves.

Case study 1

For case study 1, all cows which displayed a heat in the first six weeks were mated to FxJ daughter-proven semen. After the first six-week period beef-breed semen was utilised. For the following four weeks cows were inseminated using Speckled Park (beef) semen and for the final two weeks with SGL FxJ semen.

Case studies 2a and 2b

For case studies 2a and 2b, high BW cows were mated using Friesian daughter-proven semen for improved genetic gain of future dairy heifer replacements. This was to improve genetic merit of future progeny born and reared as dairy heifer replacements by eliminating the lowest BW cows. The aim was to ensure enough heifer replacements could be reared while improving herd BW generated from heifer replacements sired by daughter-proven semen. Over the same period, cows with lower BW were allocated Hereford (beef) semen.

A BW report was generated for all cows for both case studies 2a and 2b. The 50 cows with the lowest BW were nominated for beef-breed semen. The remaining cows were considered high BW and nominated for daughter-proven semen. The list was generated by LIC staff and provided to DTT farm staff to refer to daily over the mating period. As cows were selected for AI, the list was checked, and cows were nominated for the appropriate semen selection. For example, for six weeks from the PSM, high BW cows were mated by Friesian daughter-proven semen. During this time, lower BW cows (that a replacement heifer was not desired from) were mated using SGL Hereford (beef) semen. After this six-week period, all cows were mated to SGL Hereford (beef) semen for the following four weeks, and for the final two weeks cows were mated using SGL FxJ semen.

Table 6. An overview of the mating programmes implemented in 2020 for the case-study herds, with mating dates, breed and cow selection, and predicted calf outcome. Case studies 1 and 2a were autumn-calving herds and case studies 2b, 3a, and 3b were spring calving herds.

	Case studies																				
Variables	**1**				**2a**					**2b**					**3a**			**3b**			
Cow selection	High BW	Low BW	All cows	Heifers	High BW	Low BW 50 cows	All cows	All cows	Heifers	High BW	Low BW 50 cows	All cows	All cows	Heifers	High BW	All cows	Heifers	Highest BW cows	High BW	All cows	All cows	Heifers
Date	10-Jun	22-Jul	19-Aug	2-Jun	5-Jun	5-Jun	18-Jul	15-Aug	2-Jun	1-Oct	1-Oct	12-Nov	10-Dec	5-Oct	10-Oct	21-Nov	5-Oct	5-Oct	5-Oct	31-Oct	5-Dec	5-Oct
Duration (weeks)	6	4	2	6	6	6	4	2	6	6	6	4	2	6	6	5	-	3	3	5	3	6
Administration	AI	AI	AI	Bull	AI	AI	AI	AI	Bull	AI	AI	AI	AI	Bull	AI	AI	Bull	AI	AI	AI	AI	Bull
Semen type	D proven	Nom	SGL	Natural	D proven	SGL	SGL	SGL	Natural	D proven	SGL	SGL	SGL	Natural	D proven	SGL	Natural	SS	D proven	Nom	SGL	Natural
Sire breed	FxJ	SP	FxJ	J	F	H	H	FxJ	J	F	H	H	FxJ	J	F	H	J	F	F	Wagyu	H	J
Predicted calf outcome	HR/DB	DB	Bobby	Bobby	HR/DB	DB	DB	Bobby	Bobby	HR/DB	DB	DB	Bobby	Bobby	HR/DB	DB	Bobby	HR	HR/DB	DB	DB	Bobby
All Cows	119				302					307					168			139				

Abbreviations: BW = Breeding worth
Administration: AI = Artificial insemination technician, Bull = Natural mating by the bull
Semen type: SGL = Short gestation length, D proven = Daughter proven, Nom = Nominated, SS = Daughter proven sexed semen
*Sexed semen was allocated four straws each day and the four cows with the highest BW in heat on that day received one straw each.
Breed: H = F = Friesian, J = Jersey, FxJ = Friesian cross Jersey, H = Hereford
Predicted calf outcome: DHR = Dairy heifer replacement, DB = reared or sold as beef x dairy

Case study 3a

For case study 3a, all cows which displayed a heat in the first six weeks were mated to Friesian daughter-proven semen. After which, SGL Hereford (beef) semen was utilised after the six-week period for a further four weeks and followed by two weeks of SGL FxJ semen.

Case study 3b

For case study 3b, four Friesian fresh sexed-semen straws were allocated to early calving high BW cows daily for the first three weeks of mating (4 x 21 = 84 straws). This was to improve genetic merit of future progeny born and reared as dairy heifer replacements. A traffic light system (green, orange, and red) was used to identify suitable cows (early calving and high BW) for sexed semen. The aim of using individual cow identification was to ensure enough heifer replacements could be reared while improving herd BW generated from heifer replacements sired by fresh sexed semen.

For cow nomination a report was generated to identify cows that were; 1) early calving cows, based on the previous calving date, and 2) high BW cows. For cows to be considered 'early calving' they calved 21 days from the ASC, 15/7/2020. For cows to be considered high BW they were required to be in the top 60th percentile (60%) of the herd and were identified as 'green' in the traffic light system. Cows considered 'orange' were inbetween the 60th percentile (top 60%) and 80th percentile (top 80%) of the herd. The 'orange' cows were recommended for sexed semen if no 'green' cows were available on the day.

Over the same period, Friesian daughter-proven semen was allocated to all other cow's colour coded 'red'. The remainder of the cows not nominated for sexed semen or daughter-proven semen mated after the 30th of October 2020 were nominated for SGL Hereford (beef) semen. This plan was generated by LIC, with the suitable cows identified, colour coded (green, orange, or red), the list was provided to DTT farm staff to use daily over the mating period.

For all case studies, cows that displayed a stronger behavioural oestrus the day after insemination, were re-inseminated the following day to the previous day's bull nomination. No controlled internal drug release intervention was used. After the pre-determined Al mating period there was no natural mating period for multiparous cows.

Purchased carry-over cows

In addition to the described mating programmes for autumn-calving case studies 1 and 2a, 17 carry-over cows were purchased in 2021, to replace non-pregnant cows from 2020. Thirteen carry-over cows were allocated to case study 1 and 4 carry-over cows to case study 2a. The purchased cows had been inseminated with Galloway semen and were included in the data from the present study as these calves were reared as part of the case studies. Gestation length for the purchased carry-over cows was unavailable due to unknown insemination dates.

Reproductive performance

Submission rates and conception rates for each case study were collected and analysed using data software (MINDA^{TM}, LIC, Hamilton, New Zealand) to determine reproductive performance. These data were used to determine expected calving spread which could be compared with actual calving spread.

3.1.2 Management of animals

Calving and calf collection

For all case studies, pregnant cows were checked at least twice daily in late gestation (in the morning and the evening) and additional checks were conducted at the discretion of the DTT farm staff. All cows that calved, and the corresponding calves (dead or alive) were identified at birth and recorded daily. All calves were left on their dam until collection which occurred once daily. Trained farm staff checked that calves left with the dam for longer than six hours had been adequately fed by the dam. After collection, calves were subsequently housed on farm in the dedicated calf shed.

All calves (dead or alive) were brought to the shed after the morning milking (9–10:30 am), weighed, and identification tagged. Dead calves were recorded, weighed, and then placed aside for dead-stock collection services. Calf navels were sprayed with iodine on collection and again upon arriving at the calf rearing facilities. All calves were managed on farm in the calf-rearing facilities under NZ commercial management (MPI, 2019) in corresponding age group or class cohorts. Calves not reaching target weights were held back a cohort if needed. Calves were checked twice daily for signs of ill-health and medical assistance was sought and provided where needed. Calf facilities and equipment were cleaned and disinfected weekly. Bedding was refreshed fortnightly or on an as-needed basis. Calves were disbudded by veterinarians at 3-4 weeks old.

Calf feeding

On each case study, newborn calves were managed in a separate pen to older calves for the first 24 hours, to ensure they received first colostrum of >22% brix refractometer (Cuttance et al., 2019). Calves were fed their first colostrum 2-4L using calf feeders for the first afternoon feed after collection. Each calf received a minimum of two litres of first colostrum, and then received colostrum milk for a minimum of four days thereafter. In case studies 1, 2a, and 2b, calves were subsequently reared on whole milk, collected from the vat, and fed twice daily to appetite (until calves stopped suckling) while calves remained in the calf rearing facilities. Calves from case studies 3a and 3b were reared on whole milk, collected from the vat, and received 2.5L fed twice daily. All calves were offered ad-libitum water in in-shed water troughs and calf meal (commercial calf feed; dry matter 86%, crude protein 18%, starch 23%, neutral detergent fibre 21%, metabolisable energy 12.5 ME/kg; BHL Feeds, 2022) fed in small containers from the first day in the calf shed.

Unwell calves

Calves that displayed signs of ill health were separated and housed in a "sick pen" to minimise the spread of disease and provide care. Unwell calves were fed last to avoid cross contamination and supplied ad-libitum electrolytes in a drinking trough in addition to their normal water supply. All personal protective equipment and feeding equipment used by the DTT staff were cleaned after handling any unwell calves.

3.1.3 Measurements

Quantitative and qualitative data were collected for each case study and analysed to determine calf performance to estimate the calf shed population, feed, and labour requirements. The data collected included date of arrival to calf shed (this was documented as the birth date), liveweight at entry to and exit from the shed, and probable breed of calf. Minda (MINDA™, LIC, Hamilton, New Zealand) records were used to identify the sire and dam and the reproduction performance. For all case studies, tax invoices for sales of beef x dairy calves and bobby calf were used to document the cash transactions of calves sold or bobbied. All data were compiled and analysed to define the impact of the different mating programmes on calf rearing, resource requirement, and consequent risks and opportunities. The following information was collected by the primary calf rearer and the calf recording sheets are provided in **Appendix 1**:

1) Cow identification
2) Calving date/birth date
3) Calf birth weight (live and dead calves)
4) Visual calf dominant breed (criterion provided in **Appendix 2**)
5) Breed markings
6) Exit date
7) Exit liveweight
8) Calf outcome: reared on-farm for heifer replacement, reared on-farm for beef, sold for beef rearing, bobbied, euthanised, died
9) Reason for outcome: breed, coat, size, or frame
10) Details on calf sale (i.e., meat processor or individual calf rearer purchaser name)
11) Calf mortality
12) Reason for mortality
13) Required assistance at calving
14) Any other comments.

This research project collected the following information from digital records for each case study (MINDA^{TM}, LIC, Hamilton, New Zealand):

1) Cow identification
2) Cow age (years)
3) Cow breed
4) Mating details
5) Submission rates
6) Conception rates
7) Sire identification
8) Pregnancy diagnosis
9) Gestation length.

Qualitative interviews

In all case studies, qualitative interviews were conducted regularly with the primary calf rearer to understand the on-farm management decisions, these were one-on-one, open-ended interviews and were conducted in-person monthly with the primary calf rearers. The in-person interviews were held at a time suiting the participants, usually between 10 am and 2 pm for around 20 minutes. All protocols for the interviews were evaluated, assessed as low risk and approved for three years (Massey University Human Ethics Committee Notification 4000024502).

Calf breed identification and outcome

Calf breeds and outcomes were recorded for all calves born in all case-study herds. Calf outcome was recorded as either bobbied, reared for heifer replacement, sold for beef rearing, died, or euthanised, along with the reason for the outcome (e.g., breed, small frame, coat), and sale invoices were documented. Unlike the national averages, no option of ‘other’ was provided for the case-study herds, as all calf outcomes were identified and recorded. The specifications for each outcome and calf protocol were pre-determined before calving as detailed further in **Appendix 2**.

Heifer replacement rearing

For all case-study herds, calves selected for heifer replacements were pre-determined at mating via selection of high BW dams that were mated with daughter-proven semen. Heifer calves reared for dairy herd heifer replacements were managed as described in section 3.1.2 but remained in the calf shed until an appropriate group size was attained and weather permitted for the calves to be moved outside. The timing of this move outside, was decided at the discretion of the farm staff.

Bobby calf collection

In all case-study herds, at a minimum of 96 hours (4 days old) bobby calves were separated from other calves and relocated to the allocated sheltered pen for collection by Silver Fern Farms (**SFF**). Calves were fed within two hours of collection. Bobby calf collection was available over the calving season and 7-day collection was available during the peak spring calving. The SFF final bobby calf collection was 11th of May 2022 for autumn-calving herds and 30th of September 2022 for spring-calving herds.

Beef x dairy calf collection

For all case-study herds, the beef x dairy calf rearers had different appearance criteria for accepting calves. This prompted the development of consistent recording templates with pre-determined identification and categorisation criteria such as calf breed and coat descriptions and was to be used by calf rearers (**Appendix 2**).

The beef x dairy calves remained in the calf shed until collected by the arranged buyer, organised via direct sale or agent. Individual buyers determined the breed and visual prerequisite of the beef x dairy calf (e.g., breed, coat, and frame size) and a range of different buyers were sought to sell the calves. Calves that could not be sold to any prospective buyers were bobbied. This decision was made at the discretion of the calf rearer after all potential buyers had been contacted. Beef x dairy calves that could not be sold and were a minimum of four days old were allocated to the next available bobby calf collection. Beef x dairy calf collection was negotiated between the farm's primary calf rearer and the buyer or agent, determined by the party's availability and calf age (minimum of four-days-old) and group size (negotiated between the individuals).

In case study 3b, the Wagyu beef x dairy calves were sold under contract with a required age minimum of 10 days, and a maximum of 30 days old, and agreement of contract collection. These calves were required to be a minimum of 32 kgs liveweight and were set priced. Wagyu-sired calves were collected weekly on a pre-assigned day with a 10-calf minimum collection requirement. The exception was if calves were nearing 20 days of age, where the farm could organise an additional collection. A condition of supply was that calves could not be fed milk under antibiotic withholding period; in the instance of a mistake, calves fed antibiotics were required to be identified before collection. Calves were required to be healthy, not over-fed, and meet the selection criteria as provided within the contract. Calves heavier than 37 kg generated an additional payment for every kilogram of liveweight, representative of the calf's age, on the assumption that 0.4kg liveweight was gained per day. For the Taranaki region, spring contractual calves sired by Wagyu were required to be born between the 1st of July 2021 and 31st of August 2021. This required that the last mating date using Wagyu semen was the 21st of November 2020.

Mating measurements and analyses

Reproduction performance

Mating results used the 'actual start of mating', PSC, and the ASC dates. The actual start of mating referred to the first day that AI was used on mixed-age cows. The 2020 mating results were collected from Minda for all case-study herds and used to determine reproduction performance.

Gestation length

Gestation length was calculated in Microsoft EXCEL using the Minda mating records for insemination dates and calf birth dates (calving date). Where two mating dates were close together, the mating date closer to 281 days gestation was selected (see section 1.5.4). The gestation length for each cow and subsequent calf was calculated using the calf birth date (calving date) minus the determined mating date and determined the total days between both calf birth date and mating date, calculated by:

$$Gestation\ length\ (days) = calf\ \ birth\ date\ (date) - mating\ date\ (date)$$

As per normal farm practice, no mating dates were available for naturally mated 15-month-old heifer replacements. In addition, no mating dates were available for the purchased carry-over cows. The calves born to purchased carry-over cows were identifiable, as they were the only calves sired by Galloway.

Premature calves

Premature calves were excluded from the analyses of the case-study herds, apart from being included in calf outcome. Premature calves were determined when calculating the average gestation length. Calves were considered premature when the gestation length was less than 250 days, and the calf was recorded as dead.

Actual start of calving (ASC)

The first calf to be born, which was not premature, was used to determine the ASC, and this was documented as day 0 of calving.

Sire breed

The 'actual calf breed' for each calf was determined by sire breed. Sire breed was determined using the sire breed, insemination date, calf birth date, and gestation length. A 'summary of matings' (MINDA^{TM}, LIC, Hamilton, New Zealand) for each cow was analysed using the mating date and days to the calf birth date, producing the gestation length. The gestation length nearest to 281 days was considered the correct sire breed (section 1.5.4).

Apparent calf breed

The visual appearance of each calf was documented by trained farm personnel with a key criterion of factors determining breed (see section 1.9 and **Appendix 2**) and used to determine an 'apparent calf breed'. The distinction between actual and apparent breed was important as apparent breed (coat colouring, liveweight, and frame size) influenced the calf outcome and subsequent calf rearing requirements. For example, a calf born to a Friesian dam and a Hereford sire may produce a desirable or undesirable beef x dairy calf, depending on liveweight, frame size (large or small), coat colour (either black, red, or mixed colours with or without a white coloured face) (**Appendix 2**).

Calf performance measurements and analyses

For all case-study herds, calf performance measurements included birth and exit date, liveweights, and outcomes.

Birth and exit dates

Birth date was recorded as the date calves arrived at the calf rearing facilities. Exit date was when calves left the calf rearing facilities, including heifer replacements when they no longer resided in the calf rearing shed. The birth and exits dates were used to determine total days that calves resided in the calf shed, and was calculated by the calf exit date minus the calf birth date:

$$Total\ days\ in\ calf\ shed\ (days) = calf\ exit\ date\ (date) - calf\ birth\ date\ (date)$$

Birth and exit live weights

Birthweights (dead and alive) were recorded within 24 hours of birth. Exit liveweights were recorded immediately before calves exited the calf rearing shed, along with the corresponding exit date. The birth and exit liveweights were measured (to the nearest 0.5 kg) and the total calf liveweight gained while residing in the calf shed was calculated by exit liveweight minus the birth liveweight:

$$Total\ live\ weight\ gain\ (kg) = exit\ liveweight\ (kg) - birth\ liveweight\ (kg)$$

The total liveweight gain was used to determine the ADG while in the calf shed (kg per day). The ADG was calculated by the total liveweight gain (exit liveweight less birth liveweight) divided by the total number of days in the calf shed, using the formula (see section 1.8.5):

$$Average\ daily\ gain\ (\frac{kg}{day}) = \frac{total\ liveweight\ gain\ (kg)}{total\ days\ in\ shed\ (days)}$$

The median calf liveweight was determined as the value where 50% of the measured weights are higher and 50% are lower between birth liveweight and exit liveweight.

Resource measurements and analyses

Calf shed measurements

For each case-study herd, the calf shed was measured to determine the total capacity available for rearing calves. The calf shed's dimensions (length and width) were measured using a tape measure and multiplied (length x width) to calculate the total area available for housing calves. The total was then divided by 1.5m (the minimum area per calf) (NZ Cattle Code of Welfare, 2020) to determine the total number of calves that could be reared in the shed at any one time (shed capacity), and was calculated by:

$$Shed\ capacity\ (calves) = total\ area(m^2) \div 1.5\ (m^2)$$

The calf outcome and calf duration in the calf shed were used to determine the calf resource outputs, calculated in RStudio using R.3.5.0 (R Core Team, 2021). Each calf was plotted against time (using birth date and exit date) to determine the calving spread and the duration a calf resided in the calf shed, and each calf was categorised by calf outcome. The first day a calf entered the calf shed was considered the ASC and day 0 of calving. The total number of calves in the calf shed was used to determine the impact on the required resources (shed capacity, feed, and labour) by accumulating the total daily number of calves in the calf rearing shed.

Calf milk and meal consumption

For all case-study herds, total feed consumption for each calf was estimated based on information provided by calf rearers. Calves were offered colostrum, whole milk, and meal ad-libitum in case studies 1, 2a, and 2b. In case studies 3a and 3b, calves were fed twice daily and were allocated approximately 2L of milk per feed for the first day and approximately 2.5L of milk per feed thereafter while in the calf shed. As calves were fed milk at either 2.5L or to appetite, milk consumption equations included 2.5L/calf/feed or using 10% of the calf's median liveweight, respectively (refer to section 1.10.1). Milk feed to appetite was allocated as 10% of the calf's median liveweight to represent as best possible the increases in feed demand as the calf's liveweight increases.

The median liveweight of the calf was calculated as the average of birth liveweight and exit liveweight. In case studies 1, 2a, 2b, and 3a, the total minimum ad libitum milk consumption (litres per calf) while in the calf shed was estimated using 10% of median liveweight while the calf remained in the calf shed. The median liveweight (which represented the growth of the calf) was multiplied by 10% and then multiplied by the number of days the calf resided in the calf shed:

$$Total\ minimum\ ad\ libitum\ milk\ consumption\ (L\ per\ calf) =$$
$$median\ liveweight\ (kg) \times 0.10\ \times total\ days\ in\ the\ calf\ shed\ (day)$$

For case studies 3a and 3b, the total milk consumption (litres per calf) for each calf was estimated using 2.5L milk/feed multiplied by 2 (2 feeds per day) and multiplied by the total days the calf remained in the calf shed:

$$Total\ minimum\ restricted\ milk\ consumption\ per\ calf =$$
$$2.5\ (L\ per\ calf)\ \times\ 2\ (feeds\ per\ day)\ \times total\ days\ in\ the\ calf\ shed\ (day)$$

Labour

Interviews were conducted with the case-study herds primary calf rearers to estimate labour hours dedicated to feeding calves for each morning and afternoon feeding per day over the calving season.

