TeamMate: A longitudinal study of health in working farm dogs on the South Island of New Zealand.

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Abstract

Working farm dogs are crucial to the smooth running of sheep and beef farming operations in New Zealand, with specific types of dogs having been developed that are uniquely suited to the conditions of the country. Despite their importance to the economy of New Zealand, few studies have been carried out to examine health and welfare in these dogs, and none have examined the occurrence of new cases of disease or risk factors related to death, euthanasia or retirement.

This thesis presents data from the TeamMate project, which was a longitudinal study of health in working farm dogs on the South Island of New Zealand. The study was designed to supplement and fill gaps left by previous studies and ran from early 2004 to late 2018, collecting data during five data collection rounds. In total, data from 1930 examinations of 641 working farm dogs were collected, with 124 dog owners and staff from 11 veterinary clinics involved. Data was collected through clinical examinations of dogs carried out by veterinarians, and by asking dog owners to provide information about husbandry and workload pertaining to each dog. The data was used to produce four research chapters, each of which focused on a different aspect of health in working farm dogs.

The first research chapter detailed the study design and methodology of the TeamMate study and reported on population data, husbandry practices and prevalence of clinical abnormalities recorded on dogs' enrolment to the study. Dogs were enrolled if they were at least 18 months old and in full work on farm. The data on population and husbandry largely confirmed previous research, with an almost even mix of the two most common types of dogs (Heading dogs and Huntaways) and males and females. Dogs found to be generally lean, were usually fed a combination of meat and commercial dog food and were housed in outdoor kennels. Clinical abnormalities defined as any abnormality irrespective of clinical significance, were recorded in 74% of dogs. The most common abnormalities involved the musculoskeletal system (42% of dogs), skin (including scars and callouses; 42%) and oral cavity (including worn and broken teeth; 35%).

The second research chapter investigated whether conventional body condition scores (BCS) are appropriate when applied to lean, athletic dogs such as working farm dogs, which they have been poorly validated for. BCS was found to be correlated with a predicted measure of body fat mass, but the effect

was too weak to be useful for indicating meaningful differences in body condition between dogs. The ratio of the predicted lean body mass to skeletal size has been proposed as an alternative to BCS when assessing body condition in lean, athletic dogs such as working farm dogs. However, the equation used to predict lean mass in working farm dogs was developed using only 20 dogs and not been validated on a new set of dogs with known lean mass. Both BCS and the lean mass ratio should be validated for use in lean athletic dogs, and further investigation should be carried out to determine whether they are associated with health outcomes in working farm dogs.

The third research chapter focused on the occurrence of new instances of musculoskeletal abnormalities in 323 working farm dogs that were disease-free on enrolment to the study and had at least one follow-up examination. During the follow-up period, 184 dogs (57%) developed at least one musculoskeletal abnormality during 4,508 dog-months at risk, corresponding to approximately 4 dogs with recorded abnormalities per 100 dog-months at risk. Abnormalities in the hip and carpus were the most commonly observed. Two-thirds of dogs that experienced a musculoskeletal abnormality were observed to have a second abnormality. No major differences were observed between sexes or types or dogs. Considering the high prevalence and incidence of musculoskeletal abnormalities in this population, further research into the impact of musculoskeletal disease on the health, welfare and working ability of working farm dogs is strongly recommended.

The fourth and final research chapter investigated the factors that affected dogs' risk of being lost from the workforce. Data was included from 589 dogs where information was available on whether or not the dog had died, been euthanised or been retired from work. Eighty-one dogs (14%) were lost during the course of the study, the majority of which had died or been euthanised. A multivariable logistic regression model was used to estimate the risk dogs dying, being euthanised or being retired from work. After accounting for age, the presence of lameness was found to have a significant effect on the risk of loss ($P = 0.04$, odds ratio (OR) = 1.9). This study expands our knowledge about the impact of clinical abnormalities on the overall health of working farm dogs. Further research into the underlying issues that cause lameness in these dogs should be prioritised.

The results of this study can be used to inform and prioritise further research, and will contribute to an increased understanding of how to ensure optimal health, welfare and working ability in working farm dogs.

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Ethical statement

The TeamMate study was approved by the Massey University Animal Ethics committee (protocols 15/26 and 18/53). All dog owners gave verbal consent to their dogs being included in the study.

Written consent is not a requirement in New Zealand and there are many cases in which projects will be approved without written consent. In this survey verbal consent was considered both acceptable and appropriate: 1) the dog owners had to agree to allow the veterinarian to visit the property, 2) when the veterinarian arrived the dog owners had to consent to them being there and 3) the owner had to provide the dog to the veterinarian for examination. Further, at each round of data collection dog owners were free to withdraw. Several did withdraw from the study and others did not return phone calls. In terms of the actual process of ethical approval, when the proposal was sent to the Massey University Animal Ethics Committee the method of gaining consent was not included and the Committee did not require the inclusion of this prior to approval.

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Chapter 1

Introduction

Introduction

There are over 20,000 sheep and beef farms in New Zealand, and in 2019 beef and sheep meat exports were worth around NZ$7.1 billion, while wool exports were valued at NZ$549 million (Beef + Lamb New Zealand, 2020a). In 2017 red meat and wool exports accounted for 9% of New Zealand's total export earnings (Statistics New Zealand, 2018) and in 2018-19 New Zealand produced 9% of the world supply of wool making the country the third largest exporter in the world (Beef + Lamb New Zealand, 2020a).