Sale invoices and kill sheet documentation

Invoices for beef x dairy and bobby calf sales were collected, along with meat processor kill sheets. These were received in PDF format and transferred to an EXCEL spreadsheet for data analyses. The sale price of beef x dairy calves was negotiated between the calf rearer and agent or individual, reflecting a similar price to the more attractive calves being sold in the current market (e.g., correct coat markings, larger frame, heavier liveweight).

3.1.5 Statistical methods and analyses

Data collected for the case-study herds including, invoices, and Minda records (MINDA™, LIC, Hamilton, New Zealand) was compiled in Microsoft EXCEL. The data were then consolidated on RStudio using R.3.5.0 (R Core Team, 2021).

Data cleaning

For all case-study herds, data were collected on-farm by trained DTT farm staff. For each case study, data collected by DTT farm staff were cross-referenced with Minda records (MINDA™, LIC, Hamilton, New Zealand).

Data discrepancies

Where there were discrepancies in calf outcome between Minda and the on-farm records, the on-farm records were used in the analyses. The reason for accepting the on-farm records was because the data were relevant to the outcome (e.g., a calf bobbied was collected by SFF). Where there were discrepancies in calf breed between Minda and on-farm records, the sire breed was cross-referenced with mating records and the gestation length checked. Further investigation into discrepancies could give reason to why some farmers have difficulty doing stock reconciliation and mother and calf miss identification. After which, if there was still a discrepancy between recorded sire breed on Minda and on-farm records, then the Minda recorded sire was used.

Missing data

Mating records were used in situations where the calf was recorded, but the dam had not been recorded and matched to the calf. The data had missing variables for either birthweights (live and dead), exit liveweights, exit dates, or sale invoices. Animals were removed from the data set where no records were documented for birth date, calf sex, and calf outcome. The numbers analysed for each variable were reported.

Calculations

The calculations were used for analyses of each case-study herd. All calculations were conducted in Microsoft EXCEL, except the total number of calves in the calf shed each day, which was calculated using RStudio using R.3.5.0 (R Core Team, 2021).

Calf mortalities

All calves were included in analysing calf outcomes, including calves; reared on farm for heifer replacement, reared on farm for beef, sold for beef rearing, bobbied, died, and euthanised. Calves that died at calving or died before entering the calf rearing facilities were excluded from resource analyses. Calves that died at birth were included in data analyses for calf outcome, birth weights of all calves born, and gestation length, however; were not included in the resource analyses; birth date, exit date, days in the calf shed, and birth and exit liveweights. Calves that died or were euthanised after birth and had entered the calf shed were included in the resource analyses, as these calves required calf-rearing resources.

Twin calves

Cows that produced twins were documented and these calves followed the same protocol as all other calves (section 3.1.2). Twin calves were recorded on separate lines with the dam's number repeated for each calf. Caves born as twins were documented in the comment section of the raw data and were included in all data analyses.

Statistical analyses

Calves born to heifers and mixed-age cows were analysed together. The breed, sex, and age were treated as fixed effects. The results of variables were presented to include, count, means, and standard deviation (SD).

3.2 Scenario analyses

The aim of the scenario analyses was to identify risks and opportunities of different mating programmes implementing strategies (e.g., using sexed semen and more beef-breed semen) aimed at reducing bobby calves. Specifically, the objective was to investigate the on-farm resources required to meet animal welfare requirements during calf rearing (e.g., infrastructure, feed, and labour resources) for each scenario. The scenario analyses used the data collected from the three spring-calving case-study herds and evaluated calf outcomes, birth and exit liveweights and days in the calf shed from the different mating programmes. The scenario analyses provide insight into the calf-rearing resources required for subsequent calves born from implementing three different mating programmes.

The scenario analyses used a 'future-now' approach, first described by Chermack & Lynham (2002) and used by Shadbolt et al. (2017). The 'future-now' approach is relevant as regulatory frameworks, including animal welfare legislations, are continually being updated. For example, changes in minimum feed requirements (e.g., feeding milk to calves at 20% liveweight instead of 10% liveweight; MPI. 2022b), or the minimum age of a calf before leaving the farm (e.g., ten days instead of the current four days). Additionally, utilising more beef-breed semen will increase beef x dairy calves entering the value chain and potentially reduce market demand and price. Ultimately, changes in animal welfare or changes in supply and demand for calves could impact the calf rearing requirements in the scenarios and the associated economic outcomes. Thus, the 'future-now' approach allows for a current analyses of uncertain future circumstances.

The scenario analyses used data from the case-study herds and existing literature to develop the base assumptions for the calf-rearing model. New Zealand national averages (Edwards et al., 2021; LIC & DairyNZ, 2021) and existing literature were used to determine a 'national average NZ herd'. A simulation of calf rearing on a 444-cow herd was used and current market averages due to the uncertainties of future market conditions (e.g., impacts of increased beef supply on demand). The case-study herds were used for the assumptions for calf outcome, average calf liveweights, and average days in the calf shed. The simulation calculated the number of calves in the shed each day and determined the calf-rearing resources required (i.e., shed capacity, feed demand, and labour requirements).

Three scenarios were simulated to represent an 'average NZ herd' that implements three different mating programmes, these were:

Scenario 1) current industry mating practices and bobby calf production;

Scenario 2) mating programme to reduce bobby calves to ~22%; and

Scenario 3) a mating programme to target zero bobby calves.

3.2.1 Scenario outlines

The three scenario analyses were applied to an 'average NZ dairy farm'. The average herd was assumed to be 444 Friesian-Jersey cross-bred spring-calving cows averaging 450 kg liveweight and producing 397 kg MS/per cow from a 270-day lactation (LIC & DairyNZ, 2021). The herd grazed on a 155 effective ha pasture-based farm at 2.86 cows per hectare (LIC & DairyNZ, 2021), and the heifers remained on farm or returned to farm prior to their first calving.

For all scenarios, mating was conducted for 12 weeks using AI and bulls. The herd had a 22% dairy herd replacement rate, all replacements were sourced from calves produced by the herd (LIC & DairyNZ, 2021). Cows mated using AI were identified under 'normal' AI heat detection practices using tail paint and visual oestrous behaviour (e.g., mounting, restlessness, Flehmen, rubbed tail paint) (refer to section 1.5.1).

For each scenario, a 3-, 6-, 9- and 12- week 'calving expectation' was used to determine the expected calving pattern and thus the number of calves reared. New Zealand national averages were used to determine the herd calving expectancy for all scenarios. The calving pattern was determined using national median 'in-calf' rates and assumed that calving was finished by 12 weeks after ASC, in which 100% of cows had calved (LIC & DairyNZ, 2021). The scenario mating programmes to determine the simulation inputs are presented in **Table 7**.

Scenario 1 – Base case

The first scenario reflected the current bobby calf 'status quo' and implemented mating programmes typical to NZ dairy farms, such that ~35-45% of calves born were bobbies.

Scenario 2 – Reduced bobby calves

Scenario 2 aimed to reduce bobby calves to ~20-25%, to reflect the national average heifer replacement rates of 22% (LIC & DairyNZ, 2021). This scenario represented a situation where the 15-month-old heifer replacements were mated to Jersey bulls (as seen in case studies 3a and 3b). Scenario 2 reflects the current challenges of using AI for 15-month-old dairy heifers (e.g., reared off-farm, primiparous calvers, ease-of-calving, calf-size). Mixed-aged cows were AI using sexed semen to produce high BW daughter replacements, in conjunction beef-breed semen was used on all other mixed-age cows.

Scenario 3 – Zero bobby calves

Scenario 3 aimed to reduce bobby calf production as close to ~0% as possible, as some calves may still be bobbied due to poor markings, poor frame size, or lighter liveweights. In Scenario 3 it is assumed the 15-month-old heifers (22% of the herd) and some mixed-aged cows were AI using sexed semen to produce high BW daughter replacements. After this, all remaining 15-month-old heifers and mixed-age cows that were not AI using sexed semen were mated by beef-breed bulls.

3.2.2 Scenario assumptions

All data were compiled in Microsoft EXCEL and analysed in RStudio using R.3.5.0 (R Core Team, 2021) to evaluate the scenarios outputs (number of calves, breed, calf outcome, days in shed, and liveweights) to determine the shed infrastructure and feed requirements.

For all scenario analyses equations:

Y = cows submitted for insemination

X = number of animals

S = submission rate (%)

C = conception rate (%)

R = replacement rate (%) or (cows)

TCP = total cows pregnant (cows)

HR = herd replacement (calves)

MinC = minimum calves born sired by conventional semen (50:50 female to male ratio)

MinS = minimum calves born sired by sexed semen (90:10 female to male ratio)

FC = female calves

H = 15-month-old heifers

NPH = not pregnant heifers

SS = use of sexed semen

P = number of in-calf cows

np = number of not in-calf cows

$_h$ = heifer conception rate or submission rate was used

$_{1,2,3}$ used to show a change in the total number of cows

Table 7. The mating programmes used for scenarios 1, 2, and 3. Each scenario has a different mating programme (using daughter-proven, sexed, and beef-breed semen) aiming to achieve bobby calves (~35%, ~22%, and ~0%) simulated on a 444-cow spring-calving dairy herd in New Zealand (derived from national averages and literature).

	Scenario												
Variable	**1**			**2**				**3**					
Cow selection	All Cows	All Cows	Heifers	High BW Cows	Low BW	All cows	Heifers	High BW	Low BW	All cows	Heifers	Heifers	Heifers
Weeks from PSM	1 - 6	7 - 12	1 - 6	1 - 3	1 - 3	3 - 12	1 - 6	1 - 3	1 - 3	3 - 12	1 - 3	1 - 3	3 - 6
Duration (weeks)	6	6	6	3	3	9	6	3	3	9	3	3	3
Administration	AI	AI/Bull	Bull	AI	AI	AI	Bull	AI	AI	AI	AI	Bull	Bull
Semen type	D proven	Nom	-	SS	Nom	Nom	-	SS	Nom	Nom	SS	Nom	Nom
Breed	FxJ	Beef	J	FxJ	Beef	Beef	J	FxJ	Beef	Beef	FxJ	Beef	Beef
Calves Born Female : Male Ratio	50:50	50:50	50:50	90:10	50:50	50:50	50:50	90:10	50:50	50:50	90:10	50:50	50:50
Predicted outcome	HR/DB/Bobby	DB	Bobby	HR	DB	DB	Bobby	HR	DB	DB	HR	DB	DB

Abbreviations: BW = Breeding worth
Administration: AI = Artificial insemination technician, Bull = Natural mating by the bull
Semen type: D proven = Daughter proven, Nom = Nominated, SS = Daughter proven sexed semen
Breed: F = Friesian, J = Jersey, FxJ = Friesian cross Jersey, Beef = beef breed not specified,
Calf outcome: DHR = Dairy heifer replacement, DB = reared or sold as beef x dairy

Submission and conception rates for mixed-age lactating cows:

For mixed-age cows, an 81% three-week submission rate was used to calculate the total cows submitted for AI for each three-week mating interval (LIC & DairyNZ, 2021). A conception rate of 53% was applied for conventional semen to determine how many cows conceived to each insemination (LIC & DairyNZ, 2021). The conception rate when fresh sexed semen was used was assumed to be 48%, which was calculated at 5% less than conventional semen (as opposed to 10% less for frozen sexed semen) for both 15-month-old heifers and mixed-age cows (Xu, 2014). Submission rate and conception rate were calculated by:

$$Y = X \times S$$

$$TCP = Y \times C$$

Submission and conception rates for nulliparous 15-month-old heifers:

From our knowledge, no national means were available for naturally mated nulliparous 15-month-old heifers. The scenario assumed heifers achieved liveweight targets (60% of mature liveweight at 15 months) (DairyNZ, 2022a). Planned start of mating for heifers was one week earlier than mixed-age cows, and heifers were mated by the bull. A total of 110 heifers were on farm at 15 months old, accounting for the 5% loss from birth to weaning. The 10% loss from weaning to calving was not yet applied.

Typically, heifers have greater submission and conception rates than multiparous lactating cows as they begin mating earlier and have fewer environmental risk factors (e.g., calving difficulties, lactation) (Stevenson et al., 1996; Cartmill et al., 2001; Peters and Pursley, 2002; Tenhagen et al., 2003; LIC & DairyNZ 2022). Furthermore, greater conception rates are achieved when using a bull compared with AI due to the greater semen dose rate and multiple services (see section 1.5.3). For this reason, a six-week calving pattern of 94% was used for heifers from PSM to represent the greater conception rate resulting in more cows conceiving. For 94% of heifers to have calved by six weeks, a 82% 3-week submission rate was used from week one to week three of mating. After the initial three-weeks from PSC, the average in-calf rates for heifers were reduced from 82% to 71%, resulting in 94% of heifers pregnant by six weeks from PSM. Typically, heifers are mated prior to the planned start of mating, furthermore heifers a first calves and conceive easier, thus the in-calf rate is greater in the first ‘three’ weeks of mating to account for this difference.

For heifers to achieve a calving pattern target of 82% in the first three weeks and 94% by six weeks, the scenarios assumed a 95% submission rate. A 95% submission rate was used as it is unlikely all cows will cycle within four weeks without intervention (e.g., CIDR). For the model to facilitate the heifers being mated one week earlier, an 86% conception rate was imposed in the first three weeks. A conception rate of 86% is highly unlikely but it is accommodating a mating period of four weeks.

For heifers mated by sexed semen, a 95% submission rate and a 48% conception rate were used. From week three to week six, all scenarios maintained the assumption of a 95% submission rate while the conception rates were reduced to 75%. If a high rate of heifers were not pregnant, the total of mixed-age cow removed was reduced to carry more cows over to calving to maintain the 444-cow herd size.

Heifer replacement rate assumptions:

The national average heifer replacement rate of 22% was used to determine the number of calves reared as heifer replacements for each scenario (LIC & DairyNZ, 2021). All scenarios assumed 5% calf deaths between birth and weaning, and an additional 10% calf deaths between weaning and first calving. Therefore, to achieve a 22% heifer replacement, a 26% heifer replacement target was required at birth to account for these calf deaths. To target a heifer replacement rate of 98 calves (22% of the herd), 115 calves (or 26%) born from the 444-cow herd are required for heifer replacements (HR), calculated by:

$$HR = X \times R$$

The female to male ratio for conventional daughter-proven semen was 50:50, respectively. Thus, the mating programme in Scenario 1 requires more than two times 115 calves to produce 115 female calves for heifer replacement, demonstrated in the following equation:

$$MinC = FC \times 2$$

The female to male ratio for sexed semen was 90:10, respectively (Ingenhoff et al., 2017), calculated by:

$$MinS = R \times 1.1$$

Thus, the mating programmes in Scenarios 2 and 3 requires 129 calves to produce a minimum of 115 female calves for heifer replacement.

3.2.3 Scenario mating programmes

Scenario 1 – base case 'current industry average'

The mating programme for Scenario 1 represents a typical mating programme on NZ dairy farms for mixed-age cows and 15-month-old heifers, with a 22% heifer replacement rate targeted. The outputs from Scenario 1 determined the minimum resources required for Scenarios 2 and 3.

15-month-old heifer mating strategy

All 15-month-old heifers were mated by Jersey bulls and assumed a 95% three-week submission rate, and an 86% conception rate. The following equation determined the total number of pregnant heifers in the first three weeks of mating:

$$PH_1 = H \times S_h \times C_h$$

The total number of heifers which did not conceive in the first three weeks (NPH_1) of mating was calculated by:

$$NPH_1 = H - PH_1$$

After the first three weeks, all non-pregnant 15-month-old heifers were mated by Jersey bulls and assumed a 95% three-week submission rate, and a 75% conception rate. The following equation determined the total number of pregnant heifers for week three to six of mating:

$$PH_2 = NPH_1 \times S_h \times C_h$$

The total number of heifers which did not conceive from three to six weeks (NPH_2) from PSM was calculated by:

$$NPH_2 = NPH_1 - PH_2$$

Mixed-age cow mating strategy

The mixed-age cows used a similar formular as the heifers to determine cows submitted and pregnant. An 81% three-week submission rate and 53% conception rate were applied for all mixed-age cows throughout the 12-week mating period. In the first six weeks of mating, mixed-aged cows were mated using AI with conventional FxJ daughter-proven semen to produce heifer replacements. For the remaining six weeks mixed-age cows were mated using AI with semen from beef breeds. The reproduction results for the first three weeks of mating were calculated by:

$$X_1 = X \times S$$

$$X_{1p} = X_1 \times C$$

The total number of cows which did not conceive in the first three weeks of mating (X_{np1}) was calculated by:

$$X_{np1} = X - X_{1p}$$

The reproduction results from week three to six were calculated by:

$$X_{p2} = X_{np1} \times S \times C$$

Total number of cows that did not conceive from week three to six of mating (X_{np2}), calculated by:

$$X_{np2} = X_{np1} - X_{p2}$$

The reproduction results from week six to nine were calculated by:

$$X_{p3} = X_{np2} \times S \times C$$

The total number of cows which did not conceive from week six to nine of mating (X_{np3}) was calculated by:

$$X_{np3} = X_{np2} - X_{p3}$$

The reproduction results from week nine to twelve were calculated by:

$$X_{p4} = X_{np3} \times S \times C$$

The total number of cows which did not conceive from week nine to twelve of mating (X_{np4}) was calculated by:

$$X_{np4} = X_{np3} - X_{p4}$$

Scenario 2 – a reduction in bobby calves to 22%

The mating programme for Scenario 2 aimed to reduce bobby calves to ~22% by introducing sexed semen for producing replacement heifers and increasing the use of beef-breed semen.

15-month-old heifer mating strategy

The same mating programme was used for the 15-month-old heifers as Scenario 1 (refer to section 3.2.3: Scenario 1 – base case 'current industry average').

Mixed-age cow mating strategy

An 81% three-week submission rate was applied for all semen types. A 53% conception rate was applied for beef-breed semen and a 48% conception rate for fresh sexed semen. High BW cows in oestrous in the first 21 days of mating were mated by AI using sexed semen to generate heifer replacements. Cows that did not conceive through use of sexed semen were mated using beef-breed semen 21 days later during their next oestrus. The remaining cows that were not mated by sexed semen were mated using beef-breed semen.

For Scenario 2, the total cows to be mated by sexed semen to ensure 29% replacement rate (RR_{ss}) were calculated by:

$$HR_{ss} = RR_{ss} \times S \times C_{ss}$$

The reproduction results for cows inseminated by sexed semen for the first three weeks of mating (X_{ss1}) were calculated by:

$$X_{ss1} = X_{ss} \times S \times C_{ss}$$

The total number of cows which did not conceive using sexed semen from week three to six of mating (X_{npss1}) was calculated by:

$$X_{npss1} = X_{ss} - X_{ss1}$$

The heifer replacement rate requires 129 calves to be born, when divided by 21 days the mating programmes and requires the top BW cows to be mated by sexed semen per day, calculated by:

$$Cows\ mated\ per\ day\ by\ sexed\ semen = \frac{X_{ss1}}{21\ (days)}$$

The remaining cows were submitted for beef-breed semen from PSM to week three (X_B), calculated by:

$$X_B = X_{ss} - X_{ss1}$$

The reproduction results for cows inseminated by beef-breed semen PSM to week three, calculated by:

$$X_{pB1} = X_B \times S \times C$$

Total number of cows which did not conceive using beef-breed semen PSM to week three, calculated by:

$$X_{npB1} = X_B - X_{pB1}$$

Total cows not pregnant (from PSM to week three for both sexed and beef-breed semen) and available for submission in week three to six was calculated by:

$$X_C = X - (X_{npss} + X_{npB1})$$

The reproduction results from week three to six were calculated by:

$$X_{pD} = X_C \times S \times C$$

The total number of cows which did not conceive from week three to six of mating, calculated by:

$$X_{npD} = X_C - X_{pD}$$

The reproduction results from week six to nine were calculated by:

$$X_{pD1} = X_{npD} \times S \times C$$

The total number of cows which did not conceive from week six to nine of mating, calculated by:

$$X_{npD1} = X_{pD} - X_{pD1}$$

The reproduction results from week nine to twelve were calculated by:

$$X_{pD2} = X_{npD1} \times S \times C$$

The total number of cows which did not conceive from week nine to twelve of mating were calculated by:

$$X_{npD2} = X_{npD1} - X_{pD2}$$

Scenario 3 – a reduction in bobby calves to as close to zero as possible

The 15-month-old heifers that displayed oestrus in the first three weeks of mating were mated by AI using sexed semen. In conjunction, each day, of the total cows that displayed oestrus, only the top BW cows were mated to sexed semen, determined by the number of sexed semen straws inseminated each day, with the remainder being mated using beef-breed semen. After the first three weeks, all remaining cows and heifers were mated using beef-breed semen.

15-month-old heifer mating strategy

All 15-month-old heifers were mated by sexed semen and assumed a 95% three-week submission rate, and a 48% conception rate. The following equation determined the total number of pregnant heifers by sexed semen in the first three weeks of mating:

$$H_{pss1} = H \times S_h \times C_{ss}$$

The total number of heifers which did not conceive from PSM to week three was calculated by:

$$H_{npss1} = H - H_{pss1}$$

The remaining heifers which did not conceive in the first three weeks of mating were mated by beef bulls and assumed a 95% three-week submission rate, and an 75% conception rate. Heifers mated by the bull from week three to six was calculated by:

$$H_{p2} = X_{npa} \times S_h \times C_h$$

The following equation determined the total number of not pregnant heifers from week three to six of mating:

$$H_{np2} = H_{npss1} - H_{p2}$$

Mixed-age cows mating strategy

Mixed age cows were mated by AI using sexed semen during the first three weeks of mating to rear the required 29% (n=129) heifer replacements sired by sexed semen, calculated by:

$$HR_1 = HR - H_{pss1}$$

The mixed-age cows were mated by AI using sexed semen using an 81% submission rate and 48% conception rate and required some subsequent calves to be born for heifer replacement. The remainder of the cows were mated to beef-breed semen during these three weeks using the same 81% submission rate but a 53% conception rate.

The heifer replacement rate required additional sexed semen-sired calves to be born to mixed-age cows, when divided by 21 days the mating programmes required the top BW cows to be mated by sexed semen per day, calculated by:

$$Top\ BW\ cows\ mated\ per\ day\ by\ sexed\ semen = \frac{HR_1}{21\ (days)}$$

The reproduction results for cows inseminated by sexed semen from the PSM to week three of mating were calculated by dividing submission rate and conception rate, as the total number of required replacement calves was identified:

$$X_{pss1} = HR_1 \div S \div C_{ss}$$

The total number of cows which were not mated using sexed semen from PSM to week three and were available for insemination using beef-breed semen was calculated by:

$$X_B = X - X_{pss1}$$

The reproduction results for cows inseminated by beef-breed semen from the PSM to week three of mating were calculated by:

$$X_{pB1} = X_B \times S \times C$$

The total number of cows which did not conceive using beef-breed semen for the first three weeks of mating was calculated by:

$$X_{npB1} = X_B - X_{pB1}$$

The total cows not pregnant from beef-breed semen and available for submission in week three to six, calculated by:

$$X_1 = X - X_{pB1}$$

The reproduction results from week three to six mated by beef-breed semen were calculated by:

$$X_{p1} = X_1 \times S \times C$$

Total number of cows which did not conceive during week three to six from PSM, calculated by:

$$X_{np1} = X_1 - X_{p1}$$

The reproduction results from week six to nine mated by beef-breed semen were calculated by:

$$X_{p2} = X_{np1} \times S \times C$$

The total number of cows which did not conceive during week six to nine was calculated by:

$$X_{np2} = X_{np1} - X_{p2}$$

The reproduction results from week nine to twelve mated using beef-breed semen were calculated by:

$$X_{p3} = X_{np2} \times S \times C$$

The total number of cows which did not conceive during week nine to twelve was calculated by:

$$X_{np3} = X_{np2} - X_{p3}$$

Cows not pregnant (not in-calf rates)

For all scenarios, the total number cows which did not conceive during the twelve weeks from PSM was calculated by:

$$Not\ incalf\ rate = X_{np} \div X \times 100$$

For all scenarios, the total number of heifers which did not conceive during the twelve weeks from PSM was calculated by:

$$Not\ incalf\ rate = H_{np} \div H \times 100$$

3.2.4 Simulating calving

The calving inputs were collated from case studies 2b, 3a, and 3b.

Cow removals

For each scenario, the not in-calf rate determined the total number of cows removed (RE) from the herd. Cows mated using sexed semen were excluded from the cow removal process, as these cows had a high BW. Nominated cow removals (RM) were proportionately spread across the calving season, and the total nominated cows were calculated by:

$$RE = R - X_{np}$$

The scenario analyses-imposed mating programmes on a simulated farm with no option to assess the cows for performance other than fertility. Usually, farm managers remove cows based on poor performance, including low BW, lameness, temper, or fertility (i.e., late calving or not pregnant). Almost half of the dairy cows culled in NZ are late calvers or not pregnant (Harris, 1989; Burke and Fowler, 2014). For this reason, 50% of cows in the scenario were removed for a 'late calving date' (late-calving cows were mated in the last three weeks of mating), calculated by:

$$RM = RE \times 0.50$$

The occurrence of cows removed (O) in the last three weeks of mating was calculated by:

$$O = total\ cows\ pregnant\ in\ last\ three\ weeks\ of\ mating \div RM$$

The remainder of the cows were proportionately removed across the mating period from PSM to week nine (RM9), as these cows would have been removed for reasons other than fertility (Burke and Fowler, 2014), calculated by:

$$RM9 = RE - RM$$

The occurrence of cows removed (O9) in the first nine weeks of mating was calculated by:

$$O9 = total\ cows\ pregnant\ in\ first\ nine\ weeks\ of\ mating \div RM9$$

3.2.5 Determining calf performance, calf outcome and the occurrence of calf outcome

Analyses of the spring case studies 2b, 3a, and 3b provided the raw data on calf birth weights (live and dead depending on outcome), exit liveweights, average days in the calf shed, and the outcome of the calves born to different mating programmes over the calving period. The percentage of calves sold for beef rearing, bobbied, and deaths, reflected the data from case studies 2b, 3a, and 3b. The beef x dairy results and assumptions excluded the calves sired by Wagyu, as this is not representative of the national beef herds in NZ.

The outcome of all calves was determined across the calving period. On NZ dairy farms, a calf being bobbied or dying could occur at any point during calving, as seen in the results from case studies 2b, 3a and 3b. The total number of calves destined to an outcome (TC) was divided by the calf outcome percentage (%), calculated by:

$$TC = X \times (\% \times 100)$$

Across all calves born, the occurrence of the calf outcome (OC) was calculated by:

$$OC = X \div CX$$

3.2.6 Assumptions for simulating heifer replacement cohort

For all case-study herds, calves destined as heifer replacements were reared together until reaching a suitable group size before being reared outside. The average days in the shed for the heifer replacements was 35 days for calves born from daughter-proven semen and 29 days for those born from sexed semen. Heifer replacements are reared outside in groups (cohorts) and to simulate this, the scenario analyses needed to simulate a cohort of heifers being reared in the shed and then being reared outside as a group, thus an average days in the shed was used based on the case studies. A cohort of calves reared for heifer replacements was simulated using the total sum of calves and forming a cohort formulated on cohort numbers from case studies 2b, 3a and 3b, the scenario analyses replacement rate, and the use of a 50-teat 800L outdoor calf feeder.

Therefore, the age at which calves reared for heifer replacements were moved outside was formulated using the case-studies average days in the shed (as this is when heifer replacement calves left to be reared on-farm outside), across the entire cohort, with the dates evenly distributed.

4 Results

4.1 Case-study herds

4.1.1 Calf outcome overview

The calf outcomes differed among the case-study herds. Calves bobbied for case studies 1, 2a, and 2b, ranged between 41-44%, whereas for case studies 3a and 3b, only 23% and 21% of calves were bobbied, respectively. Calves reared for heifer replacements were relatively stable for case studies 1, 2a, and 2b, between 22%-28%. Few calves on any farm were reared on farm for beef, between 4%. Calves sold for beef rearing for case studies 1, 2a, and 2b, were between 15-21%, and higher for case studies 3a and 3b at 30% and 37%, respectively. Mortality rates varied among case studies 1,2a, and 2b, between 3-9%, and calves euthanized were between 3-6%. In contrast, the mortality rate on case studies 3a and 3b was 9%, but no calves were euthanised.

Overall, case study 3a produced the lowest number of calves bobbied and the highest number of calves sold for beef rearing. The outcomes of calves born in 2021 to each of the different mating programmes have been presented in **Figure 7**.

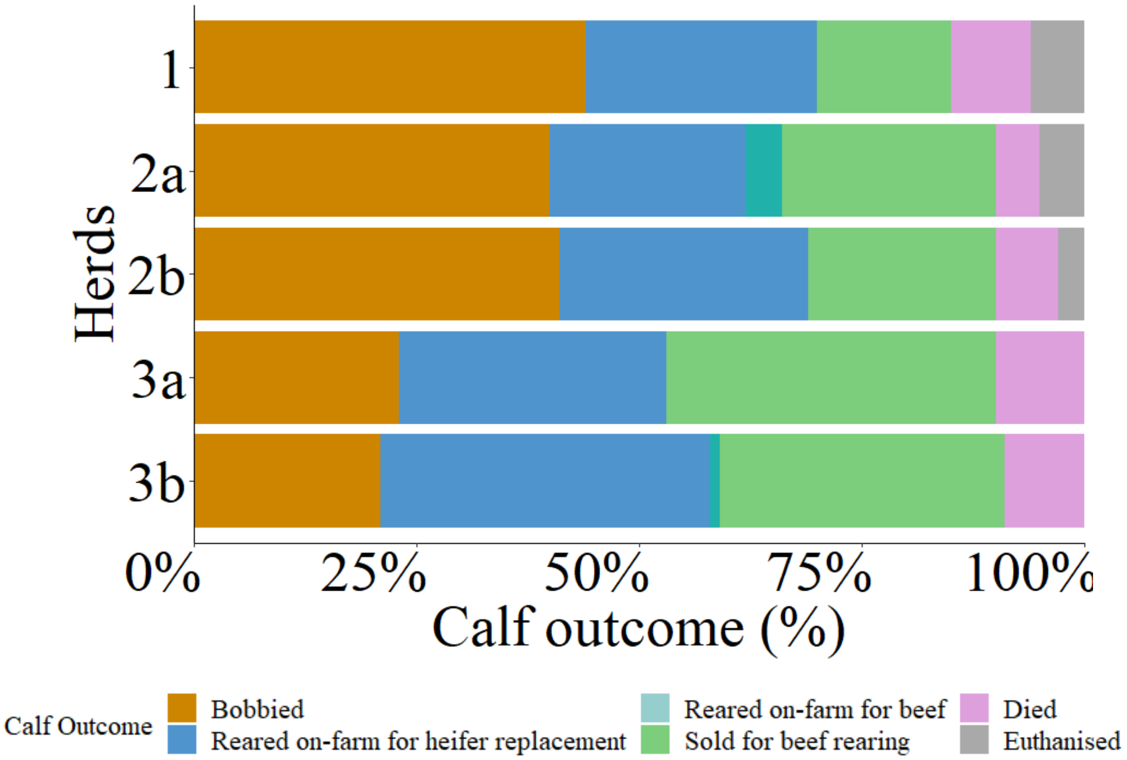


Figure 7. The percentage of calves born on each case-study herd that were bobbied, reared for heifer replacement, reared on-farm for beef, sold for beef rearing, died, or euthanised, for all calves born in 2021 from case studies 1, 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds).

4.1.2 Calf outcomes based on sire breed

Calves sired by different bull breeds had different calf outcomes. For each case-study herd, the calves sired by different breeds and semen type have been presented proportionately to total calf outcome for each breed and semen type in **Figure 8**. The percentage and total number of calf outcomes across the case-study herds have been presented in **Table 8.**

Within the case-study herds, calves sired by Jersey bull had the greatest within breed and semen type percentage of bobbies, 87-97%. Calves sired by conventional FxJ semen had the second greatest within breed and semen-type bobby rate (49%). Bobby calves sired by conventional Friesian semen ranged between 2-50%. Calves sired by conventional beef-breed semen produced the lowest within breed and semen-type bobby rate; Hereford 0-33%, Galloway 0-8%, Speckle Park 0%, and Wagyu 0%.

All calves reared for heifer replacement were sired by conventional and sexed FxJ- or Friesian semen. Within the case-study herds, the calves generated by conventional FxJ- and Friesian semen resulted in 43-65% calves reared for heifer replacements, excluding calves sired by sexed semen. Calves sired by Friesian sexed semen resulted in 96% of the calves being reared for heifer replacement, and the one male calf (4%) sold for beef rearing. Calves sired by conventional beef-breed semen, or the Jersey bull produced 0% calves reared for heifer replacement.

Within the case-study herds, the percentage of calves sold for beef rearing varied among the dairy and beef breeds. Within breed and semen type, between 18-42% of calves were sold for beef rearing for Friesian-sired calves by conventional semen. Some calves sired by SGL FxJ bulls were sold for beef rearing (2 calves). In contrast, calves sired by conventional beef-breed semen produced the largest within breed percentage of calves sold for beef rearing (67-100%). Calves reared on farm for beef were Galloway-sired (4 calves) and Hereford-sired (9 calves), and one Friesian bull for charity.

For each case-study herd, calf mortality rates varied within sire breed and semen types. Calves sired by dairy bulls had a mortality rate of 3-22%, while calves sired by beef breeds had a mortality rate of 5-33%. Calves sired by SGL FxJ-bred semen had the greatest within breed and semen type euthanasia rate (67-73%). Jersey was the only other sire breed to produce calves resulting in euthanasia (5-6% within breed and semen type).

Table 8. The different outcomes of calves sired by different beef and dairy breeds by different semen types (conventional semen, sexed semen, and the bull) across five case-study herds using different mating programmes implemented in 2020.

	Case Study	1a					2a						2b				3a				3b				
	Calf Outcome	B	HR	SBR	D	E	B	HR	Reared for Beef	SBR	D	E	B	HR	SBR	D	B	HR	SBR	D	B	HR	Reared for Beef	SBR	D
Sire breed	(SS) F																					27 (96)		1 (4)	
	Friesian						50 (32)	70 (45)		29 (19)	7 (4)		38 (23)	86 (52)	29 (18)	12 (7)	5 (4)	52 (43)	51 (42)	13 (11)	2 (5)	26 (65)	1 (3)	8 (20)	3 (8)
	F X J	36 (49)	32 (43)		6 (8)																				
	Jersey Bull	16 (89)			1 (6)	1 (6)	73 (87)			1 (1)	6 (7)	4 (5)	71 (87)			11 (13)	35 (97)			1 (3)	26 (90)				3 (10)
	(SGL) F x J	1 (11)			2 (22)	6 (67)	1 (7)			2 (13)	1 (7)	11 (73)	8 (80)			2 (20%)									
	Speckle Park			6 (67)	3 (33)																				
	Galloway	1 (8)		12 (92)					4 (100)																
	Hereford						6 (10)		9 (15)	43 (69)	3 (5)	1 (2)	3 (6)		42 (81)	7 (13)			13 (87)	2 (13)	2 (33)			4 (67)	
	Wagyu																							33 (100)	

Values presented are the count of calves and the percentage by breed and outcome in brackets.
Breed: F = Friesian, FxJ = Friesian cross Jersey
Outcome: B = Bobbied, HR = Heifer replacement reared, SBR = Sold for beef rearing, D = Died, E = Euthanised
Semen: SGL = Short gestation length, SS = Sexed semen

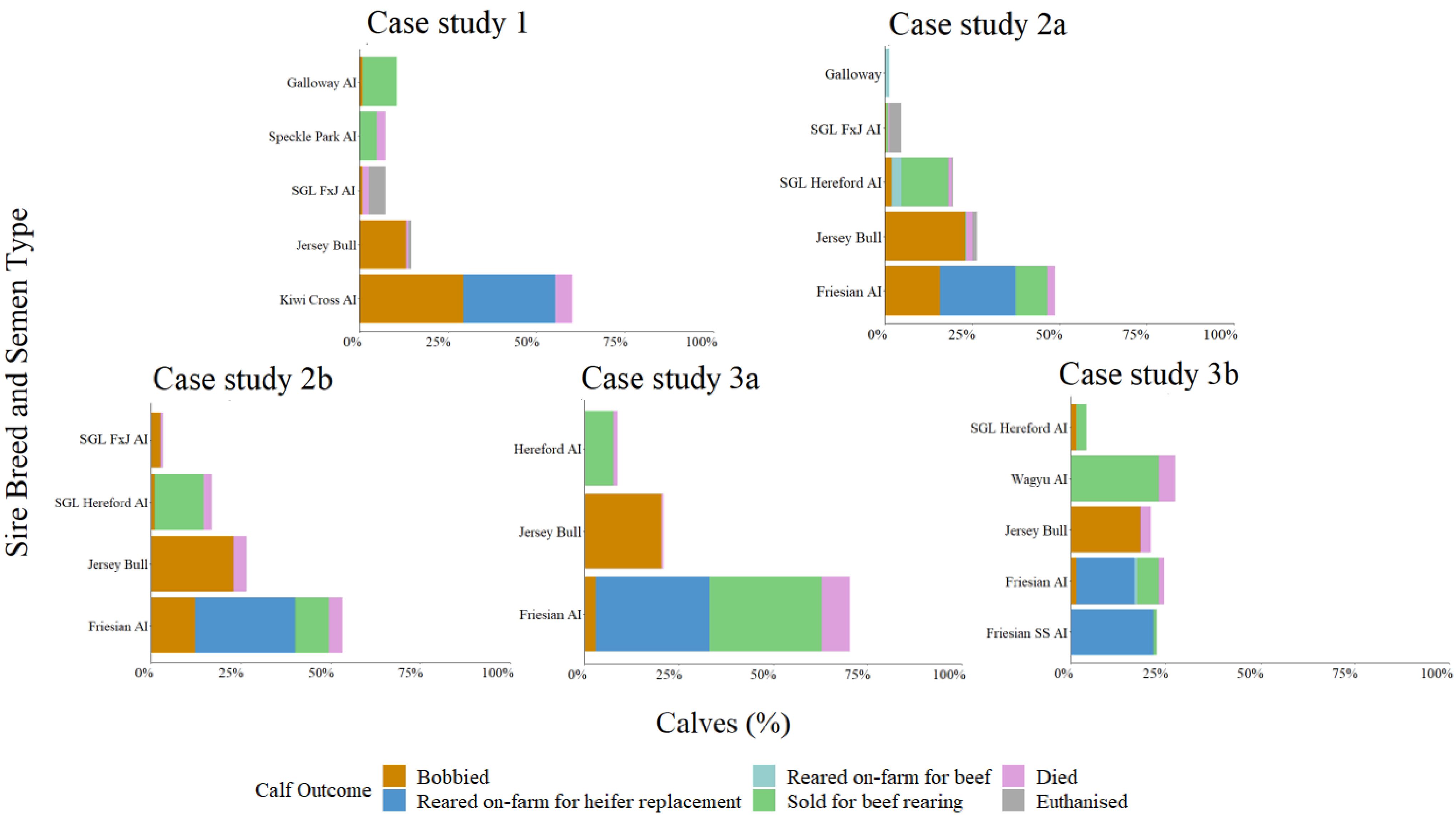


Figure 8. The calf outcomes from calves sired by different breeds and insemination types, collected during the 2021 calving from case studies 1 and 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds). Calf outcomes were bobbied, reared for heifer replacement, reared for beef, sold for beef rearing, died, or euthanised. For each case study, the calves sired by different breeds have been presented proportionately to the total number of calves outcomes for each breed and semen type. AI = artificial insemination, SS = sexed semen, SGL = short gestation length, FxJ = Friesian cross Jersey.

4.1.3 *Calf breed and outcome determined the average days in the calf shed*

On discussion with the managers, heifer replacement calves remained in the shed until a suitable number of calves could form a cohort for outdoor rearing and based on fitting around a portable calf-feeder. The beef x dairy calves reared on-farm were reared in conjunction with heifer replacement calves (**Figure 9**). Across the case-study herds, heifer replacements remained in the shed for the longest period; 22-45 days in spring and 16-18 days in autumn. On average, spring-born heifer replacements sired by FxJ sexed semen remained in the shed for 29 days.