Sheep and beef in New Zealand are typically raised extensively on pasture and must be moved regularly, sometimes across large areas (Cranston et al., 2017; Morris, 2017). In 2017 45% of New Zealand farms, covering 63% of the country's agricultural land, produced sheep and beef products (Beef + Lamb New Zealand, 2020a). In 2017 the average size of all farms in New Zealand was 266 hectares (Beef + Lamb New Zealand, 2020a). In comparison, sheep and beef farms had an average effective size of 684 hectares, with South Island high country farms on average 8162 hectares (Beef + Lamb New Zealand, 2020b). High country farms are located at high altitudes, and hill country farms are those with steep terrain and low fertility soils (Beef + Lamb New Zealand, 2020c). Seventy percent of New Zealand's pastoral land is classified as hill country and seventy percent of beef calves and lambs are born and weaned on hill country farms (Thom, 2016). This rough terrain combined with the large size of some sheep and beef farms make it difficult for farmers to gather and move livestock without the aid of working dogs. Working farm dogs, thought to descend from dogs brought by British shepherds in the 19th century, are extensively used on New Zealand sheep, beef and, more recently, deer farms (Hughes, 2013).

Farm dogs in New Zealand are divided into two main groups, Heading dogs and Huntaways (Dalton, 1996; Oliver et al., 2009; Redwood, 1980; Rennie, 1984). The names "Heading dog" and "Huntaway" describe the type of work the dogs do rather than their physical characteristics. Physical differences are a result of breeding dogs to do specific jobs rather than to a breed standard, and as a result phenotypes vary widely within both groups. Heading dogs are smaller and slimmer than Huntaways, and work quietly to head off, gather and turn stock, and to separate individuals from the mob. In many ways they can be describes as smooth-haired cousins to the better-known working Border Collies, which are occasionally used as Heading dogs on New Zealand farms. In contrast, Huntaways are larger and more powerfully built than Heading dogs, and are usually coloured black and tan, black or brindle in contrast to Heading dogs' black and white or tricolour. Huntaways are noisy dogs that use their powerful barks and positioning to drive mobs of animals in front of them. Unlike Heading dogs they are usually not used for fine manoeuvring of stock, but rather to apply pressure from behind and keep the mob moving while the Heading dogs direct where the mob should go. When used as a team, Heading dogs and

Huntaways can move large mobs very effectively across long distances. The Huntaway dog is unique to New Zealand and has recently been registered as a breed by Dogs New Zealand (formerly the New Zealand Kennel Club), though it is emphasized that it should only be bred for work (Dogs New Zealand, 2013).

Working farm dogs need to be physically highly fit to work long days controlling stock in rough terrain and they need to be capable of following complex commands from their handler while working in a team of other dogs. This type of work is very different from that done by working dogs such as racing dogs (Bell et al., 2016; Loftus et al., 2014), search and patrol dogs (Diverio et al., 2017; Haverbeke et al., 2009; Mullis et al., 2015), and personal service and assistance dogs (Audrestch et al., 2015; Batt et al., 2010). Consequently, farm dogs are exposed to different types of risks to their health than other types of working and pet dogs that live and work in very different environments. For example, farm dogs are at risk of injury through close encounters with stock, farm equipment and vehicles. One survey found that traumatic injury in New Zealand farm dogs treated in veterinary clinics was most commonly caused by livestock, automotive accidents (often involving dogs jumping onto or off the vehicle), crossing of fence lines and dog bites (Cave et al., 2009). Due to the differences how they work, farm dogs are also likely to have different dietary and husbandry requirements than other working dogs if they are to stay healthy and be able to continue working at a satisfactory level for many years.

Farm dog owners have an intrinsic interest in their dogs' working ability and consequently in their health. In a survey, New Zealand farmers considered 19% of their dogs to be underweight (Sheard, 2014). An Australian survey indicate that 90% of working dog owners in private industry take their dogs to be examined by a veterinarian 'routinely', 'as required' or 'annually' (Branson et al., 2010), indicating they are willing to invest in their dogs' health as necessary. A better knowledge base could alleviate some of the concern farm dog owners may have about the health of their dogs by enabling them to provide care based on evidence in addition to traditional knowledge and habit. Such an evidence-based change in husbandry practices may help reduce dogs' risk of injury and illness and prolong their working careers.

Given New Zealand farmers' reliance on dogs to help in the management of their farms and the importance of farming to the economy, there is sound reason to investigate the health and welfare of working farm dogs in more detail. Work has been done to investigate demographics and prevalence of illness and injury in New Zealand working farm dogs (Cave et al., 2009; Jerram, 2013; O'Connell, 2012; O'Connell et al., 2019; Sheard, 2014; Singh et al., 2011). While these studies provide us with estimates of demographics and the prevalence of disease in subsets of the population, none of them follow dogs over time, making it difficult to investigate risk factors associated with the development of disease, injury or death. The lack of data about how health issues develop makes it difficult to make recommendations on best husbandry practices, such as feeding, housing and preventive veterinary care.

TeamMate is a longitudinal study of working farm dogs on New Zealand's South Island. The project is a collaboration between Vetlife, a chain of veterinary clinics, and the Massey University Working Dog Centre. TeamMate aims to investigate a range of questions regarding the health, husbandry and working careers of farm dogs.

This thesis will aim to use the rich data provided by TeamMate to investigate some of the basic issues of interest when considering health and welfare of working farm dogs and is divided into seven sections.

Following this introduction, the second chapter will summarise the relevant literature, give an in-depth discussion of current knowledge and discuss areas where this knowledge can be expanded. Additionally, the chapter will provide an overview of epidemiologic principles that are commonly used to investigate veterinary population health.

The third chapter will describe design and implementation of the TeamMate project, along with data collected on the characteristics of the working farm dog sample population and the prevalence of disease on dogs' enrolment to the study.