Across the case-study herds, the average range for Jersey-sired calves remained in the shed for longer in autumn (6-9 days) than spring (3-6 days), similar to SGL FxJ-sired calves (3-12 days in autumn and 4-6 days in spring). The autumn-calving herds had a less frequent bobby calf collection (every few days to weekly) than the spring-calving herds (almost daily for most of calving), which explained the longer duration in the calf shed. For case study 1, bobby calf collection ceased after 60 days from the ASC and 75 days for case study 2a. The end to bobby calf collection corresponded with the increased euthanasia of calves sired by SGL FxJ.

During autumn, there was a range of average days in the shed across the case-study herds; Hereford-sired calves were reared in the calf shed for 7-11 days for heifers and bulls, respectively. In addition, autumn-born Galloway-sired calves were reared in the shed for 8 days and 10-12 days for heifers and bulls, respectively, while Speckle Park-sired heifer calves were in the shed for 6 days. During spring, calves sired from Hereford were reared in the calf shed for less time; heifers (3-6 days) and bulls (6 days). Calves sired by Wagyu had the most extended duration in the calf shed; heifers (30 days) and bulls (25 days). The FxJ-sired bull remained in the calf shed for 8-9 days in autumn and 5-8 days in spring. Therefore, the average range for calves sired by beef-breed semen were reared in the calf shed for 6-12 days during autumn and 5-8 days during spring, depending on breed.

Discussion with the managers revealed that collection agreement for calves sold for beef rearing was dependent on individual beef rearer. Each beef rearer had a different beef trait criterion when purchasing calves, relating to sex, frame size, and coat colouring. The case-study herds had 2-4 beef calf rearers purchasing calves sold for beef rearing. The collection agreements varied depending on cohort size and availability of the beef rearers.

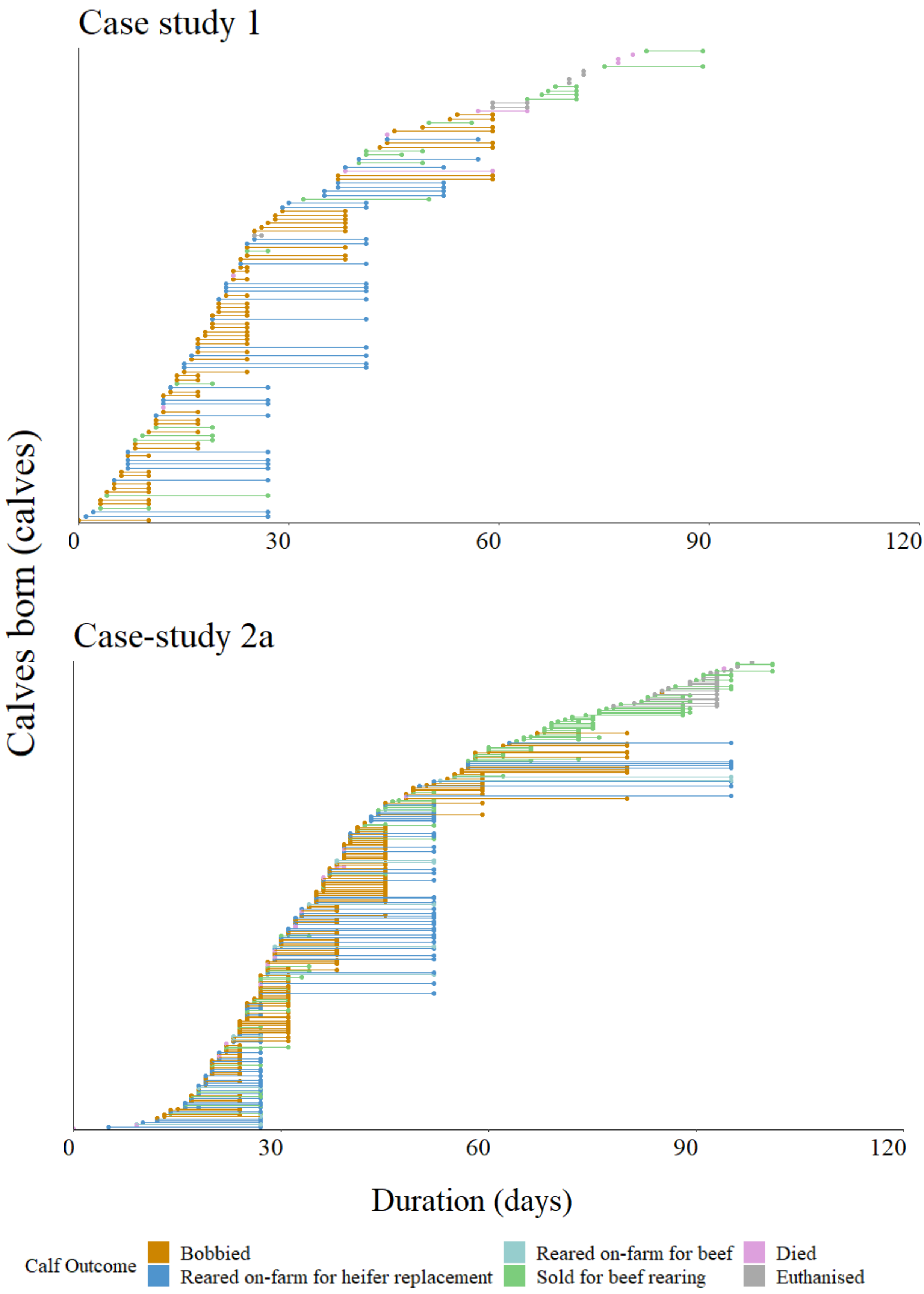
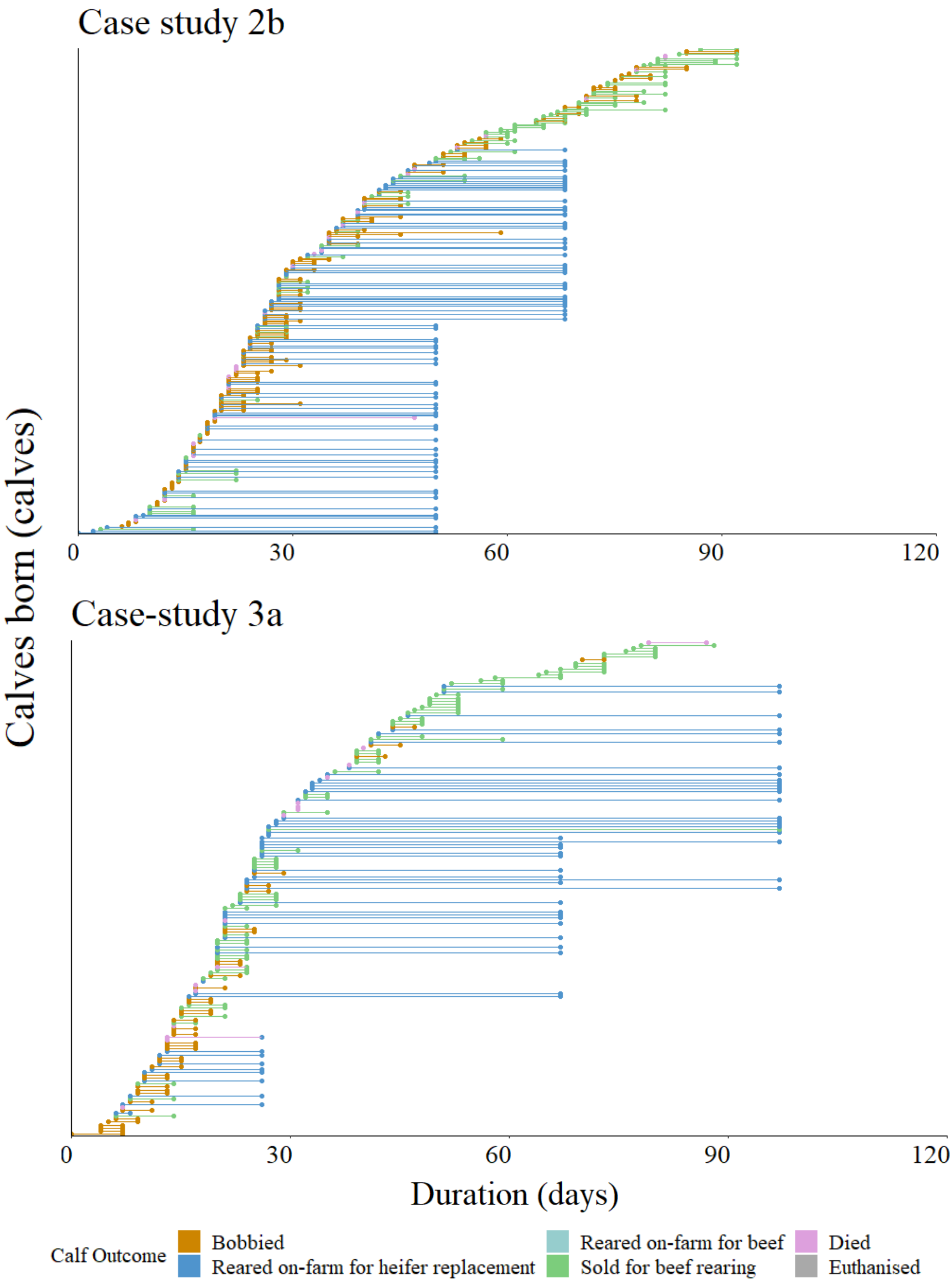
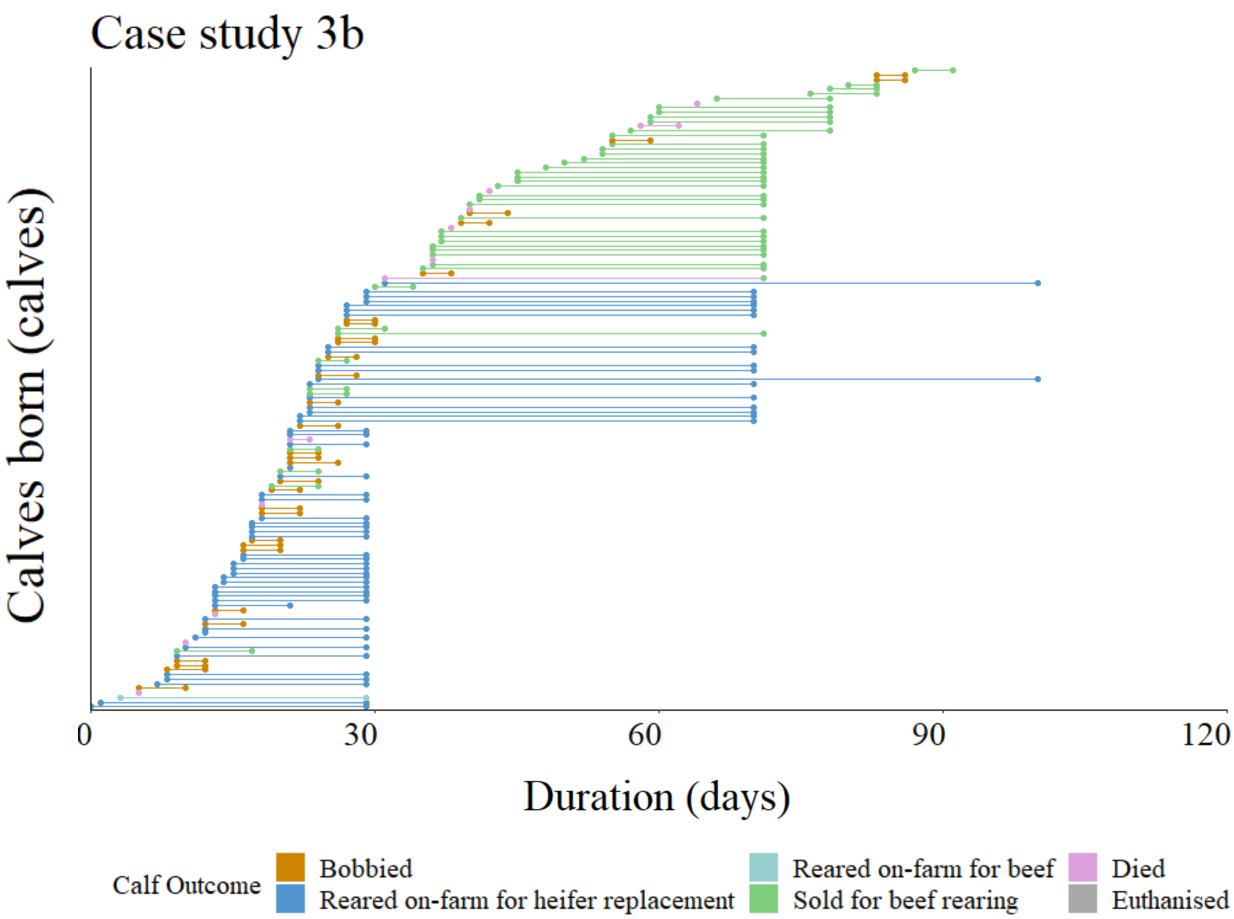


Figure 9. The day each calf was born from the actual start of calving (ASC) till the final calf had exit the calf shed, the outcome of each calf, and the duration the calf was reared in the calf shed during the 2021 calving from case studies 1 and 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds).



Continuted Figure 9. The day each calf was born from the actual start of calving (ASC) till the final calf had exit the calf shed, the outcome of each calf, and the duration the calf was reared in the calf shed during the 2021 calving from case studies 1 and 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds).



Continued Figure 9. The day each calf was born from the actual start of calving (ASC) till the final calf had exit the calf shed, the outcome of each calf, and the duration the calf was reared in the calf shed during the 2021 calving from case studies 1 and 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds).

4.1.4 Calf outcome and days in the calf shed affects calf shed capacity

The available shed capacity varied in each case-study herd, with calves leaving in cohorts dependent on management decisions, collection availability, weather, and portable calf feeder size. The shed measurements for each case-study herd are presented in **Table 9**. The total calves reared in the calf shed and the calf outcomes over the calving period are presented in **Figure 10**.

For case study 1, the calf shed could accommodate 96 calves. At peak calf rearing 44 calves resided in the calf shed, occupying 64% of capacity. For case studies 2a and 2b, the calf rearing sheds were designed to hold and facilitate a spring calving herd and afforded space to rear 261 calves. The peak calves reared in the calf shed were 85 and 89 for the autumn-calving and spring-calving herds, respectively. As a result, the calf shed never reached capacity as calves occupied 33% and 35% of capacity in autumn and spring, respectively.

Table 9. Calf shed measurements and calf holding capacity (area/1.5 m^2) across the five case-study herds, based on current New Zealand animal welfare regulations and recommendations (2019).

Case studies	1	2a/2b	3a[1]			3b[1]		
Shed	All calves	All calves	HR and Beef rearing[2]	Beef Overflow	Bobby	HR and Beef rearing[2]	Beef Overflow	Bobby
Length (m)	18	40	18	18	9	18	18	9
Width (m)	6	10	8	4	4	8	4	4
Area (m^2)	104	392	146	77	38	146	77	38
Total Calf Capacity (area / 1.5)	69	261	54	28	14	44	23	11

[1] Case studies 3a (168 cows) and 3b (139 cows) had different mating programmes; however, shared the same calf shed, for this reason, shed capacity was proportionately distributed between the two herds. Case studies 3a and 3b had three separate calf sheds for rearing, one for heifer replacements and calves sired by beef breeds, one overflow shed for beef-sired calves, and one shed for bobby calves.
[2] HR = calves reared for heifer replacement, Beef = calves reared and sold for beef rearing.

For case study 3a, the total available shed capacity across the three sheds was 95 calves, remembering that shed capacity was proportionality distributed across 3a and 3b and were treated as individual sheds to both herds. During the peak of calving, 51 calves were in the calf shed, occupying 54% of capacity. However, these calves were managed and separated depending on the calf outcome. Calves reared for heifer replacements and sold for beef rearing were in the calf shed capable of rearing 54 calves; at peak calving, the shed held 40 calves, occupying 81% of capacity. The bobby calf shed had capacity for 14 calves and at peak calving housed 11 calves, occupying 79% of capacity. On speaking with the farm manager, the beef overflow shed was set up later in the season and could house up to 28 calves, this was utilised when the heifer replacement shed was nearing capacity.

For case study 3b, the available shed capacity across the three sheds was 78 calves; during peak calving 58 calves were reared in the shed, occupying 74% of capacity. However, these calves were managed and separated depending on the calf outcome. Calves reared for heifer replacements and beef rearing were in the calf shed capable of rearing 44 calves; at peak calving, the shed held 49 heifer replacement calves, in addition 3 calves for beef rearing, totalling 53 calves. Thus, occupying 120% of capacity. Upon discussion with the calf rearer, the heifer replacement and beef rearing shed reached capacity at 29 days and resulted in a cohort of replacement heifer calves exiting the shed to be reared outside.

Furthermore, for case study 3b, the beef overflow shed was constructed later in the season and provided additional space for rearing 23 beef x dairy calves, affording a capacity total of 67 calves across the two sheds. On day 70, shed capacity across the two sheds was a total of 51 calves,18 heifer replacements and 33 calves for beef rearing, occupying 76% of capacity. The bobby calf shed had capacity for 11 calves and at peak calving housed 8 calves, occupying 73% of capacity. Using sexed semen resulted in a greater number of heifer replacements born at the beginning of the calving season. Wagyu-sired calves increased the number of calves reared after 25 days from ASC as the Wagyu rearing contractual agreements required rearing calves for longer (10-30 days).

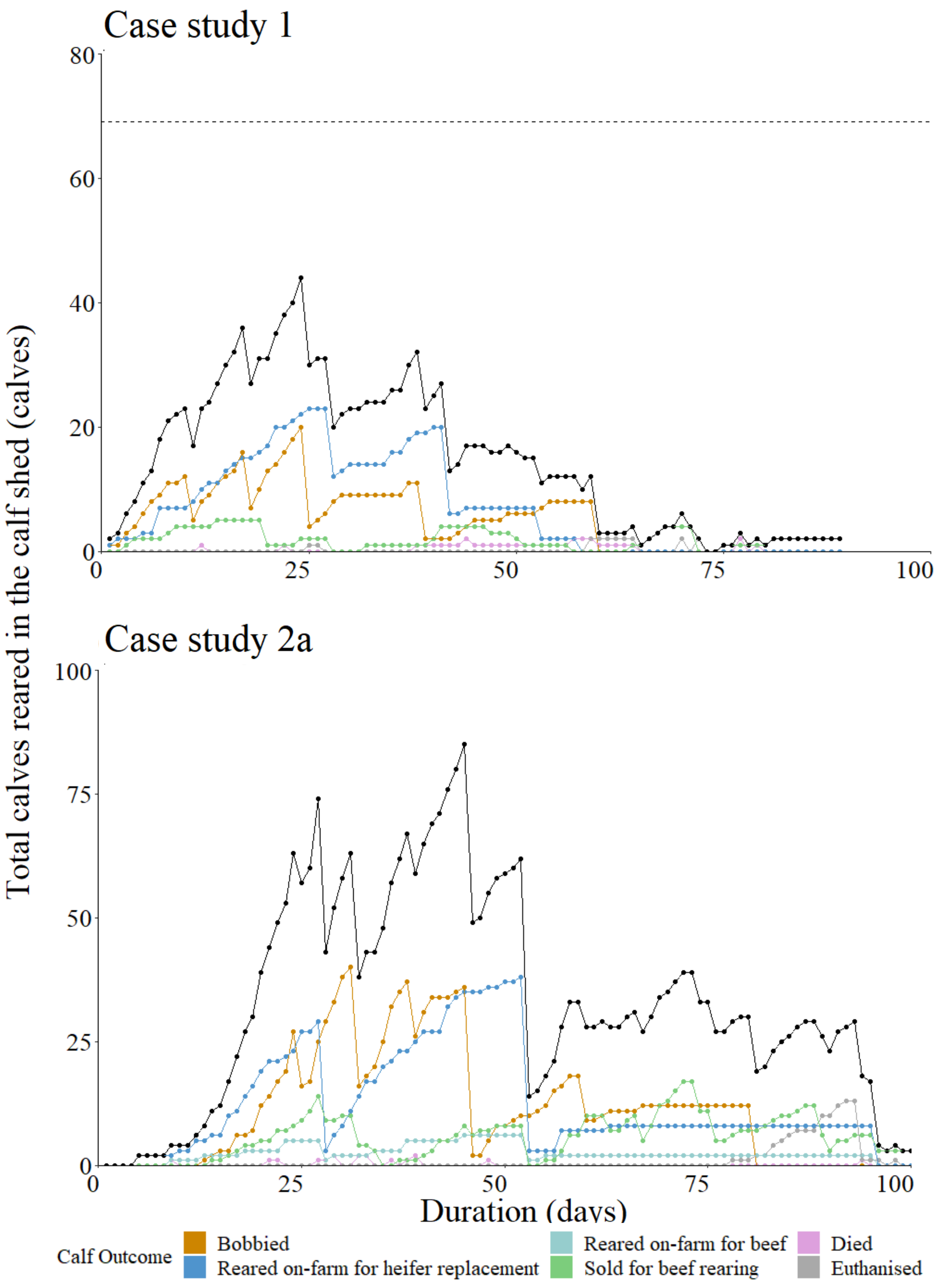
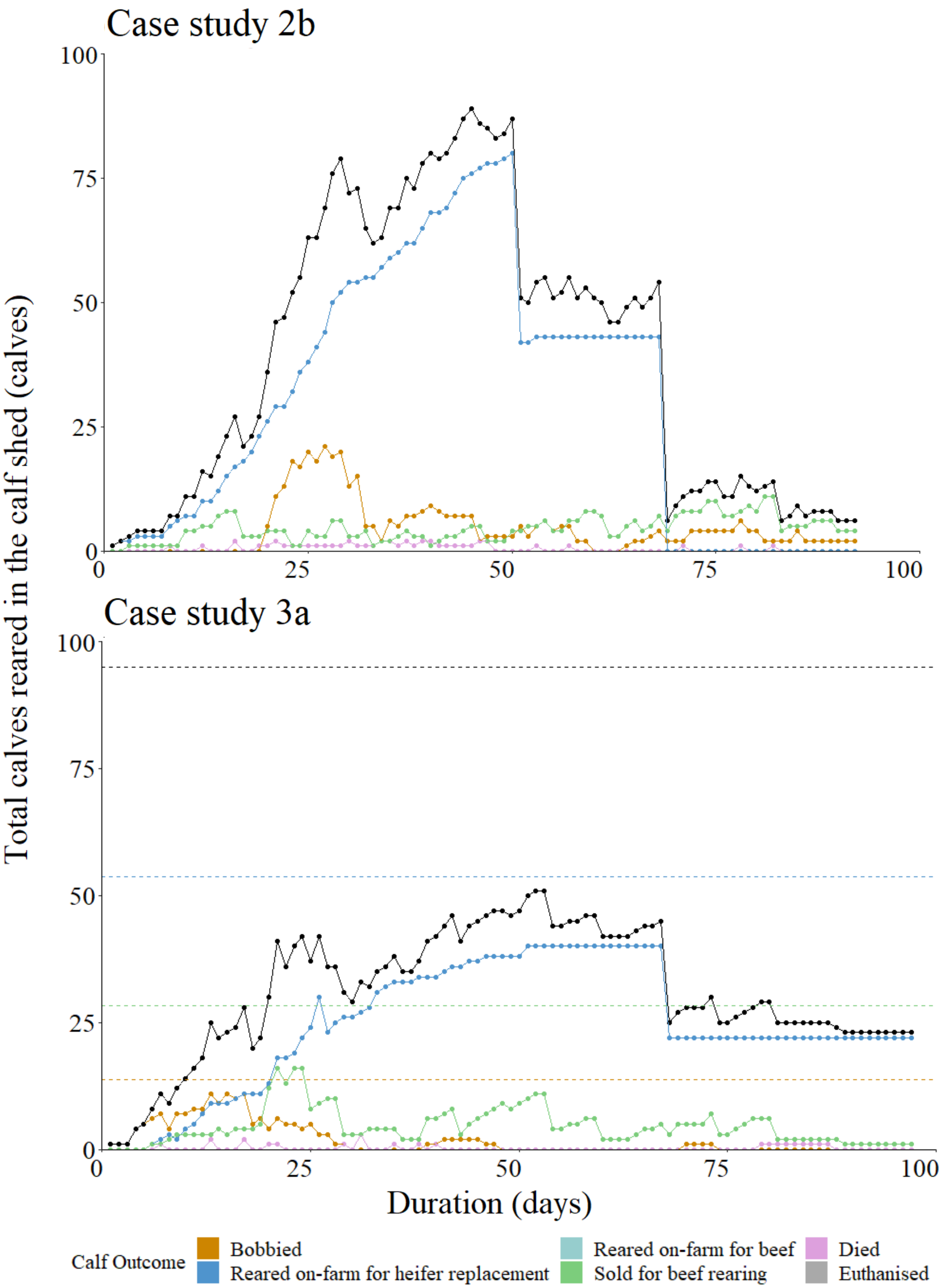
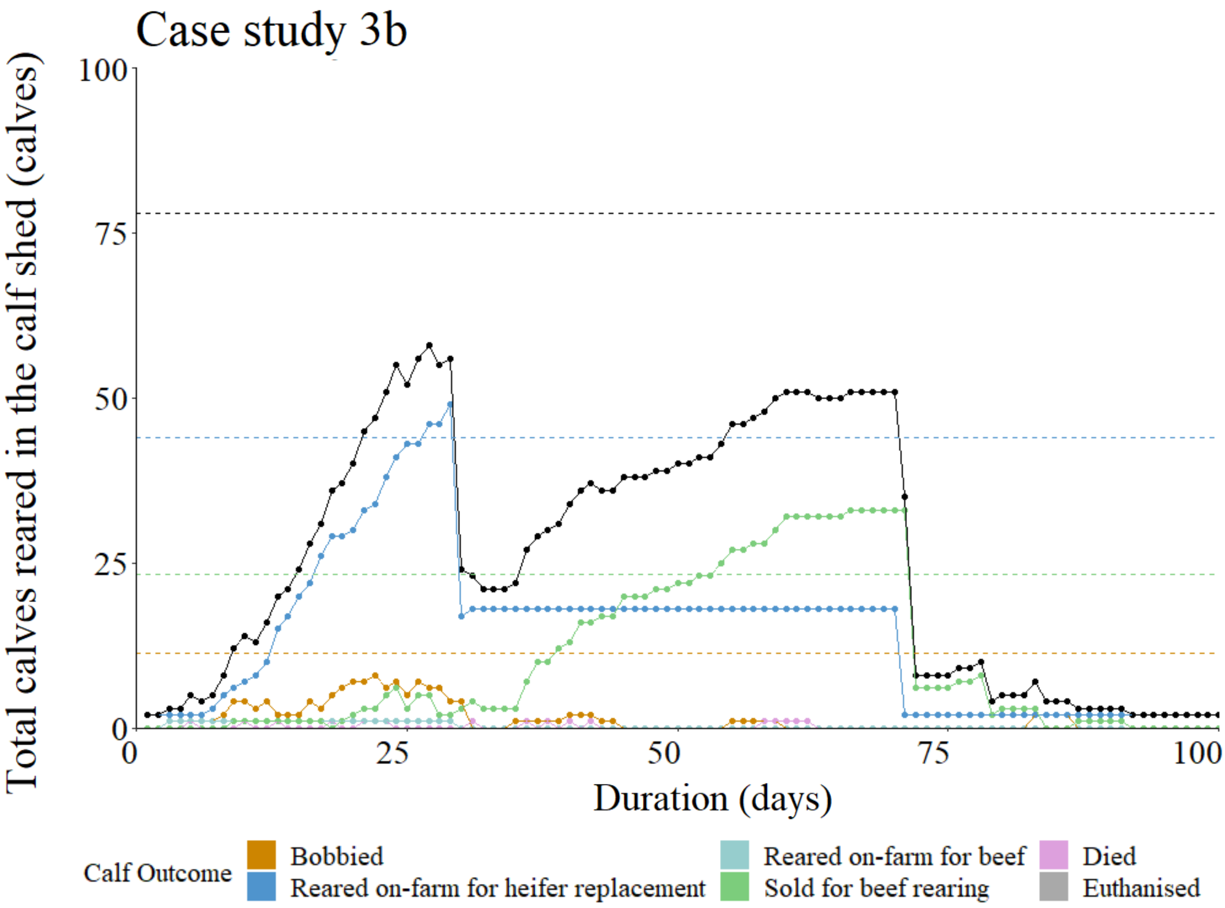


Figure 10. The shed capacity and the total number of calves reared in the calf shed from the actual start of calving (ASC) to final calf-exited the calf rearing shed during the 2021 calving across two autumn-calving case-study herds (1 and 2a) and three spring-calving case-study herds (2b, 3a, and 3b). Horizontal line indicates shed capacity, black line is total shed capacity, and the coloured lines (by outcome) are broken down are for three multiple sheds used for case studies 3a and 3b.



Continue Figure 10. The shed capacity and the total number of calves reared in the calf shed from the actual start of calving (ASC) to final calf-exited the calf rearing shed during the 2021 calving from case studies 1 and 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds). Horizontal line indicates shed capacity, black line is total shed capacity, and the coloured lines (by outcome) are broken down are for three multiple sheds used for case studies 3a and 3b.



Continue Figure 10. The shed capacity and the total number of calves reared in the calf shed from the actual start of calving (ASC) to final calf-exited the calf rearing shed during the 2021 calving from case studies 1 and 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds). Horizontal line indicates shed capacity, black line is total shed capacity, and the coloured lines (by outcome) are broken down are for three multiple sheds used for case studies 3a and 3b.

4.1.5 Reproduction performance influenced calving pattern

The reproduction performance and, as a result, calving patterns were different across the case-study herds. The fertility results (2020) and calving pattern (2021) are presented in **Table 10**. The six-week in-calf rates ranged between 63% and 78%. The six-week in-calf rates for the 15-month-old heifers were between 90% and 94%. Mixed-aged cows and heifers combined had a six-week calving pattern between 81% and 91%. The greater six-week in-calf rates resulted in greater calving rates.

4.1.6 Calf liveweights and feed demand

The birth weights (live and dead), exit liveweights, and ADG have been presented in **Appendix 3, 4, 5, 6, and 7**. Jersey-sired calves weighed the lightest at birth, the average range across the case-study herds was 23-32kg and 24-34kg for females and males, respectively. Jersey-sired calf exit liveweight average ranged across the case studies from 29-40kg and 30-39kg for females and males, respectively.

Table 10. Submission rates and reproduction results from 2020 mating programmes and calving patterns in 2021 for case studies 1, 2a (autumn-calving herds) and 2b, 3a, and 3b (spring-calving herds).

Variable	Case studies			
	1	2a	2b	3a & 3b
Start of AI mating (date)	10/06/2020	6/02/2020	1/10/2020	10/10/2020
Duration of AI mating (days)	83	NA	84	74
Submission rate 3 week (%)	82	86	91	85
Conception rate (%)	37	41	43	50
AI cows pregnant 3 weeks (%)	35	43	40	49
AI cows pregnant 3-6 weeks (%)	57	57	60	73
AI cows pregnant 6-9 weeks (%)	63	66	71	78
AI cows pregnant 9+ weeks (%)	NA	75	80	NA
First calvers pregnant 3 weeks (%)	83	77	75	80
First calvers pregnant 6 weeks (%)	93	94	94	90
Planned start of calving (date)	19/03/2021	14/03/2021	10/07/2021	19/07/2021
Actual Start of calving	13/03/2021	25/02/2021	27/06/2021	6/07/2021
Actual duration of calving (days)	81	93	87	87
All cows actual calving pattern < PSC (%)	10	16	9	11
All cows actual calving pattern 3 weeks (%)	63	64	57	66
All cows actual calving pattern 6 weeks (%)	84	81	81	91
All cows actual calving pattern 9 weeks (%)	92	92	94	96

Results derived from each case-study herd LIC Minda 2021 Fertility Focus Report (MINDA^{TM}, LIC, Hamilton, New Zealand)
Actual calving date does not include premature calves (calves born where gestation length was <250 days and the calf was recorded as dead).

Friesian-sired calves weighed lighter than calves sired by beef breeds, with the average birthweight across the case studies 2a, 2b, 3a, and 3b, ranging between 35-37kg and 37-41kg, for females and males, respectively. Friesian-sired calf exit liveweight averages ranged across the case studies 2a, 2b, 3a, and 3b, from 37-60 kg and 37-45kg for females and males, respectively. However, average birthweights were lighter for FxJ-sired calves at 29kg for both females and males on case study 1, while exit liveweights were 42 kg and 37kg for males and females, respectively. In addition, SGL Friesian-sired calves weighed lighter at birth with the averages across the case-study herds ranging between 31-34kg for females and 29-37kg for males, while case study 1 calves were lighter weighing 25kg and 26kg at birth for females and males, respectively.

Beef-sired calves weighed heaviest for both birthweights and exit liveweights. For case studies 2a, 2b, 3a, and 3b, the average birthweights ranged between 36-40kg and 36-43kg for female and males, respectively. For case studies 2a, 2b, 3a, and 3b, the average exit liveweights ranged between 37-49kg and 45-50kg for female and males, respectively. For case study 1, for beef-sired calves, the average birthweights ranged between 29-32kg and 32-36kg, while the average exit liveweights were 35-38kg and 44kg, for females and males, respectively. For all case-study herds, the average milk consumption is presented in **Appendix 3, 4, 5, 6, and 7** formulated using liveweights and days in the calf shed**.**

4.1.7 *Calf value overview*

A range of sale prices for bobbies and beef x dairy calves were attained across the case-study herds. On average, bobby calves ranged between $15.23 to $34.89 per head, with the spring calves of greater value than the autumn calves. Beef x dairy calves ranged from $53.33 to $141.43 for bulls and $38.89 to $59.00 for heifers, reflecting that male calves are greater in value than females. Friesian bull calves were of greater value in autumn than winter $99.03 (case study 2a) compared to $91.25 (case study 2b). The calves sired by Wagyu, both bull and heifer, were sold for on average $157.79, reflecting their greater age and specialised supply contract. The different average prices for calf sales have been presented in **Table 9.**

Table 11. The average price per head, quantity, and total income (NZ$) for case studies 1 and 2a (autumn-calving herds) and 2b, 3a, and 3b (spring-calving herds) from sales of beef x dairy calves for heifers and bulls sold under 50 days of age to all beef rearers and for all calves sold to Silver Fern Farms (SFF) under 30 days of age, collected in 2021. Including averages for price per kilogram and per head, dressing out percentage (%), liveweights, and calves condemned (deaths).

		Case studies							
		1		2a		2b		3a & 3b	
	Variable	H	B	H	B	H	B	H	B
Sold for beef rearing	Friesian Av. price/kg				$99		$91		$81
	Galloway Av. price/kg	$39	$53						
	Speckle Park Av. price/kg	$50	$100						
	Hereford Av. price/kg			$51	$96	$56	$111	$59	$141
	Wagyu Av. price/kg							$158	
	Qty	17		73		65		111	
	Av. price/head	$48		$84		$88		$106	
	Total	$810		$6,155		$5,750		$11,717	
Bobbied	Qty of bobby calves	54		121		120		70	
	Bobby calves condemned (excluded from below)	2		3		0		0	
	Bobby average kg/head	$17		$19		$16		$17	
	Bobby Av. live exit weight (kg)	$35		$40		$34		$36	
	Bobby Av. dressing out (%)	48		48		46		48	
	Av. price/kg	$0.9		$1.0		$1.9		$2.0	
	Av. price/head	$15		$19		$31		$35	
	Total meat (kg)	875		2289		1905		1209	
	Total price paid ($)	$792		$2,265		$3,669		$2,443	

Abbreviations: Av = Average, Qty = Quantity, H = Heifers, B = bulls

4.2 Scenario Analyses

4.2.1 Calf outcome overview

There were a range of outcomes for calves born to the three scenario mating programmes simulated on an average 444-cow herd. The model inputs for mating programmes and calf outcome have been presented in **Appendix 8** and **Appendix 9**. Scenario 1 resulted in 40% of calves bobbied, 29% reared on farm for heifer replacement, 21% sold for beef rearing, and 10% calf mortalities. In contrast, Scenario 2 reduced bobby calves to 25%, with an additional 25% reared on farm for heifer replacement, 40% sold for beef rearing and 10% calf mortalities. Scenario 3 had the most significant reduction of bobby calves, to 7%, which were all 'undesired' calves for beef rearing. For Scenario 3, calves reared on farm for heifer replacement remained the same as in Scenario 2 at 25%, with an additional 57% sold for beef rearing, and 11% calf mortalities.

Overall, Scenario 3 produced the lowest number of bobby calves and the highest percentage of calves sold for beef rearing. The outcomes of calves born in each of the different scenario mating programmes have been presented in **Figure 11**. The total calves reared in the calf shed and the calf outcomes over the calving period have been presented in **Figure 12**.

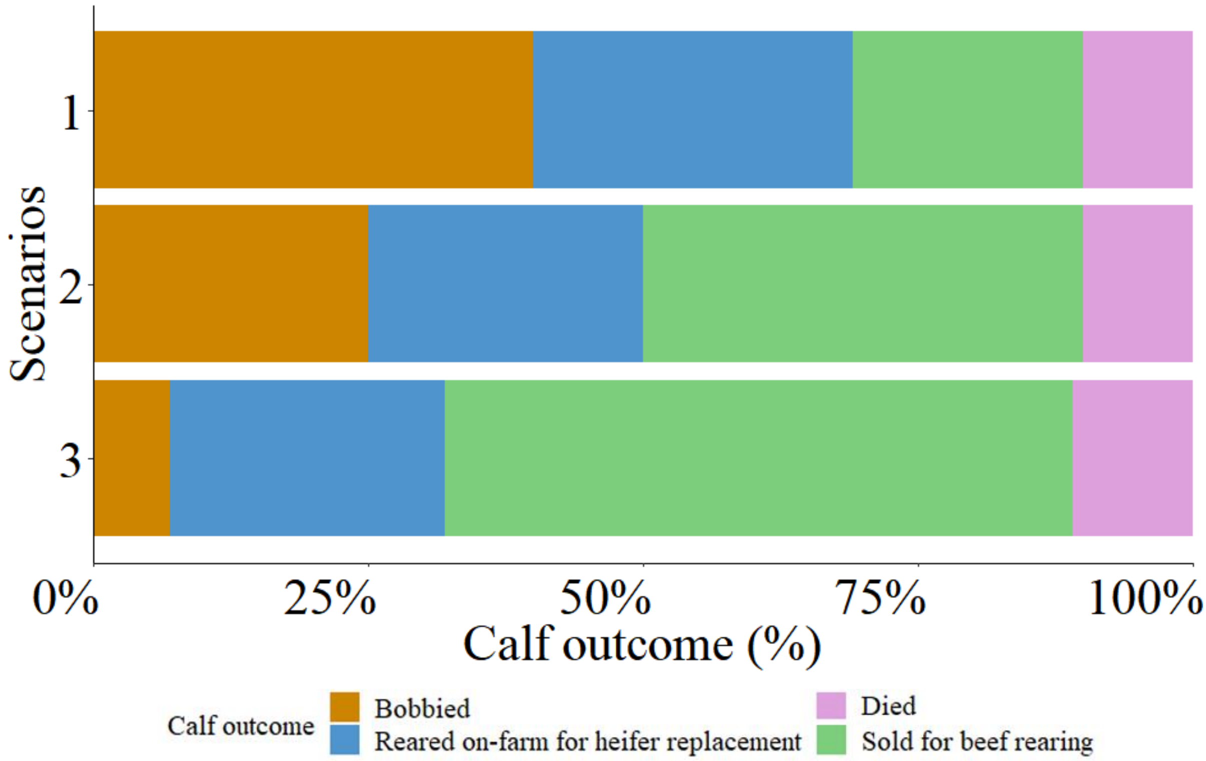


Figure 11. The total percentage of calf outcomes for all calves born in an average 444-cow New Zealand herd. The scenario analyses used data from the case-study herds and existing literature to develop the base assumptions and were simulated on a 444-cow spring-calving herd and implemented mating programmes aiming to reduce bobby calves and impact on the calf-rearing resources, scenario analyses 1 (40% bobby calves), 2 (25% bobby calves), and 3 (7% bobby calves).