The fourth chapter will investigate how body condition can be assessed in New Zealand Heading dogs and Huntaways. The aim of this investigation is to examine two different methods of assessing body condition in lean, athletic dogs, while also providing an overview of body size and body condition in Heading dogs and Huntaways that were enrolled in TeamMate.

The fifth chapter will present the incidence of musculoskeletal abnormalities in the population, identify the most commonly occurring types of musculoskeletal abnormalities and investigate whether there are differences in the incidence between the sexes and types of dogs.

Chapter six will investigate the career spans of working farm dogs, and analyse which factors are associated with dogs' risk of being lost from the workforce through death or retirement.

Chapter 2

Literature review

Literature review

2.1 Introduction

From the establishment of European settlers in New Zealand, dogs have played a crucial part of farm life. Between 1856 and 1987, sheep farming was New Zealand's largest agricultural industry (Stringleman and Peden, 2015). At its height in 1982, there were over 70 million sheep in New Zealand, although this number has fallen to just under 30 million in 2019 (Beef + Lamb New Zealand, 2019). Farmers used dogs extensively for managing stock from the very beginning. Not much is known about the establishment and use of farm dogs in the early days of New Zealand sheep farming, although texts and books written for the general public make some assertions. It is said that station managers hired experienced British shepherds who brought their working dogs with them (Oliver et al., 2009; Walrond, 2008). The dogs were and still are used for gathering and mustering sheep and beef stock (Cogger and Sheard, 2017). Dogs are extremely helpful in farming New Zealand's rough terrain, and types of working dogs have been developed through selective breeding that are well suited to it. The skills of New Zealand's working farm dogs have always been a source of pride for farmers, and one of the earliest recorded sheepdog trials in the world was held in Wanaka, Otago in April 1867 ("Trial of Sheep Dogs," 1867).

Dogs continue to be widely used to work with livestock farms across New Zealand, and they are often seen as a quintessential part of rural New Zealand identity. This can be illustrated by for example the lasting popularity of "*Footrot Flats*", a comic strip and animated film about a farm dog and his owner (Forrester, 2019), or the fact that sheepdog trials continue to be a popular competitive sport in rural areas (The Project, 2021). However, there is a perception among some veterinary and farming professionals that that more people are starting to question whether working farm dogs are healthy and have good welfare. This perception fits within a general societal trend towards increased awareness for the welfare of animals in production systems (Hampton et al., 2020). To maintain their social licence to operate it could be that farmers will soon need to provide evidence that the health and welfare of their dogs is good and a high priority for the industry (Cobb et al., 2015; Hampton et al., 2020).

Dogs in New Zealand are protected through the *Animal Welfare Act* (1999) and the *Animal Welfare (Care and Procedures) Regulations* (2018). These are enforced by the Ministry for Primary Industries (Ministry for Primary Industries, 2021) and the Royal New Zealand Society for the Prevention of Cruelty of Animals (Royal New Zealand Society for the Prevention of Cruelty to Animals, n.d.). Minimum and recommended standards for the care of dogs are set out in the Code of Welfare for Dogs (National Animal Welfare Advisory Committee, 2018). However, the scientific underpinnings of the Code are unclear and the minimum requirements defined in the Code may not always be adequate to ensure good welfare. Little data are currently available about welfare in working farm dogs, or whether current standards and practices are adequate to ensure good welfare outcomes. Further study is necessary to determine whether improvements are necessary and to assure both the public and dog owners that working farm dogs are healthy and well cared for.

Studies of New Zealand working farm dogs have described population characteristics, common husbandry practices and prevalence of illness and injury (Cave et al., 2009; Jerram, 2013; Jolly et al., 2002; O'Connell, 2012; O'Connell et al., 2019; Sheard, 2014; Singh et al., 2011). Except for one survey of farm dogs treated in veterinary clinics (Cave et al., 2009) and another where researchers collected faecal samples and conducted eye examinations (O'Connell et al., 2019), all these studies relied on interviews with owners, which risks introducing biases connected with dog owners' ability to assess and recall health events regarding their dogs accurately. While gaining useful information about the dog population and prevalence of common illnesses and injuries, none of these studies have attempted to track dogs over time or to determine risk factors that may affect the incidence of injury, disease, or dogs dying or being retired from work.

Given the economic value of working farm dogs to their owners (Arnott et al., 2014a), and the limited current knowledge about how to improve health and welfare outcomes in these dogs, data is needed on factors that may impact dogs' health and longevity. Such data will improve our understanding of health in the working farm dog population, help develop evidence-based husbandry practices and highlight factors that may increase the risk of dogs dying or being retired from work. The aim of this review is to give an overview of population and health in working farm dogs in New Zealand, and to discuss ways in which the current gaps in knowledge may be investigated. The review is divided into six sections. The second section, after this introduction, discusses the use of observational studies as a way of investigating population health in animals. The third section describes the origins of modern working dogs and how behaviour and training define the different types of work the dogs do. The fourth describes what is currently known about population features and husbandry of New Zealand working farm dogs. The fifth section describes current knowledge about the health status of New Zealand working farm dogs and puts this into the context of what is known about health in pet dogs and other types of working dog. The sixth section briefly summarises the current knowledge about working farm dogs and highlights gaps that should be investigated further.

2.2 Observational studies for working dog health

This thesis will be using observational data to study the epidemiology of health and the loss of farm dogs from the workforce through retirement, euthanasia or death. This section of the literature review aims to provide an overview of common epidemiological techniques that can be used to study population health in working farm dogs and to introduce concepts that are used throughout the thesis.