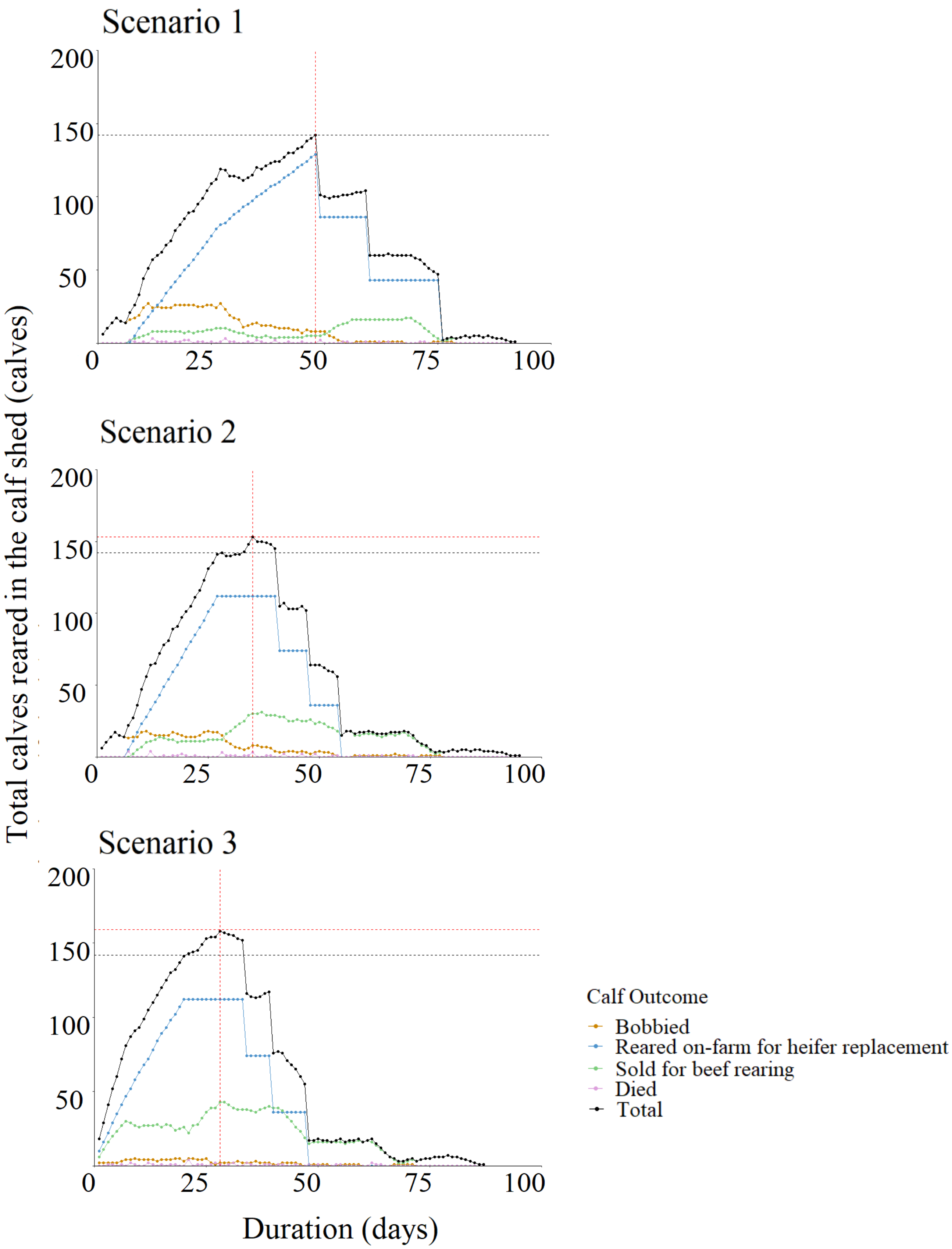


Figure 12. Total calves reared in shed for Scenario 1 (40% bobby calves), Scenario 2 (25% bobby calves), Scenario 3 (7% bobby calves). The scenario analyses used data from the case-study herds and existing literature to develop the base assumptions and were simulated on a 444-cow spring-calving herd and implemented mating programmes aiming to reduce bobby calves and impact on the calf-rearing resources. Horizontal lines indicate baseline shed capacity and increased capacity across scenarios. Vertical lines indicate the duration that shed capacity has been reached when compared to Scenario 1. The red vertical line indicates peak capacity.

Breakdown of calf outcomes

Calf outcome for conventional FxJ daughter-proven semen

Calves sired by conventional daughter-proven semen were predominantly reared for heifer replacement (94%). Daughter-proven semen had a female to male ratio of 50:50. The remaining female calves not reared for heifer replacement were bobbied (2%), deaths (3.5%), and sold for beef rearing (0.6%). Male calves sired by FxJ daughter-proven semen were sold for beef rearing (14%), bobbied (58%), and deaths (14%).

Calf outcome for bull calves for calves sired by FxJ semen

The spring case studies 2b, 3a, and 3b, were predominantly Friesian herds in which calves were sired by FxJ semen. The calves born to FxJ dams and sired by FxJ bulls would produce greater unfavourable beef traits due to a larger dairy genetic influence. Therefore, for Scenario 1, the outcomes for bull calves sired by FxJ daughter-proven semen that were sold to beef rearing and calves bobbied were reversed to reflect what would occur in real life. In Scenario 1, 58% of bull calves sired by FxJ daughter-proven semen were bobbied and 28% were sold for beef rearing. In the case studies 2b, 3a and 3b, 58% of bull calves sired by FxJ semen were sold for beef rearing and 14% were bobbied.

Calf outcome for calves sired by FxJ sexed semen

For Scenarios 2 and 3, calves born to FxJ dams and sired by FxJ sexed semen were predominantly reared for heifer replacement (89%) and the male calves were bobbied (9%), there was 2% deaths across both males and female calves.

Calf outcome for calves sired by Jersey semen

Calves born to FxJ 15-month-old heifers and sired by Jersey bulls were mostly bobbied (90%) and the remaining were deaths (10%).

Determining calf outcome for calves sired by beef-breed semen

Calves born to FxJ dams and sired by beef-breed semen were mostly sold for beef rearing (80%), and there were some bobbied (7%), and deaths (13%). The 7% of calves bobbied were due to undesirable beef characteristics.

4.2.2 Calves reared for heifer replacement cohorts

For all scenarios, 49 calves were reared per cohort for heifer replacement, which ensured that each calf could feed on the 50-teat feeder. For Scenario 1, all calves reared for heifer replacement sired by conventional semen were born in the first 42 days. The first cohort of heifer replacements went outside on day 42 (30–41-day-old calves), and the last cohort went outside on day 69 (27-45-day-old calves). In Scenarios 2 and 3, all calves reared for heifer replacement sired by sexed semen were born by day 21, and the first cohort went outside on day 34 (27–33-day-old calves), with the last cohort going outside on day 48 (27–33-day-old calves – the same as the first cohort as this was calculated by the number of calves fitting around the calf feeder and the same average and range of days in the calf shed). The total number of calves reared at peak occurred 21 days earlier when comparing Scenario 3 to Scenario 1, the earlier peak concomitant with the last cohort of calves reared for heifer replacement exiting the shed. Thus, heifer replacement cohorts were established three weeks earlier compared to Scenario 1. For Scenarios 2 and 3, the mating programmes condensed the birth dates for calves reared for heifer replacements.

4.2.3 Calf shed capacity

Scenario 1 set the baseline of shed capacity for Scenarios 2 and 3, with 142 calves residing in the calf shed at peak calving. Scenario 2 increased required shed capacity from 142 calves to 153 calves, a total of 11 calves (8% increase). Scenario 3 further increased required shed capacity to 159 calves at peak calving, an increase of 17 calves or 12%. Peak shed capacity occurred on day 48, 35, and 28 for Scenario 1, 2, and 3, respectively.

4.2.4 Duration of exceeding shed capacity

The duration of peak shed capacity increased from Scenario 1 by between 7 and 12 days, for Scenarios 2 and 3, respectively. Scenario 2 exceeded shed capacity during day 33 to day 40, and Scenario 3 exceeded shed capacity during day 21 to day 33. The duration of peak shed capacity increased by five days (71%) from Scenario 2 to Scenario 3. Across all scenarios, Scenario 3 placed the greatest pressure on the shed capacity for a longer duration earlier in the calving season.

4.2.5 Feed requirements

The total milk requirements for calves have been presented in **Table 12**. Scenario 1 required 26,091L to rear all calves for the duration that calves resided in the calf shed. For Scenarios 2 and 3 total milk demand decreased when compared to Scenario 1, with 20,572L and 21,403L of milk required for Scenarios 2 and 3, respectively. The heifer calves left the shed earlier in Scenarios 2 and 3, however remained on farm, this is because calves sired by sexed semen have a more condensed birth period and thus have a short duration in the calf shed (because they form cohorts faster) compared with daughter proven-sired calves. The heifer calves would still receive milk as they are reared on farm regardless of the day they exit the shed. So, to see a true change in the milk consumption between the scenarios, heifer calves need to be excluded, leaving calves sold for beef rearing and bobbies. For all scenarios, when calves reared for heifer replacements were excluded the total milk demand was less; however, within Scenarios 2 and 3 total milk demand increased when compared to Scenario 1, as greater number of beef calves and longer days in shed means ultimately a greater milk demand.

Removing the calves reared for heifer replacements allows for a fairer assessment, as these calves may still be reared on milk despite no longer residing in the calf shed. Once the calves reared for heifer replacement were removed, there was an increase in milk demand in Scenarios 2 and 3. The total milk consumption (10% of calf liveweight per day) increased from 4,884L to 6,111L and 6,977L in Scenarios 1, 2, and 3, respectively. This was an increase in milk demand of 43% when bobby calves reduced from 40% in Scenario 1 to 7% in Scenario 3. The difference in milk consumption between Scenario 1 and Scenario 3 was 2,093L of whole milk (43% increase). The increased cost of the greater demand for whole milk can be estimated. If converting to milksolids (8%) (Johnson, 2007; NZAGBIZ, 2022) and using a supply payout average from the past four years ($7.70) (LIC & DairyNZ, 2021) the cost of milk would be $3,011, $3,765, and $4,297 for Scenarios 1, 2, and 3, respectively. The difference equating to $1,286 greater cost from Scenario 1 to Scenario 3 for the additional whole milk required.

In comparison, if calves were fed calf milk replacer powder (26% protein, 20% fat, 43.5% lactose, 3.5% moisture, and 7% minerals; NZAGBIZ, 2022), costing $113.49 (including GST) per 20kg bag (Fonterra, 2022b) and assuming 150g powder/L mixed with water (NZAGBIZ, 2022), then each scenario used approximately 36, 46, and 52 bags, equating to $4,157, $5,179 and $5,876 total cost for Scenarios 1, 2 and 3, respectively. This equated to an additional $1,719 for calf milk replacer in Scenario 3 compared with Scenario 1.

Table 12. Total milk consumption for Scenarios 1 (SA1), 2 (SA2), and 3 (SA3), based on average liveweight and days in the calf shed.

	Scenarios		
Variable	**SA1**	**SA2**	**SA3**
All calves 10% LW/day	26,091	20,572	21,403
All calves 20% LW/day	52,183	41,145	42,807
All calves 4L/day	23,612	19,580	20,020
All calves ex. HR 10% LW/day	4,884	6,111	6,977
All calves ex. HR 20% LW/day	9,817	12,223	13,945
All calves ex. HR 4L/day	5,192	6,128	6,600

Abbreviations: HR = Calves reared for heifer replacement, L = Litres, LW = Liveweight

5 Discussion

5.1 Case-study herds

The objective of analysing the case study herds was to determine the calf-rearing resources (shed capacity, milk, and labour requirements) required for different mating programmes on five Dairy Trust Taranaki herds.

5.1.1 Case-study herds mating programmes and calf outcomes

The mating programmes were implemented in 2020 on the DTT farms across the five case-study herds. The case-study herds used a range of semen across Jersey and FxJ dams. The literature supports the use of sexed and beef-breed semen to reduce bobby calves (Haskell et al., 2020; Balzani et al., 2021). The reduction in bobby calves was evident in case studies 3a and 3b, achieving a 23% and 21% bobby calf rate, lower than documented national averages of 35% (Edwards et al., 2021). Although case study 3a did not utilise sexed semen, fewer cows were mated by daughter-proven semen for heifer replacement production. Using sexed and beef-breed semen increased the number of heifer replacements, and calves sold for beef rearing, while decreasing the number of bobby calves.

Furthermore, producing more beef-sired calves meant there was a greater number of calves suitable for beef rearing, and thus reduced bobby calves. The literature supports using the correct breed and sire selection to produce beef x dairy calves as a viable option for producing quality beef characteristics (Coleman et al., 2016; Martin et al., 2021b; Pritchard et al., 2021). The greater production of calves sold for beef rearing is evident in case studies 3a (30%) and 3b (37%). This is comparable data from Western Australia (Dairy Australia, 2019), where 42% of calves were sold for beef rearing. A greater number of calves were sold for beef rearing when born from Friesian cows compared with those born from Jersey cows. Calves from Friesian cows produced more suitable beef x dairy carcass characteristics for beef rearing when compared to calves from Jersey cows, which is consistent with Williamson et al. (2022). Thus, changing mating programmes to include more beef-breed semen can reduce bobby calves due to the number of beef x dairy calves sold for beef rearing.

However, some calves born to Friesian dams and sired by FxJ bulls (2 calves) were sold for beef rearing with the requirement that the calves were of larger size and correct coat markings. However, it is likely these calves were less than suitable for beef production due to the Jersey influence (refer to section 1.8). Although a small number of calves with Jersey parentage were sold, if there were an additional two million beef x dairy calves on the market nationally, rearers are likely to exercise greater selectivity, and calves such as these may not be sellable.

Finally, a further reduction in bobby calves requires greater mating programme changes. It is evident, that for the case-study herds to reduce bobby calves (beyond 20-25%) then mating programmes that include changes in the semen used for 15-month-old dairy heifer replacements must be considered. In addition, data collected from the case-study herds demonstrated that calves sired by Jersey bulls resulted in the greatest within breed and semen type bobby rate (87-97%). Thus, viable alternatives to Jersey bulls for use over dairy heifers are needed if bobby calves are to be reduced further.

Ultimately, the dam and breed of sire selection influences the calf outcome. However, the time at which the subsequent calves are born over the season also influences the calf outcome due to bobby calf collection availability and beef demand. Furthermore, if regulations were introduced that required calves to be reared to beyond four-days-old (i.e., 10-30 days of age; Pike et al., 2019; Ritter et al., 2022), then the calf-rearing resources and rearing capabilities would increase as more calves would be reared for longer. Therefore, future mating programmes must consider potential resources required to meet the subsequent calves' resource demands.

5.1.2 Calf outcome and adverse effects on calf-rearing requirements

Euthanasia and adverse effects on calf-rearing requirements

The autumn-calving herds had greater calf euthanasia and presented the opportunity for more beef-sired calves. Calves sired by SGL FxJ at the end of calving, born from autumn-calving herds result in a greater euthanasia rate (67%-73%). On average, calf euthanasia ranged between 3-6%, comparable to other studies that documented on-farm mortalities (Cuttance et al., 2019; Edwards et al., 2021). However, the autumn-calving herds had greater within breed and semen type euthanasia rates (67-73%). Milk processors 'terms of supply' are highlighting the issue of calf euthanasia, and the literature has emphasised the requirement for rearing calves beyond four days of age (Pike et al., 2019; Fonterra, 2022a; Ritter et al., 2022). The greater euthanasia rate of calves sired by SGL FxJ semen presented the opportunity for more beef-sired calves.

Bobby calf collection frequency and adverse effects on calf-rearing requirements

Over the autumn period there is reduced bobby calf collection (every few days) compared to the regular bobby calf collection in spring (alternate days). The high euthanasia of calves in autumn-calving herds highlights the complexities around the supply chain, calf outcome, and current mating programmes. One solution to address the SGL FxJ calves born towards the end of autumn could be for the industry to continue bobby calf collection, which ceased at 65 and 75 days in autumn for case studies 1 and 2a, respectively. Although the service is currently provided it is not guaranteed. Extending the autumn bobby calf collection depends on abattoir processing capabilities and capacity in the current supply chain as it is managed to service both the dairy and beef and sheep sectors. Furthermore, the number of processing calves will be low, making it less viable for processors. Thus, there are, complexities to be considered which do not guarantee bobby calf collection, as explained in section 1.10.4. Thus, extending the bobby calf collection period may not be possible.

Although, SGL semen provides a shorter gestation length, which in turn increases days in milk and condenses the calving spread (see section 1.5.4 and 1.5.5) in the future due to changing regulations, the risk of calf euthanasia later the calving period in autumn could outweigh the benefits of using the SGL semen. The limited demand for unrecorded FxJ calves emphasises the potential risk for farmers. As the demand for beef x dairy calves that increases in autumn, there is an opportunity for beef-breed semen to replace SGL FxJ semen in mating programmes for autumn-calving herds. Ultimately, the use of beef-breed semen in mating programmes for autumn calving herds can reduce bobby calves and the need for euthanasia of calves, thus reducing mortality rates while providing the opportunity to increase beef x dairy calf production and sales.

Calves reared for heifer replacement and adverse effects on calf-rearing requirements

The effect of climate was reflected in heifer replacement calves' days in the calf shed. Replacement calves reared on autumn-calving herds had a shorter duration in the calf rearing shed. For case study 1, heifer replacement calves exited the calving shed earlier (16-18 days) over the autumn period compared to the spring-calving herds (22-45 days). The greater variation of days in the calf shed for the spring-calving herds could be due to the volatile weather that typically occurs in spring, particularly as spring calving herds start calving in late winter, when it is often cold and wet. The autumn typically provides warmer and drier weather which is more suitable for calves to be reared outside. However, in case studies 1 and 2b heifer replacement calves were reared for longer in the calf rearing sheds towards the end of autumn as the weather became colder and wetter as winter approached (Yang et al., 2018; Beef + Lamb NZ, 2022b). The days in shed on the case study herds highlighted the effect that climate plays on calf rearing and the ability to move calves outdoors for rearing.

A cohort of replacement heifer calves went outside in a group relative to age, weight, and feeding ability for rearing and if suitable weather conditions permitted. Therefore, heifer replacement calves were reared in the calf rearing sheds for longer until the weather provided a suitable day for new calves to be released outside while still being offered outdoor shelter and protection from the natural environment. The longer days in the shed for the heifer replacement calves from the spring-calving herds, reflects the poorer weather conditions during this period, which prevented the calves from exiting the shed when planned during spring.

Regardless, calves sired by sexed semen were born in a more condensed timeframe and formed cohorts and exited the calf shed earlier compared with calves sired by conventional daughter-proven semen. In case studies 3a and 3b there were reduced days in the calf shed for calves sired by sexed semen, on average 29 days, compared with a 35-day average for calves sired by conventional semen. The shorter days in the shed for the calves sired by sexed semen are a result of calves being born in a more condensed pattern and thus forming cohorts quicker than calves from conventional daughter-proven semen. Thus, sexed semen could provide an opportunity to rear heifer replacements in condensed cohorts and move them outdoors earlier with less time spent in calf rearing sheds. Another opportunity for calves to exit the shed earlier, is if beef calves were reared on farm and reared with heifer replacements to form cohorts quicker; this scenario was not investigated due to other required considerations (e.g., land capacity on the milking platform).

Calves sold for beef rearing and adverse effects on calf-rearing requirements

Calves sold for beef rearing required greater calf-rearing resources compared to calves bobbied. The different outcomes of calves born from different mating programmes impacted the resources required for calf rearing, consistent with Costa et al. (2016) and Vicic et al. (2022). In the spring-calving herds, days in the calf shed were longer for beef x dairy calves than bobby calves, indicating that increasing the use of beef-breed semen in mating programmes results in a greater resource requirement to rear calves sold for beef rearing when compared to calves bobbied. The findings in this study quantify the age that calves are sold for beef rearing in NZ (8 days for autumn-calving herds and 6 days for spring-calving herds). Haskell (2020) and Wilson (2020) suggest calves sold for beef rearing are usually transported to calf rearers around 8 days of age in Scottland and 3-7 days in Canada, respectively. However, the same comparison was not evident in the autumn-calving herds. Due to a less frequent bobby calf collection, beef calves were sold earlier when compared to calves bobbied this further supports the opportunity for greater use of beef-breed semen in autumn-calving herds if beef calf demand remains consistent and reliable.

The Wagyu calves produced very different results from all other beef breeds. Wagyu calves remained in the calf rearing shed for longer. In case-study 3b there was a Wagyu-sired calf rearing contract requiring calves to be partially reared between 10-30 days of age and weighing a minimum of 32kgs. Calf collections were available weekly and required a minimum of 10 calves for collection. This contractual requirement resulted in Wagyu beef x dairy calves remaining in the calf rearing sheds for longer than other beef x dairy breeds. This highlights the demands a farmer can expect if the rearing age of a bobby calf was to be extended beyond four-days-old, as indicated in the literature (Pike et al., 2019). Furthermore, the requirement of a maximum of 30 days of age and fed milk with no antibiotics may limit calf rearing options with Wagyu-sired calves.