Epidemiology has been defined as 'the study of disease in populations and of factors that determine its occurrence' (Thrusfield, 2018, p. 28). Epidemiological studies can be both observational and experimental. In experimental studies, the researchers choose which subjects are exposed to possible risk factors and examine whether there are differences in the outcomes of the groups. Observational studies, on the other hand, investigate naturally occurring health events where the risk factors under study are not under the control of the researchers. Although they are generally considered to produce lower quality data than experimental studies due to a lack of control over confounding effects and biases, observational studies are commonly used to investigate health in both human and animal populations. However, experimental studies are not immune to sources of error, bias or confounding (Grimes and Schulz, 2002a; Rothman, 2014). Additionally, experimental studies are often difficult or impossible to carry out as not all research questions can be answered appropriately, ethically or practically using an experimental approach. For example, an experimental study cannot provide data on which types of diseases are most commonly seen in a population, and if little is known about a certain condition it could be difficult to determine which exposures are worth investigating experimentally. Once hypotheses have been generated it would theoretically be possible to experimentally investigate, for example, the effect on working farm dogs of risk factors such as ambient temperature, diet, or previous injuries, by randomly assigning dogs to different exposures. However, the ethics of purposefully exposing dogs to certain risk factors might be questionable, and recruiting dog owners to participate in such studies would be difficult, especially if it requires them to make changes that could impair dogs' health and welfare or interfere with the effective running of their farms. Instead, observational studies can be designed and carried out that aim to answer questions about the frequency of and risk factors related to health events. Observational studies involve less control of the study population and their exposures than experimental studies, increasing the risk of encountering methodological problems. However, appropriate study design and analysis can account for most or all of the perceived disadvantages of observational studies. A systematic review of human health studies found that there were no differences in the conclusions of randomized controlled trials and observational studies of the same conditions, provided the studies were well designed and the results were analysed appropriately (Anglemyer et al., 2014). Here, we discuss the use of observational studies to investigate population health in veterinary medicine, how they can be used to investigate population health in working farm dogs, and common problems that are encountered when conducting and analysing data generated from observational studies.

2.2.1 Internal and external validity

Validity in scientific research refers to either internal validity, which is whether the results of a study are accurate in relation to what the researchers set out to measure, or external validity, which is whether the results and conclusions can be extrapolated to populations and situations other than those being directly studied (Dohoo et al., 2009, p. 35). In epidemiology, internal validity refers to whether the results obtained from a sample population are valid in relation to the source population they were sampled from. For example, a study might sample a fraction of dogs that were treated in a certain veterinary hospital. If the results of the study indicated that females in the population were more likely to break their legs than males, these results should be similar or identical if we had access to data from all dogs that were treated in the hospital. There are many reasons why the results of a study may be invalid and much of the methodology and study design that is used in scientific research has the goal of obtaining results that are as internally valid as possible. How some of these methods are used in epidemiological observational research is described in the following sections.

External validity in epidemiology refers to whether the results of a study can be extrapolated to a different or larger population, often called a target population, than the one that was directly studied (Dohoo et al., 2009, p. 35). Because their data are recorded from real-world situations rather than in controlled settings, observational studies have an advantage with regards to external validity in comparison to experimental studies. External validity should always be considered when reading or writing scientific studies. What the larger population consists of is often not defined and depends on the perspective of the reader. While it is valuable to be able to confidently make inferences about a larger population based on study results, it is rare to find a study that does not have any restrictions on the external validity of the results. For example, the results of a study investigating optimal nutrition in relation to health in pet dogs may be applicable to most pet and personal assistance dogs but less so to sporting dogs and working dogs in the police, military or on farm, which have different nutritional needs due to their high activity levels. However, such population differences do not mean that the study on pet dogs has no relevance to readers who are interested in nutrition in working and sporting dogs. Instead, they should take into consideration the differences between the relevant populations and assess the reported results critically based on the existing literature on the subject. While energy requirements and macronutrient needs are likely to be different between dogs with low and high activity levels (Wakshlag and Shmalberg, 2014), vitamin and mineral requirements might be more similar,

A common misconception around the concept of validity is that a study population must be representative of the source population in order for study results to be valid (Rothman et al., 2013). If the goal of the study is to describe the occurrence of disease or proportion of animals exposed, this is appropriate. However, if the aim is to investigate the effects of risk factors or differences between groups, the focus should be on gaining large enough samples in all the groups of interest to be able to analyse the data appropriately rather than attempting to obtain a sample that is representative of the study population. The goal of the study should therefore be considered before sampling is carried out and care should be taken to ensure that the data collected from the sample population will enable researchers to answer the question they intend to investigate.

2.2.2 Measuring health and mortality

Describing how common a disease or health event is in a population and how quickly new cases develop are fundamental goals of epidemiology. Such data are important in themselves as they can provide important information to stakeholders about which types of conditions are most likely to be a problem in the population. Additionally, data can be examined for differences between groups or whether certain factors change the rate at which cases develop. The concepts described here in relation to measures of disease and mortality can also be used to measure other outcomes of interest such as pregnancies, whether animals are sold, or the frequency of veterinary examinations. No matter what the outcome of interest is, there are a number of different ways to measure their occurrence, and to examine whether they are associated with population attributes (e.g. sex, breed or age) or other risk factors.

Measures of disease frequency are dependent on a number of factors that should be considered both when designing studies and interpreting results. Some studies last over extended periods of time while others collect data at a single time point. Animals can be at risk of developing some diseases only during a short time period (for example diseases related to pregnancy), during long periods of time (for example the risk of developing lameness, or of dying, are lifelong), or intermittently (for example if they recover from an illness and return to being at risk of developing the same illness). Additionally, different injuries and conditions develop more or less frequently and can have long or short durations, influencing the chance that they will be recorded during the course of a study. Thus, epidemiological data are highly dependent on a number of factors related to time which must be taken into consideration when results are interpreted.

2.2.2.1 <u>Incidence</u>

Incidence is the measure of the number of new cases of a disease or an outcome of interest that develop in a population over time (Rothman, 2002, p. 24). To be able to measure incidence only those individuals that are at risk of developing the disease are included in the study population and these animals are followed until they develop disease or reach the end of the study period. Incidence measures can be used to analyse factors that affect the risk of an outcome occurring, because the data on exposures are collected before the outcome. This allows researchers to make inferences about causation that would not be possible if data on the outcome and the exposure were collected simultaneously.

Defining which animals are at risk of developing disease is an important first step in carrying out research aimed at collecting data for incidence calculations. In most cases which animals are at risk is interpreted broadly as any animal that may plausibly develop the disease of interest. Animals that have the disease at the beginning of the study are excluded from analysis as they are not considered to be at risk. Similarly, animals may be excluded due to being immune from previous infection or vaccination, or not possessing the necessary prerequisites for disease. For example, females are not at risk of developing testicular cancer.

Incidence is commonly reported as either incidence risk or incidence rate (Thrusfield, 2018, p. 67). Incidence risk is the proportion of animals at risk of developing disease that actually developed the disease during the study period. Defining the duration of the study period or the amount of time animals were at risk is important since it is not possible to interpret incidence unless a measure of time is included. For example, a 10% incidence risk of a dog developing lameness in the course of a week is a much higher risk than a 10% risk of developing lameness in a year. Incidence risk is useful for making predictions about the probability that individuals will develop a condition. For example, a study of dorsometacarpal disease in racehorses enrolled 335 horses and followed them for two years (Verheyen et al., 2004). During the course of the study 79 horses developed disease, resulting in a 24% incidence risk that horses develop dorsometacarpal disease in a two-year period. However, incidence risk does not take into consideration the duration of the disease, whether animals recovered or whether animals develop more than one case of disease (Dohoo et al., 2009, p. 76).

Incidence rate is the number of animals at risk that developed the disease per unit of time animals were at risk during the course of the study and is calculated as the number of cases divided by the total animal-time at risk. Time at risk refers to the amount of time that passed between the first observation of an animal and the time when it either developed the disease or reached the end of the study, and total animal-time at risk is the sum of the time at risk of all animals in the study. Animals can also contribute more than one period of time at risk. For example, if an animal develops the disease under study and recovers, and it is possible to develop the disease more than once, the animal would contribute to time at risk before the first instance of illness and after the point of recovery. Time at risk can be expressed as any unit of animal time at risk, such as days, months, years, etc., depending on what is reasonable in the context of the study. For example, in the study of dorsometacarpal disease in racehorses by Verheyen et al. (2004) 335 horses were at risk for a total of 4235 horse-months, during which 79 developed disease. This corresponds to an incidence rate of just under 2 injuries per 100 horse-months. In other words, if 100 horses were followed for one month, it is likely that two of them would develop dorsometacarpal disease. Incidence rate expresses how many instances of an outcome are likely to occur during a period of time, and is often used in studies investigating risk factors related to disease occurrence.

2.2.2.2 Prevalence

Prevalence is the proportion of all individuals in a population that are affected by a disease or an outcome of interest at a point in time or over a certain time period, independently of whether the cases are new or pre-existing (Thrusfield, 2018, p. 67). The measured prevalence is linked to both the incidence rate and the duration of the disease, with duration referring to how quickly animals either recover to become disease free or die and therefore leave the population (Thrusfield, 2018, p. 70). Conditions with similar durations have different prevalence if one has a low incidence rate and the other a high incidence rate. Similarly, diseases with short durations, such as most respiratory infections or conditions such as gastric dilatation volvulus that cause rapid death unless treated, have low prevalence despite being relatively commonly occurring. Conversely, diseases with long durations, such as arthritis, are likely to have relatively high prevalence. This link between prevalence and duration can cause somewhat counterintuitive effects. For example, developing a treatment that increases the lifespan of animals affected by a disease is likely to result in an increase in the prevalence of the disease as the animals are no longer dying. Depending on the disease being studied, prevalence may therefore be a poor measure of whether a treatment is effective. However, prevalence does indicate how commonly diseases or conditions are found in populations and is very useful, for example, to clinicians considering differential diagnoses in animals, to governments when determining which diseases are of economic importance, or to researchers deciding which conditions should be prioritised when planning future research. In cases where little is known about the epidemiology of a condition in a population, a measure of prevalence can be an important first step. When planning an epidemiological study, it is therefore important to think about the relationships that exist between measures of prevalence, incidence and the duration of the outcome of interest, and whether the data that will be collected can be used to answer the research questions.

2.2.3 Types of epidemiological studies

2.2.3.1 Cross-sectional studies

Cross-sectional studies collect data from a population at a point in time or during a specified time period (Dohoo et al., 2009, p. 158). Cross-sectional studies always collect prevalence data and they can be described as ‘snapshots’ of the status of the outcomes of interest in a population. Because cross-sectional studies record data on outcomes and exposures from the same time or time period it is impossible to use cross-sectional data to make inferences about causal links (Rothman, 2002, p. 90). For example, a study may find that working farm dogs on smaller farms with easier terrain have a higher prevalence of degenerative joint disease than dogs on large, hill country farms. It would be easy to conclude that dogs on small, easy farms are at higher risk of joint disease. However, an alternative and more plausible possibility would be that dogs on easier farms are able to stay in work for longer despite the presence of joint disease and that some dogs on larger, more demanding farms are relocated to farms with easier terrain if they develop signs of disease. However, to determine whether this is the case the data needs to include records of when exposures and outcomes occurred in relation to each other. Such data cannot be recorded using a cross-sectional study.