5.1.3 Feed demand

On average, the beef x dairy calves from the case-study herds were heavier than the dairy breeds and were comparable to the literature (Muir et al., 2000; Coleman et al., 2016; Pritchard et al., 2021; Williamson et al. (2022). It is to be noted, liveweights could have been influenced by variation in gut fill, emphasised by small sample size. The greater liveweight indicates that rearing more beef x dairy calves would require greater feed requirements. Furthermore, calves with prolonged exit dates, when compared to bobby calves, are reared in the calf rearing shed for longer and require greater feed requirements than calves reared for fewer days. Thus, beef x dairy calves reared during spring required greater feed resources than bobby calves due to prolonged exit dates and heavier liveweights.

If farmers were to rear more beef x dairy calves, they could expect greater feed resource requirements. Calves need a feed allocation for milk of 10% of liveweight (MPI, 2019). As a result, calves with a heavier birthweight and greater exit liveweight required greater feed inputs when compared to calves with lighter liveweights. Calves born to Jersey dams and sired by Jersey bulls were the lightest when compared to all other breeds across the case-study herds. Thus, heavier calves sired by beef bulls require greater rearing resources.

The proposed Code of Animal Welfare, Cattle (MPI. 2022b) proposes an increased feed allocation of 20% of the calf's liveweight. Data from the case-study herds indicate a greater feed demand when milk was allocated at 10% of the calf's liveweight for beef x dairy calves compared to calves bobbied. Therefore, farmers can expect an even greater increase in feed demand if milk is allocated at 20% of the calf's live weight. Data from the case-study herds indicate that farmers need to consider the calf-rearing resources when utilising more beef-breed semen in mating programmes for feed demand, labour requirements, and shed capacity.

5.1.4 Shed capacity

There was a difference in calf rearing infrastructure and feed requirements among case-study herds due to different mating programmes used. Reproduction results from the case-study herds affected calving spread and breed selection, which determined the calf outcome and this altered days in shed and shed capacity requirements. Total calves reared can place pressure on the calf rearing facilities and is influenced by farm management decisions, condensed calving pattern, and different mating programmes (Costa et al., 2016; Verdon, 2021; Vicic et al., 2022). The number of calves in the shed dropped considerably when heifer replacements left the calf shed, indicating that on-farm management decisions are a key driver of the shed use and the shed capacity requirements. A similar effect could be seen if fertility rates improved or declined. Improved reproduction results would increase calving rates, as a greater number of calves would be expected to be born in the first six weeks and this would in turn increase the peak calf-rearing resources, this could result in cohorts forming quicker and more calves exiting the calf shed earlier.

5.1.5 Labour requirements

The average days in the shed could be used as an indicator for labour requirements. Calves that require more days in the calf shed would result in greater labour requirements to meet the needs of calf rearing and could negatively impact on workload and profitability. The study requires further investigation into the actual labour time spent and level of stress, in relation to numbers of calves per full time employee, and methods to alleviate time requirements and stress, for example, the utilisation of automatic feeders to compensate the increased feed demand.

5.1.6 Case study discussion conclusion

In conclusion, shed capacity was never reached on the case-study herds, thus farmers may not require capital investment when mating programmes are altered to reduce bobby calves. However, during the calving period, the shed capacity peaked due to different mating programmes, calving rates, and individual calf rearing management decisions. Overall, data from the case-study herds indicate that using a more complex mating programme can add pressure to the calf rearing facilities and are influenced by different management decisions. Furthermore, the ability to remove calves from the calf shed is dependent on climate and calf demand. Therefore, various mating programmes must consider the resources required to meet the subsequent calves’ resource demands.

5.2 Scenario analyses

The objective of the scenario analyses was to quantify the expected calf-rearing resources (shed capacity, milk, and labour requirements) required for different mating programmes (utilising different sire breeds and semen types), aiming to reduce bobby calves based on an average NZ herd, and identify the risks and opportunities for each scenario’s mating programme and subsequent calf outcomes.

5.2.1 Scenario analyses mating programmes and calf outcomes

The overall calf outcomes across the three scenarios are consistent with the case study results. Ritter et al. (2019); Haskell et al. (2020); and Balzani et al. (2021) proposed that one solution to reduce bobby calves is by utilising sexed and beef-breed semen in mating programmes. In the current study, data from the case-study herds indicated that mating programmes using sexed and beef-breed semen can reduce the number of calves bobbied. The scenario analyses supported this, as the different mating programmes and subsequent calf outcomes altered the resources and management requirements during calf rearing (Costa et al., 2016; Vicic et al., 2022).

Scenario 1 formed the base scenario for Scenarios 2 and 3. Scenario 1 equated to 40% bobby calves, comparable to the reported 41-44% in case studies 1, 2a, 2b (which did not utilise sexed semen nor increased beef-breed semen) and similar with documented national averages (Edwards et al., 2021). For Scenario 2, bobby calves were reduced to 25%, comparable to case studies 3a and 3b at 21% and 23%, respectively.

For Scenario 3, bobby calves were reduced to 7% and were concomitant with an increase in beef-sired calves (57%), achieving the greatest reduction compared to the national averages and case-study herds. Thus, the scenario analyses confirmed that mating programmes utilising sexed and beef-breed semen can significantly reduce bobby calves. However, Scenario 3 still had 7% bobby calves, despite a target of 0%, due to unsuitable calves for beef rearing being bobbied due to their dairy exterior characteristics. This is similar to the data from Western Australia (9% bobbies; Dairy Australia, 2019), and emphasises the importance of sire and subsequent calf selection at a young age for beef-rearing characteristics if a further reduction of bobby calves is to be achieved.

Across all scenarios, calf mortalities ranged from 10-11%. The scenario analyses accounted for 5% mortality rate from birth to weaning and this is included in the 10-11%. An outcome of the mortality rate in the scenario analyses was a reduction in calves reared for heifer replacements. For example, in Scenario 1, the heifer replacement rate dropped from 26% to 25%. The slight reduction of heifer replacement calves was expected and accounted for in designing the mating programmes, to ensure that enough calves would enter the herd as heifer replacements.

5.2.2 Calf-rearing resources

The key calf rearing resource requirements are shed capacity, feed, and labour (Costa et al., 2016; Vicic et al., 2022). The scenario analyses indicated changes in calf-rearing resources when incorporating sexed and beef-breed semen due to differing subsequent calf outcomes.

Effect on feed demand

If replacement heifers were included, there was a reduction in milk requirements when comparing Scenarios 1, 2, and 3 as this only considered the milk requirement while the calves were in the shed. However, removing calves reared for heifer replacement, as most NZ farms rear these calves on farm until weaning, increased milk demand by 43% when bobby calves decreased from 40% (Scenario 1) to 7% (Scenario 3). The scenario analyses were consistent with the case-study herds, in that increasing number of days in the calf shed, and growing heavier calves, increased feed demand.

Interestingly, the conversion between using the 10% liveweight milk requirement and 4L/day was very close for all scenarios, except in Scenario 1. In Scenario 1 there was a difference between feeding 4L of milk/day and 10% calf liveweight/day (including calves reared for heifer replacement), of 2,479L. The difference is because an allocation of 4L of milk per calf per day is not accounting for liveweight gain throughout the average of 35 days in the calf shed. Calves reared in the shed for longer will have greater liveweight gain, and thus require more milk if calculated using 10% liveweight. This was evident in the case-study herds. Liveweight gain increases feed demand, and this is accounted for when using 10% of the calf's liveweight, but not with 4L per calf per day. Therefore, using the percentage of liveweight for feed demand is more accurate as this represents the growth calves would have incurred while in the shed.

Effect on shed capacity

The consolidation of heifer replacements and the utilisation of beef-breed semen contribute to peak shed capacity. The heifer replacement cohort rate is driven by the 35-day average days in the calf shed established from case studies 2b, 3a and 3b (spring-calving herds) and a 29-day average for the sexed semen established from case study 3b (spring-calving herd). For Scenarios 2 and 3, the base shed capacity requirements increased, demonstrating the need for greater infrastructure resources or for changing management decisions on when calves exited the shed to meet the demands of calf-rearing requirements from the different mating programmes for these scenarios. The increase in resource requirements supports the hypothesis and highlights the risk of greater pressure on farmers to make informed management decisions before implementing mating programmes aiming to reduce bobby calves.

Effect on labour requirements

Across the three scenarios, the feed demand and shed capacity indicate a minimal increased labour requirement. In total, the shed capacity increased by 17 calves for 12 days, which suggested that labour might be under greater pressure during these 12 days without altering management decisions (e.g., removing calves from the calf shed through sale or moving calves outside). Management decisions could be changed so that groups of beef x dairy calves were formed quicker and are picked up sooner, or likewise, heifer replacements cohorts could be put outside sooner, although this would depend on climate and weather conditions at that time.

Feed demand also increased across the scenarios, as Scenario 3 required an extra 17 bags of milk replacer, and this could increase labour requirements. Based on shed capacity and feed demand, there could be additional stress placed on the farm team (labour requirements) for a short duration in the calving period. The impact on labour will vary farm by farm, a well-staffed farm where there is a capable calf rearer that has extra time could adjust to the increased rearing requirements. However, a farm minimally staffed with everyone working to the limit could place the farm and its staff under unreasonable stress. The productivity required from labour could be greater due to the more condensed calving period when comparing Scenarios 1, 2, and 3. In Scenarios 2 and 3, the peak calf rearing occurred earlier as the calving spread was condensed due to the different mating programmes. This consolidation of calving could increase labour requirements for a shorter period, e.g., from ~75 days in Scenario 1 to ~50 days in Scenarios 2 and 3. The cost or benefit of this would depend on the farm labour team. There is an opportunity for shorter and more intense calving's and subsequent calf rearing in Scenarios 2 and 3; however, this may be beyond the limits of the team.

5.2.3 Adverse effects on calf-rearing resources and increasing shed population

There are adverse effects on calf rearing resources when using different mating strategies, and farmers need to consider rearing requirements before implementing different mating programmes. For example, rearing Wagyu-sired calves would have an impact on the calf-rearing resources along with creating extended gestations and reduced lactations (as described in section 1.8.2). Furthermore, there are adverse effects with increased shed capacity. The increasing calf population of wagyu-sired calves could contribute to illness, and this would have a negative economic impact on the farm system through increased mortalities or reduced calf performance.

Overall, from Scenario 3 compared to Scenario 1, there was a 170% increase in calves sold for beef rearing. Pike et al.(2019) suggested rearing calves beyond 30 days of age, is a complex issue due to limited land use, limited beef cattle population and required suitability for NZ beef production (e.g., growth and carcass characteristics), as explained in section 1.8. The resulting increase in beef production and a low demand for beef calves could extend the number of days spent in the calf shed or on farm for calves sold for beef rearing. As evidenced in case study 3b, the Wagyu-sired calves increased calf rearing resources. If dairy farmers were required to reduce dairy cattle numbers to rear more beef cattle, then resources and income would be affected.

In addition, there are challenges in scaling this option to a national level, primarily with the increased number of beef x dairy calves reared which may negatively affect beef x dairy calf prices. Current market conditions using rolling averages were used in the scenarios due to the uncertainties of future market conditions. Changes in international, domestic, and geopolitical environments and their impact on cattle market conditions have not been evaluated. For example, an increase in the production and rearing of beef x dairy calves, through greater utilisation of beef-breed semen in dairy mating programmes, would increase beef x dairy calf supply, potentially devaluing the financial return from the calves. For the NZ beef and dairy sectors, Thompson and Hickson, (2022) used a modelling exercise to demonstrate that if beef production was to replace bobby calf production it would not be economically feasible in NZ. Thus, the scenario assumptions used current market conditions to understand the resource requirements (shed capacity, milk consumption, and labour) to meet the demands of mating programmes aimed to reduce bobby calves. These data highlight the risks and opportunities of different mating programmes in current market conditions.

5.2.4 Scenario analyses conclusion

The scenario analyses provided evidence on the required calf-rearing resources when implementing different mating programmes aiming to reduce bobby calves. The results confirmed the hypothesis that mating programmes aiming to reduce bobby calves will increase the required calf-rearing resources. Farmers could use the information provided to measure the impact and determine the appropriate management decisions for calf rearing resources (shed infrastructure, feed demand, and staff requirements) before implementing different mating programmes.

Chapter 6. Limitations to this study and overall conclusions

6.1 Limitations to this study

Information bias

From our knowledge, there is limited literature on the implications of mating programmes and subsequent calf outcomes on calf-rearing resources. Due to this limitation, I acknowledge the potential for information bias when discussing the impacts of calf outcomes and days in calf shed, exit dates, and exit liveweights. Thus, the current study filled a gap in the literature, evaluating the risks and opportunities of mating programmes and subsequent calf outcomes on calf-rearing resources. Furthermore, the mathematical model developed for the scenario analyses could be used for further research or used by farmers wanting to predict outcomes from their own individualised mating programmes.

Sample size and data collection

The case-study herd analyses provided critical insights into some of the opportunities and risks regarding infrastructure and feed resources required for dairy farmers using different mating programmes that aim to reduce bobby calves. However, the case-study herds and scenario analyses were conducted on a relatively small scale. Furthermore, data from the case-study herds were obtained on farm, and as a result, some missing data were identified during data analyses. The small sample size could have skewed results, for example, mating programme outcomes, days in the calf shed, calf collection frequency, and calf feed demand.

Few beef breeds were used in the case-study herds, and the selection of additional types of semen to that used could influence the mating programme calf outcomes and measurements. Calf collection varies depending on the circumstances arranged between the purchaser and seller. The case-study herds had pre-arranged regular collections and a range of buyers to negotiate the different desirable calves. However, if the regular collection was not available and beef-sired calves were in low demand, then the average days in the calf shed could increase, thus increasing further the required rearing resources. Furthermore, the small sample size could contribute to discrepancies between birthweights, exit liveweights, and feed allocation, although this did not appear to happen as results from the present study supported those in the literature.

Current market conditions

If more farms were to rear more beef x dairy calves, the land available to rear these calves would be limited, and increased calf numbers could saturate the market and drive beef prices down. Furthermore, the ability to sell these calves in a reasonable time for a price that would cover the cost of rearing, could become a limitation, and the delay of sale could require dairy farmers to rear calves for a longer time, ultimately increasing the rearing resources. Thus, current market conditions limit the ability to use more beef-breed semen in mating programmes. Farmers would be required to rear calves on the farm at the cost of dairy production and negatively impact beef farmers through devaluing stock.

Primarily, the increased number of beef x dairy calves can negatively affect all beef demand. Farmers should select sires and breeds for gestation length, calving ease, beef growth rates, and beef carcass characteristics, and also where possible, select for elite beef-breed sires. By doing so, farmers can help ensure that demand for beef x dairy calves is high. However, there are risks of saturating the supply of beef, which would increase rearing resources and costs associated with beef-sired calves. Thus, greater dairy, beef, and abattoir industry research is required to guarantee beef x dairy calf demand before recommending increased production of beef-sired calves.

6.2 Future research

Potential for utilising beef-breed semen instead of short gestation length dairy semen in autumn

In autumn, there are limited supply chain options for calves sired by short gestation length semen. There is an opportunity to utilise beef-breed semen as a viable option for increasing the number of calves entering the supply chain. Further investigation is required on the outcomes of calves and their value born in autumn-calving herds.

Earlier identification of appropriate calves for beef production

Data from the case-study herds was used to identify that some calves sold for beef rearing were below beef production standards due to undesirable dairy traits. This highlights the critical need for calves to be identifiable at four days old as suitable or unsuitable for beef production. Appropriate calf selection for beef production is critical, as poorer liveweight growth and beef-breed characteristics contribute to low returns for beef producers and is economically unsustainable (McIntyre et al., 2009; Bown et al., 2016; Hunt et al., 2019; Berry & Ring, 2020; Wetlesen et al., 2020; Coleman et al., 2016; Martin et al., 2021b; Pritchard et al., 2021). As suggested by Pike et al. (2019) a separate classification for yearling production is required for viability. There is currently no appropriate classification for beef x dairy calves at four days old, and data from the case-study herds highlighted the requirement for this, for both the dairy and beef sectors. Selecting high-performing calves earlier could increase the confidence of beef producers to purchase beef x dairy calves.

Understanding adverse effects of different mating programmes on calf rearing, and actual calf intake and labour requirements due to increasing calf shed population

The milk requirements in the present study were based on liveweights, and in reality, the actual calf consumption of milk might vary. Research measuring the actual milk consumption of calves could provide comparative data to the liveweights measured in the present research for different calf outcomes. In addition, labour requirements were not measured but can be assumed to be related to the number of calves being reared at any one time. Therefore, research measuring actual labour time and increased stress or productivity during calf rearing could provide insight into the associated labour requirements during the peak shed capacity and peak duration for different mating programmes. This proposed research could further include the potential for declining calf health associated with increasing the number of calves reared in the shed, and the impacts on required calf-rearing resources. Data from this proposed research could also be used to further understand mating programme impacts and subsequent calf outcomes.

6.3 Conclusion and Implications

In summary, farmers must consider resource requirements before implementing different mating programmes aiming to reduce bobby calves. Currently, the dairy industry is facing changing animal welfare regulations, terms of conditions to supply milk, and market pressure, all requiring them to reduce bobby calves. Data from the present study indicated that using different semen types and sire breeds can alter the calf outcome, reducing bobby calf numbers and increasing the number of calves sold for beef production.

However, there is a direct impact on the calf-rearing resources and management decisions required to meet mating programme changes, as shed capacity increases when utilising beef and sexed semen to increase beef x dairy calf production. Rearing more calves for beef reduced bobby calves from 40% to 7% and increased the required peak capacity of the shed by 12%. More calves were on farm for 12 days and this occurred around 28 days after start of calving compared to the average current farm practices. This outcome will depend on the ability to move calves outside and to sell bobbies or beef x dairy calves to other rearers or beef producers. In addition, farmers entering into a contractual agreement that requires rearing calves longer than four days, will further increase resource requirements.

Furthermore, more milk is required for feeding calves when utilising beef-breed semen. The average weight of beef x dairy calves is greater than dairy calves and they spend longer in the calf shed in spring. Feeding milk based on calf liveweight (e.g., 10% of liveweight) increases feed demand when there are more calves reared or sold for beef rearing. Thus, utilising more beef-breed semen in mating programmes will increase calf-rearing resources. Overall, the increased feed demand and shed capacity are expected to increase labour requirements. There is also a risk of low demand for calves bred for beef rearing and a requirement for dairy farmers to rear calves beyond 4 days. Increased supply when demand does not increase simultaneously will increase the number of days a calf is on farm and lower the prices received for the beef x dairy calves Finally, there are challenges in changing mating programmes for increased beef production at a national scale.

Chapter 7. References

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Chapter 8. Appendices

Appendix 1

Dam and calf measurements collected for Dairy Trust Taranaki case studies 1, 2a (autumn-calving herd) and case studies 2a, 3a, and 3b (spring-calving herds), measurements were recorded at calf collection and calf exit, in 2021.

Farm Name: _________ Calving: Autumn/Spring **PAGE NUMBER: ....**

Calving Date	Cow	Sex	Birth Weight	Dominant Breed	Fate	Reason for Fate	Herd Code	Calf #	Date left farm	Sold to	Docket Number	Date put outside	Weight left farm	Comments/Calving Difficulties/Calf Behaviour
Eg. 12/3	126	M / F	38.5	F / X / J / H / W / SP / G [2]	R / S / B / D	1,2,3 [1]	Auto fill for individual farm	1103369	17/03	Calf Rearer Name or Silver Fern Farms (SFF)	1101	23/03/2021	41.5	Did not feed well / Premature / Unwell
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
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		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									
		M / F			R / S / B / D									

[1] Use the number system for reason of fate, put more than one number down if there are multiple reasons;1, Undesired Markings or Colour, 2, Small Frame 3, Naturally Mated.

[2] Abbreviations: F = Friesian, J = Jersey, X = Friesian cross Jersey, H = Hereford, W = Wagyu, SP = Speckle Park, G = Galloway.

Appendix 2.

Dairy calf breed identification for Dairy Trust Taranaki farm staff for consistency in calf breed recordings for case studies 1, 2a (autumn-calving herds) and case studies 2b, 3a, and 3b (spring-calving herds).