Compared to other types of observational studies, cross-sectional studies can be relatively easy to plan and carry out (Grimes and Schulz, 2002b), and they often do not require the cooperation of many participants over long periods of time. In addition, cross-sectional studies can provide data that are very useful for administrative purposes and planning disease control strategies, and they can generate hypotheses that future investigations can build on (Thrusfield, 2018, p. 72). In veterinary epidemiology cross-sectional studies are common and many of the studies cited in this literature review are cross-sectional (Cave et al., 2009; Jerram, 2013; O’Connell et al., 2019; Sheard, 2014; Singh et al., 2011).

2.2.3.2 Case-control studies

In most epidemiological studies, study groups are chosen based on exposure to risk factors before determining whether there are differences in the outcome of interest. In contrast, in case-control studies the study groups are chosen based on whether they have the outcome of interest before determining whether there are differences in their exposures to certain risk factors (Vandenbroucke and Pearce, 2012). Animals (or groups of animals) that have the outcome of interest are called the cases, and the animals that do not are the controls. Good case-control study design depends on having well-defined criteria for what constitutes a case and a carefully chosen control group. An appropriate control group should be free of the outcome of interest, representative of the population at risk of the outcome and selected independently of the exposure of interest (Grimes and Schulz, 2005). Selecting appropriate controls can be difficult to do in practice for a number of reasons including the lack of well-defined source populations for the cases. The risk of introducing bias due to poor selection of controls is one of the biggest risks / limitations of case-control studies (Grimes and Schulz, 2002c).

Case-control studies can be both prospective, where cases are selected as they appear in a population and retrospective, where known cases are selected and their history of risk factor exposure is recorded after the fact. Well-designed prospective case-control studies can provide excellent data, but consume more time and resources than retrospective studies (Vandenbroucke and Pearce, 2012). However, because retrospective case-control studies select cases and controls before examining the groups for risk factors, they share the weakness of cross-sectional studies in not measuring the duration of disease, and depend on records or interviews to determine whether a risk factor was present before the onset of disease (Thrusfield, 2018, p. 321).

Because the subjects under study are chosen based on outcome status, case-control studies are especially useful in studying rare outcomes or diseases. However, for the same reason case-control studies are limited to the study of single, targeted outcomes. Additionally they cannot be used to explore, for example, which types of illnesses or injuries most commonly occur in working farm dogs. As one of the aims of this thesis is to determine which types of health outcomes in working farm dogs warrant further investigation, case-control studies were not considered to be appropriate.

2.2.3.3 Longitudinal studies

Longitudinal studies, sometimes termed cohort studies, are observational studies that follow a sample population and record data on risk factor exposures and outcomes over a period of time (Grimes and Schulz, 2002c). Data collection procedures for longitudinal studies are often similar to cross-sectional studies, but rather than collecting data only once it is collected from the same population repeatedly. Because longitudinal studies collect data from the same individuals more than once, they can be used to calculate incidence and to determine the order in which exposures and outcomes occurred (Grimes and Schulz, 2002c). Depending on data collection procedures, they may also be able to determine disease duration with some accuracy. These advantages allow researchers to make causal inferences that may not be apparent when using cross-sectional or case-control data (Thrusfield, 2018, p. 72). In the example involving degenerative joint disease in working farm dogs working on flat and steep terrain, the information about which type of terrain dogs work on can be collected at the start of the study and the number of disease-free dogs that subsequently developed degenerative joint disease can be compared between each type of terrain. If dogs working on steep hill country terrain develop more cases of disease than the remaining study population it can be postulated that the additional strain of working in such terrain contributes towards the development of degenerative joint disease.

A strength of longitudinal studies in relation to case-control studies is that because there is no need to select cases at the beginning of the study, more than one outcome can be investigated longitudinally in the same sample of animals (Euser et al., 2009). An example of this is the Golden Retriever Lifetime Study which is following 3000 dogs throughout their lifetime with the primary aim of studying the occurrence of cancers (Guy et al., 2015). The nature of the data allows researchers to investigate a range of exposures and outcomes, and studies that analyse longitudinal data have so far been published on gonadectomy as a risk factor for obesity and orthopaedic injuries (Simpson et al., 2019) and on the effect of inbreeding on reproductive fecundity (Chu et al., 2019). In working farm dogs there is a range of exposures and conditions that may affect dogs' overall health, welfare and lifespans. A longitudinal study allows us to collect data and investigate risk factors related to a number of these outcomes. Additionally, smaller cross-sectional studies can be conducted using the data collected for the longitudinal study. In this thesis, an initial cross-sectional study of the health status in the sample population on enrolment will be used to inform which outcomes of interest will be analysed longitudinally.

While longitudinal studies are the best available choice when exploring the incidence of and risk factors related to outcomes of interest, they are also subject to problems related to how the data is collected, the intervals between follow-up data collection and loss of subjects to follow-up. In order to detect rare conditions, the sample size of the population needs to be large, and the follow-up time as long as possible. Following a large population over a lengthy period of time is both resource intensive and poses the risk of significant losses to follow-up as participants lose interest or move out of the study population (Rothman, 2002, p. 27). Case-control studies are often better suited to answer research questions relating to rare outcomes than longitudinal studies (Schulz and Grimes, 2002). However, because exposure status is determined at the outset longitudinal studies have an advantage when investigating rare exposures (Grimes and Schulz, 2002c). An additional weakness of longitudinal studies is that to detect conditions that resolve quickly data collection must be either continuous or follow-up intervals must be short enough to detect a reasonable proportion of cases. Collecting data at a high enough frequency can be cost-prohibitive, especially if the data is collected through pre-arranged physical examinations or interviews with participants. When designing a longitudinal study, decisions around the necessary sample size and follow-up intervals must therefore consider not only statistical power, but also the risk of losing participants along the way and the costs surrounding data collection.

2.2.4 Error, bias and confounding in observational studies

Like all scientific research, observational studies are vulnerable to a range of methodological problems that can cast doubt on their results. Such issues need to be considered at every stage of research in order to ensure that any inferences drawn from the results are valid. Error in epidemiological research can be random or systematic, and both can change the conclusions of a study if not appropriately dealt with (Rothman, 2002, p. 94). Random error can be defined as the variability that is left in a study after biases and confounders that are present in the data have been accounted for (Rothman, 2002, p. 113) or the variability that is present due to chance (Thrusfield, 2018, p. 383). Random errors do not change the measured relationships between study groups, but they can reduce our confidence that our results are close to the 'true' values in the study population. While random error cannot be removed through analysis, it can be minimised through careful study design and accounted for through the use of confidence intervals and statistical analysis. Systematic error is usually termed 'bias' and can be a result of the way the study subjects were selected, how measurements were carried out or confounding by a factor that has not been accounted for. As such, systematic error can be minimised through both study design and data analysis. The following sections describe some common types of bias and confounding and how they can be dealt with.

2.2.4.1 Selection bias

Selection bias refers to a situation where the way data was collected causes an over- or underestimation of exposures or outcomes of interest (Jepsen et al., 2004). For example, many observational studies rely on convenience samples, often because there is no available sampling frame from which to draw a random sample. Convenience samples are often based on geographical location, being known to the researchers conducting the study or being connected to an organisation such as a special interest association or a veterinary clinic. An example of a study that is likely to have had significant selection bias is one which investigated differences in the prevalence of hip dysplasia in the two main types of working farm dogs in New Zealand, Heading dogs and Huntaways (Hughes, 2001). Dog owners who were interested in the study were recruited through advertisement in a veterinary clinic newsletter and by the author personally approaching people to ask them to participate. The stated reason for the study being carried out was the author's personal observation that hip dysplasia seemed to be becoming more common in Huntaways over the previous two decades. As such it is possible that dog owners who suspected that they had a problem with hip dysplasia in their Huntaways were more likely to both be approached for recruitment and to participate in the study. The study found that Huntaways were at much higher risk of having hip dysplasia than Heading dogs. While this result may be valid, it is difficult to rule out selection bias for Huntaways with hip disease in this study. However, this does not suggest that the result should be discarded, only that caution should be exercised when extrapolating from the study, and that more studies should be carried out to attempt to confirm or deny the findings.

Other types of selection bias include bias in loss to follow-up, and selective entry bias. In a case of selective entry bias, subjects are more likely to be recruited into the study for reasons that are associated with an exposure factor or an outcome of interest. Selective entry bias is often called the 'healthy worker effect' in human studies (Kirkeleit et al., 2013; Monson, 1986). For example, working farm dogs that develop severe musculoskeletal disease are more likely to be euthanised or retired, and as such are both less likely to be enrolled in a study and more likely to be lost to follow-up. This is an important problem in veterinary epidemiology when studying populations that have been selected for some type of performance, such as meat or milk production, stock work or racing performance. In working farm dogs, by selecting adult, actively working dogs researchers are excluding dogs that have been removed from the working population due to for example illness or injury. As such, the section of the population that is actively working is likely to be healthier than the population of farm dogs that are not working. The healthy worker effect can be an important problem if the intention of the researchers is to extrapolate their results to the general population, independently of working status. Efforts should be made to minimise selection bias during the study design phase. However, if possible effects on the results are acknowledged and discussed, a study is not necessarily invalidated due to the presence of selection bias.

2.2.4.2 Information bias

Information bias refers to misclassification or measurement error of exposure or outcome variables that may affect the study results (Dohoo et al., 2009, p. 255). Differential misclassification, is where data collected from a subgroup of the study population consistently contain wrong measurements for a certain value, possibly changing the significance of the results (Jepsen et al., 2004). In retrospective case-control studies that depend on interviews for data collection, recall bias is a common type of differential misclassification (Schulz and Grimes, 2002). For example, people who develop serious diseases such as cancer or owners of livestock that experienced disease outbreaks may try to determine what caused the illness, making them more likely to remember details about exposures than controls. In longitudinal studies, information bias is less likely to affect the initial measurement of exposures. However, since data is collected more than once, knowledge about past exposures may influence how outcomes or time varying exposures are recorded or assessed (Thrusfield, 2018, p. 244). Another type of information bias is non-differential misclassification or measurement errors, which happens uniformly throughout the population. This may happen if for example more than one person (or group) is responsible for data collection and there are disagreements or misunderstandings about how the data is collected. This kind of information bias can be difficult to completely exclude, especially in large studies involving multiple people collecting data. Unless there are substantial differences in the sub-populations being sampled, such differences in data collected by different people of groups should cause non-differential errors in the collected data. While such errors won't change the relationship between the exposure and the outcome, it can dilute the effect and make it more difficult to detect (Jepsen et al., 2004; Rothman, 2002, p. 101). Choosing an appropriate study design and providing training in how data should be collected and recorded in standardised ways can minimise the risk of both differential and non-differential misclassification errors. Additionally, some issues can be accounted for using multivariable analysis techniques. For example, if there is suspicion that there are group differences in how data was collected, these groups can be included in the analysis as fixed or random explanatory effects.

2.2.4.3 Confounding

Confounding is a mixing of different effects on an outcome (Grimes and Schulz, 2002d). When a separate factor influences the apparent association between an exposure and an outcome, this factor is called a confounder. In a classic example from human medicine increasing birth order was found to increase the risk of whether children were born with Down Syndrome (Stark and Mantel, 1966). However, when the age of the mother was taken into account the effect of birth order was no longer seen to have any effect. Birth order was found to affect the occurrence of Down Syndrome because older mothers are more likely to have had several children, not because birth order was in itself a risk factor. In this way birth order acts as a confounder on the effect of maternal age.