Jersey | Friesian cross Jersey | Friesian | Wagyu | Hereford

Jersey | Friesian cross Jersey | Friesian | Wagyu (circled) | Hereford

IDENTIFICAITON (left to right):

J = Jersey
FxJ = Friesian cross Jersey: White marks visible but does not have a complete five points or all black/brown – no white points
F = Friesian: Five white points: four feet and tail
W = Wagyu: Black and narrow face.
Hereford- H1R or H1B or Tiger Note (not shown here): No broken face and record if red or black or tiger strip (T), if the calf has an eye patch it belongs in this category (bottom picture).
Hereford - H2R or H2B or Tiger Note: Broken face and record if red or black or tiger strip (T)
SP = Speckle Park - not show here: All recording identification Speckle Park

Appendix 3.

The average gestation length, birthweights, live birthweights and exit liveweights, for case study 1 dairy and beef x dairy calves born in autumn 2021.

Case study 1 - Performance

Variables		Dairy calves						Beef x dairy calves			
Sire breed (semen type)		**Jersey (Bull)**		**SGL FxJ (AI)**		**FxJ (AI)**		**SP (AI)**		**Galloway (AI)**	
Sex		**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**
All calves born		**9**	**9**	**6**	**3**	**35**	**37**	**8**	**1**	**6**	**7**
Average gestation length (days)	**Average**	-	-	271	274	280	280	288	288	-	-
	SD	-	-	4.0	0.0	3.8	5.0	3.2	-	-	-
	n	-	-	-	**2**	**34**	**34**	-	-	-	-
Birthweight of - all calves (kg)	**Average**	23.3	24.6	25.8	26.0	29.2	29.0	29.8	46.0	32.3	36.0
	SD	3.19	3.09	6.06	2.83	3.03	4.98	4.65	-	2.50	5.32
	n	-	-	**5**	**2**	**34**	**34**	-	-	**6**	**7**
Average birth liveweight - all live calves (kg)	**Average**	-	-	24.0	-	-	-	-	-	-	-
	SD	-	-	7.07	-	-	-	-	-	-	-
	n	-	-	2	-	-	-	-	-	-	-
Average exit liveweight (kg)	**Average**	28.7	30.1	33.0	-	42.1	37.0	35.5	-	38.3	44.3
	SD	4.18	4.53	-	-	4.93	7.14	5.32	-	6.74	5.22
	n	-	**7**	**1**	-	**34**	**34**	**6**	-	**6**	**7**

Abbreviations: FxJ = Friesian cross Jersey, SP = Speckle Park, AI = Artificial insemination, SGL = Short gestation length

n = number. Total calves have been presented at the top of the table and where a change in total has occurred throughout the table, in the case of no number, no change occurred,

The average days old at exit, average daily gain (ADG), and milk consumption for case study 1 dairy and beef x dairy calves born in autumn 2021.

Case study 1 - Inputs

Variables		Dairy calves						Beef x dairy calves			
Sire breed		**Jersey (Bull)**		**SGL FxJ (AI)**		**FxJ (AI)**		**SP (AI)**		**Galloway (AI)**	
Sex		**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**
Count		**9**	**9**	**2**	**2**	**34**	**34**	**8**	**0**	**6**	**7**
Average days old at exit (days)	**Average**	6	7	3	5	18	9	6	-	8	6
	SD	1.5	6.9	4.2	0.0	5.4	5.1	4.1	-	5.3	6.1
Average daily gain (ADG)	**Average**	1.0	0.6	0.3	0.0	0.7	0.9	0.7	-	0.6	0.8
	SD	0.84	0.64	0.47	0.00	0.23	0.35	0.64	-	0.81	0.21
Average milk consumption - 10% liveweight/day (L)	**Average**	68	71	48	68	128	112	93	-	126	163
	SD	15.7	22.9	68.0	14.7	23.1	35.4	44.8	-	24.1	40.3
Average total milk - 4L/day (L)	**Average**	104	105	62	104	142	132	113	-	141	161
	SD	12.4	18.0	87.7	11.3	12.8	22.9	48.5	-	13.8	19.0

Abbreviations: FxJ = Friesian cross Jersey, SP= Speckle Park, AI = Artificial insemination, SGL = Short gestation length

Appendix 4.

The average gestation length, birthweights, live birthweights and exit liveweights for case study 2a dairy and beef-cross dairy calves born in autumn 2021.

Case study 2a - Performance

Variables		Class									
		Dairy						Beef x dairy			
Sire Breed		Jersey (Bull)		SGL FxJ (AI)		Friesian (AI)		SGL Hereford (AI)		Galloway (AI)	
Sex		Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls
Total Count of All Calves Born		35	49	5	10	76	80	23	39	0	4
Average gestation length (days)	Average	-	-	269	273	276	280	277	281	-	-
	SD	-	-	3.7	4.9	5.4	6.1	5.4	6.2	-	-
	n	-	-	-	-	-	79	-	38	-	-
Birthweight of - all calves (kg)	Average	32.3	33.4	31.7	37.2	37.1	37.5	36.1	39.9	-	40.3
	SD	3.97	4.68	2.31	2.97	5.81	5.38	5.87	6.14	-	2.06
	n	31	48	3	-	75	72	21	36	-	-
Average birth liveweight - all live calves (kg)	Average	32.6	33.7	-	37.1	37.1	37.7	-	40.7	-	-
	SD	4.04	4.55	-	3.14	5.82	5.41	-	5.56	-	-
	n	28	44	-	9	74	69	-	33	-	-
Average exit liveweight (kg)	Average	39.5	39.3	36.7	41.3	51.8	43.6	43.1	50.8	-	51.3
	SD	5.55	4.55	1.53	3.28	12.62	6.62	5.73	9.87	-	6.13
	n	28	44	3	9	43	69	21	33	-	-

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length
n = number. Total calves have been presented at the top of the table and where a change in total has occurred throughout the table, in the case of no number, no change occurred,

The average days old at exit, average daily gain (ADG), and milk consumption for case study 2a dairy and beef-cross dairy calves born in spring 2021.

Case study 2a - Inputs

Variables		Class									
		Dairy						Beef x dairy			
Sire Breed		Jersey (Bull)		SGL FxJ (AI)		Friesian (AI)		SGL Hereford (AI)		Galloway (AI)	
Sex		Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls
Count		29	44	3	9	74	69	21	34	0	4
Average days old at exit (days)	Average	9	7	12	5	16	8	7	11	-	12
	SD	6.9	4.9	2.5	2.7	10.8	4.8	2.4	9.3	-	8.4
	n	-	-	-	-	-	-	-	-	-	-
Average daily gain (ADG)	Average	1.0	1.0	0.4	0.9	0.8	0.8	1.1	1.0	-	1.0
	SD	0.84	1.18	0.17	0.54	0.28	0.59	0.79	0.48	-	0.36
	n	28	-	-	-	42	-	-	33	-	-
Average milk consumption - 10% liveweight/day (L)	Average	31	27	42	18	90	34	29	53	-	56
	SD	23.7	15.8	7.8	10.7	68.0	22.6	11.6	56.5	-	41.0
	n	28	-	-	-	42	-	-	-		-
Average total milk - 4L/day (L)	Average	34	30	49	18	63	33	28	42	-	48
	SD	26.8	19.6	10.1	10.6	43.2	19.3	9.5	37.1	-	33.8
	n	28	-	-	-	-	-	-	-	-	-

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length

Appendix 5.

The average gestation length, birthweights, live birthweights, exit weights, days old at exit, average daily gain (ADG), and milk consumption for case study 2b dairy and beef-cross dairy calves born in spring 2021

Case-study 2b - Performance

Variables		Class							
		Dairy						Beef x dairy	
Sire Breed		Jersey (Bull)		SGL FxJ (AI)		Friesian (AI)		SGL Hereford (AI)	
Sex		Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls
Total Count of All Calves Born		42	40	6	4	90	75	22	30
Average gestation length (days)	Average	-	-	268	271	279	280	283	283
	SD	-	-	5.5	4.4	4.5	3.7	5.2	4.3
	n	-	-	-	**3**	-	**73**	**21**	-
Birthweight of - all calves (kg)	Average	30.5	30.9	33.8	29.8	34.5	37.0	39.3	40.0
	SD	3.23	4.01	7.57	6.39	4.82	5.61	5.62	6.20
	n	-	**39**	-	-	**89**	**74**	**21**	-
Average birth liveweight - all live calves (kg)	Average	30.6	30.9	33.4	32.7	34.4	37.1	39.6	40.6
	SD	3.19	4.23	8.38	3.21	4.68	5.13	5.94	6.25
	n	**40**	**32**	**5**	**3**	**87**	**64**	**18**	**27**
Average exit liveweight (kg)	Average	32.1	32.9	38.0	34.5	55.9	40.5	43.1	45.8
	SD	3.29	4.96	8.52	0.71	8.38	5.57	6.28	5.74
	n	**37**	**29**	**4**	**2**	**83**	**56**	**16**	**24**

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length
n = number. Total calves have been presented at the top of the table and where a change in total has occurred throughout the table, in the case of no number, no change occurred,

The average days old at exit, average daily gain (ADG), and milk consumption for case study 2b dairy and beef-cross dairy calves born in spring 2021.

Case-study 2b - Inputs

Variables		Class							
		Dairy						Beef x dairy	
Sire Breed		Jersey (Bull)		SGL FxJ (AI)		Friesian (AI)		SGL Hereford (AI)	
Sex		Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls
Count		25	19	4	2	83	46	16	24
Average days old at exit (days)	Average	5	6	4	6	32	5	5	6
	SD	2.2	7.1	2.0	2.1	8.3	2.1	3.2	2.8
	n	-	-	-	-	-	-	-	-
Average daily gain (ADG)	Average	0.5	0.6	0.9	0.3	0.7	0.7	0.9	1.0
	SD	0.64	0.81	0.39	0.78	0.18	0.68	0.70	0.66
	n	**23**	**16**	-	-	-	**45**	-	-
Average milk consumption - 10% liveweight/day (L)	Average	14	16	15	18	146	19	22	25
	SD	7.1	14.2	7.4	6.1	46.5	8.8	13.9	13.0
	n	**23**	**16**	-	-	-	**45**	-	-
Average total milk - 4L/day (L)	Average	19	25	16	22	128	20	21	23
	SD	8.7	28.2	8.0	8.5	33.2	8.2	13.0	11.1
	n	-	-	-	-	-	-	-	-

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length

Appendix 6.

The average gestation length, birthweights, live birthweights and exit liveweights for case study 3a dairy and beef x dairy calves born in spring 2021.

Case study 3a - Performance

Variables		**Class**					
		Dairy calves				**Beef x dairy calves**	
Sire breed (semen type)		**Jersey (Bull)**		**Friesian (AI)**		**SGL Hereford (AI)**	
Sex		**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**
All calves born		**20**	**16**	**56**	**64**	**9**	**5**
Average gestation length (days)	**Average**	-	-	281	281	280	281
	SD	-	-	3.9	5.4	3.0	6.4
	n	-	-	**50**	**63**	**8**	-
Birthweight of all Calves Born (kg)	**Average**	31.7	34.3	35.1	37.9	37.1	43.0
	SD	3.60	2.75	4.06	5.91	6.50	6.00
	n	-	-	**55**	**63**	-	-
Average birth liveweight - all live calves (kg)	**Average**	31.4	-	35.1	38.4	-	-
	SD	3.43	-	4.10	5.23	-	-
	n	**19**	-	**53**	**55**	-	-
Average exit liveweight (kg)	**Average**	33.5	37.3	60.5	42.2	37.3	45.4
	SD	2.57	3.24	14.70	8.29	8.81	8.78
	n	**15**	**13**	**53**	**55**	**5**	**4**

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length
n = number. Total calves have been presented at the top of the table and where a change in total has occurred throughout the table, in the case of no number, no change occurred,

The average days old at exit, average daily gain (ADG), and milk consumption for case study 3a dairy and beef-cross dairy calves born in spring 2021.

Case study 3a - Inputs

Variables		**Class**					
		Dairy calves				**Beef x dairy calves**	
Sire breed (semen type)		**Jersey (Bull)**		**Friesian (AI)**		**SGL Hereford (AI)**	
Sex		**Heifers**	**Bulls**	**Heifers**	**Bulls**	**Heifers**	**Bulls**
Count		**19**	**15**	**52**	**55**	**9**	**5**
Average days old at exit (days)	**Average**	3	4	45	6	5	6
	SD	0.5	1.0	20.6	9.2	3.0	2.9
	n	-	-	-	**54**	-	-
Average daily gain (ADG)	**Average**	0.8	0.7	0.6	0.7	0.2	0.8
	SD	0.50	0.79	0.19	0.82	0.27	0.95
	n	**15**	**13**	-	-	**5**	**4**
Average milk consumption - 10% liveweight/day (L)	**Average**	11	14	229	26	19	23
	SD	2.1	4.1	124.7	56.1	15.7	7.9
	n	**15**	**13**	-	-	**5**	**4**
Average total milk - 4L/day (L)	**Average**	14	15	179	23	20	26
	SD	2.1	4.1	82.4	36.8	11.8	11.5
	n	-	-	-	**54**	-	-

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length

Appendix 7.

The average gestation length, birthweights, live birthweights and exit liveweights for case study 3b dairy and beef-cross dairy calves born in spring 2021.

Case study 3b - Performance

Variables		Class									
		Dairy						Beef x dairy			
Sire Breed		Jersey (Bull)		Friesian (AI)		Friesian SS (AI)		SGL Hereford (AI)		Wagyu (AI)	
Sex		Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls
Total Count of All Calves Born		**17**	**13**	**24**	**11**	**31**	**1**	**4**	**2**	**17**	**21**
Average gestation length (days)	Average	-	-	281	282	282	279	285	287	286	288
	SD	-	-	4.0	3.6	4.5	-	2.9	2.8	6.3	4.2
	n	-	-	-	-	-	-	-	-	-	-
Birthweight of - all calves (kg)	Average	31.8	34.1	36.0	41.2	35.9	40.5	40.12	41.8	36.5	38.0
	SD	3.48	4.05	3.17	4.20	5.31	-	3.07	7.42	6.23	5.35
	n	-	-	**22**	-	-	-	-	-	-	-
Average birth liveweight - all live calves (kg)	Average	-	-	-	-	-	-	-	-	-	-
	SD	-	-	-	-	-	-	-	-	-	-
	n	-	-	-	-	-	-	-	-	-	-
Average exit liveweight (kg)	Average	34.9	37.9	48.1	45.3	50.3	46.0	39.8	46.3	49.2	48.0
	SD	2.97	2.39	11.87	7.62	12.83	-	4.07	8.84	9.70	9.95
	n	**11**	**11**	**20**	-	**29**	-	**3**	-	**13**	**20**

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length
n = number. Total calves have been presented at the top of the table and where a change in total has occurred throughout the table, in the case of no number, no change occurred,

The average days old at exit, average daily gain (ADG), and milk consumption for case study 3b dairy and beef-cross dairy calves born in spring 2021.

Case study 3b - Inputs

Variables		Class									
		Dairy						Beef x dairy			
Sire Breed		Jersey (Bull)		Friesian (AI)		Friesian SS (AI)		SGL Hereford (AI)		Wagyu (AI)	
Sex		Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls	Heifers	Bulls
Count		**14**	**13**	**22**	**11**	**30**	**1**	**4**	**2**	**13**	**20**
Average days old at exit (days)	Average	4	4	22	6	29	8	3	6	30	25
	SD	0.5	0.7	15.0	6.7	19.1	-	0.5	1.4	8.4	7.5
	n	-	-	**20**	-	**30**	-	-	-	-	-
Average daily gain (ADG)	Average	0.7	0.8	0.4	0.7	0.4	0.7	0.2	0.7	0.4	0.4
	SD	0.40	0.60	0.38	0.67	0.27	-	0.44	0.06	0.18	0.19
	n	**11**	**11**	**18**	-	**29**	-	**3**	-	-	-
Average milk consumption - 10% liveweight/day (L)	Average	12	13	105	28	135	35	12	27	133	108
	SD	2.3	2.2	82.7	37.4	104.6	-	1.1	11.1	50.4	44.5
	n	**11**	**11**	**18**	-	**29**	-	**3**	-	-	-
Average total milk - 4L/day (L)	Average	-	14	86	24	117	32	13	24	122	99
	SD	2.1	2.6	59.9	26.7	76.3	-	2	5.7	33.6	30.0
	n	-	-	**20**	-	**30**	-	-	-	-	-

Abbreviations: FxJ = Friesian cross Jersey, AI = Artificial insemination, SGL = Short gestation length

Appendix 8.

Mating input table for Scenario 1 (40% bobby calves), Scenario 2 (25% bobby calves), Scenario 3 (7% bobby calves) using three different mating programmes aiming to reduce bobby calves stimulated on an average 444-cow dairy farm in New Zealand.

Scenario	Class	Weeks	Sire Breed	Total cows in-calf	In-calf rate %	Total calving per day	Not-in-calf rate (%)	Total not-in-calf rate (cows)
1	Cows	3	FxJ Daughter proven[1 3]	190	43	9	11%	47
		6	FxJ Daughter proven[1 3]	109	67	5		
		9	Beef[1 3]	62	81	3		
		12	Beef[1 3]	36	89	2		
	Heifers	3	Jersey bull[2 5]	80	82	3	2%	1
		6	Jersey bull[2 6]	13	95	1		
		9	Jersey bull[2 6]	4	98	0		
			Totals	493			12%	49
2	Cows	3	FxJ Sexed Semen[1 4]	129	40	6	11%	50
		3	Beef[1 3]	48		2		
		6	Beef[1 3]	115	66	5		
		9	Beef[1 3]	66	80	3		
		12	Beef[1 3]	37	89	2		
	Heifers	3	Jersey bull[2 5]	80	82	4	2%	1
		6	Jersey bull[2 6]	13	95	1		
		9	Jersey bull[2 6]	4	98	0		
			Totals	491			13%	51
3	Cows	3	FxJ Sexed Semen[1 4]	85	41	4	11%	49
		3	Beef[1 3]	96		5		
		6	Beef[1 3]	113	66	5		
		9	Beef[1 3]	64	81	3		
		12	Beef[1 3]	37	89	2		
	Heifers	3	FxJ Sexed Semen[2 4]	45	46	2	4%	4
		6	Beef[2 6]	38	84	2		
		9	Beef[2 6]	11	96	1		
			Totals	488			16%	54

Submission rate: [1] 81%, [2] 95%.
Conception rate: [3] 53%, [4] 48%, [5] 86%, [6] 75%.
Breed: FxJ = Friesian cross Jersey

Appendix 9.

Calving output for Scenario 1 (40% bobby calves), Scenario 2 (25% bobby calves), Scenario 3 (7% bobby calves) using three different mating programmes aiming to reduce bobby calves stimulated on an average 444-cow dairy farm in New Zealand.

Variables					Heifers				Bulls		
					Bobbies	Reared for Heifer Replacement	Sold for Beef Rearing	Mortality	Bobbied	Sold for Beef Rearing	Mortality
Scenario Analysis	**Class**	**Weeks**	**Sire Breed**	**Count minus cow culls**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
1	Cows	3	FxJ Daughter proven	175	2	82	1	3	51	25	12
		6	FxJ Daughter proven	102	1	48	0	2	30	14	7
		9	Beef	56	2		22	4	2	24	3
		12	Beef	11	0		4	1	0	5	1
	Heifers	3	Jersey bull	85	38			4	38		4
		6	Jersey bull	13	6			1	6		1
			Total	**442**	**49**	**130**	**27**	**15**	**126**	**67**	**28**
2	Cows	3	FxJ Sexed semen	129	0	111	0	4	4	7	2
			Beef	41	2		16	3	1	17	2
		6	Beef	103	4		40	7	3	43	6
		9	Beef	60	3		23	4	2	25	3
		12	Beef	13	1		5	1	0	5	1
	Heifers	3	Jersey bull	80	36			4	36		4
		6	Jersey bull	14	6			1	6		1
		9	Jersey bull		0			0	0		0
			Total	**440**	**52**	**111**	**84**	**24**	**52**	**99**	**18**
3	Cows	3	FxJ Sexed semen	79	0	68	0	2	5	2	1
			Beef	96	4		37	7	3	40	5
		6	Beef	103	4		40	7	3	43	6
		9	Beef	56	2		22	4	2	24	3
		12	Beef	15	1		6	1	0	6	1
	Heifers	3	FxJ Sexed semen	50	0	43	0	2	3	1	1
		6	Beef	43	2		17	3	1	18	2
			Total	**442**	**13**	**111**	**121**	**26**	**16**	**135**	**19**

Breed: FxJ = Friesian cross Jersey