In observational studies, confounding can be dealt with by restricted sampling, by matching, or with analytical techniques (Dohoo et al., 2009, p. 275). Both restricted sampling and matching removes the removes the possibility of analysing the confounder as a possible risk factor. If researchers choose to use these methods they should therefore be certain that they do not want to explore the effect of the variable they are controlling for. Restricted sampling is when the sample population is restricted to those who belong to a certain group within a confounding variable (Rothman, 2002, p. 109). For example, in studies of mammary cancer, the entire sample population will be chosen to be female since males are extremely unlikely to develop breast cancer. Similarly, the sample population can be chosen from within a certain age group, breed or animals that are fed a certain type of food. Matching is done by ensuring that the distribution of the confounding variable is the same in both the exposed and the non-exposed groups (Dohoo et al., 2009, p. 276; Thrusfield, 2018, p. 334). For example, if we wanted to analyse the effect of birth order on the risk of children developing Down Syndrome, we could do so by choosing subjects in such a way that the age distribution of the mothers was the same at all levels of birth order. In case-control studies matching can introduce selection bias by changing the distribution of the exposure to be more similar between cases and controls due to the association between the confounder and the exposure. Matching should therefore be used with caution in such studies.

If the sample size is large enough multivariable analytical techniques are usually used to account for confounding as it allows researchers to account for multiple confounders in a cost-effective way. By using such techniques, several variables can be examined as risk factors simultaneously, while at the same time their confounding effects on each other are accounted for. Multivariable linear and logistic regression modelling is commonly used when analysing risk factors in large populations, while survival analysis is a powerful tool when analysing time to event data (Grimes and Schulz, 2002d; Moore, 2016).

In addition, mixed effects modelling can be used to account for clustering by for example farm (Zuur et al., 2009). In this thesis, multivariable logistic regression modelling was used in Chapter 6 to analyse risk factors related to death and retirement in working farm dogs. As we had a range of possible risk factors, many of which were also possible confounders, multivariable modelling was judged to be the best way to analyse the data.

The epidemiological concepts and techniques described in this section on observational studies were considered when writing the remainder of this literature review, when designing the study on New Zealand working farm dogs that formed the basis for this thesis, and when analysing the resulting data. It is therefore hoped that the section provides context when critiquing the existing literature on working farm dogs, and the work detailed in the remainder of this thesis.

2.3 The origins and behaviours of working dogs

Working dogs are used to perform a large variety of tasks, such as scent detection, guarding, livestock herding and providing assistance to the disabled, and specialised types or breeds of dogs have been developed to carry out certain types of jobs. Due to their acute senses, trainability and intelligence, dogs are able to carry out many jobs at a lower cost, better and more reliably than humans and it has been suggested that some dogs could be considered to possess true expertise in their fields of work (Helton et al., 2009). The development of specialised types of working dogs is likely to have been gradual, with dogs following hunting parties and livestock herders who found them to be useful both in tracking and hunting prey, and in keeping carnivores away (Coppinger and Coppinger, 2001; Stafford, 2007). Over time, as people started to rely on dogs to carry out certain tasks, they may have started to cull those dogs that did not show the desired abilities or behaviours, laying the groundwork for modern specialised dog breeds. For example, livestock guardian dogs are highly specialised and recognizable as distinct types or breeds, such as the Italian Maremma and the Turkish Anatolian, but traditionally they have not been purposefully bred (Coppinger and Coppinger, 2001; Lord et al., 2017). Rather, they have been allowed to breed freely unless they were culled for undesired behaviours such as aggression towards livestock, died from illness or injury, or were left behind when they failed to follow the flock between seasonal grazing areas. In this way working breeds have naturally developed that are well suited to their jobs and local environments. It's likely that many working dog breeds have similar origins as livestock guardians, with humans culling unwanted individuals rather than breeding specific dogs to each other. The modern concept of dog breeds, meaning genetically isolated pedigree dogs as opposed to 'mongrels', was not conceived of until the late 19th century with the advent of dog shows and the founding of the British Kennel Club (Case, 2005). The Kennel Club's focus on physical appearance and pedigree breeding has led to the loss of working ability in a number of pedigree dog breeds that originated as working dogs, such as the English Bulldog or the Old English Sheepdog (Coppinger and Coppinger, 2001). However, working dogs are still widely used, and many of them have been specifically bred to be able to carry out certain types of work.

To be able to carry out their jobs, working dogs need to have the appropriate behavioural traits, be trainable and to be motivated to carry out their tasks. Working dogs such as guide dogs, military, police and scent detection dogs need to remain calm and continue working at the direction of their handler even in stressful environments and over extended periods of time (Haverbeke et al., 2009; Pfaffenberger and Scott, 1976; Sinn et al., 2010). While all working dogs need to have a strong ability to follow directions from their handlers, their specific behaviours and personality traits vary depending on the type of job they are trained to carry out. For example, in addition to being able to be calm and keep working in chaotic situations, guide dogs also need an ability for independent decision making, for example by the dog refusing to cross a road when it sees a car approaching. Therefore, behaviours described as aggressive and distracted are commonly associated with guide dogs being rejected from training (Arata et al., 2010; Asher et al., 2009; Goddard and Beilharz, 1985, 1984, 1983; Tomkins et al., 2011). In comparison, military and police patrol dogs are trained to defend their handlers and to help apprehend hostile persons and as such need to be able to display aggressive and defensive behaviours in specific situations (Haverbeke et al., 2009; Sinn et al., 2010; Svartberg, 2002).

Less research has been carried out to investigate the specific behaviours and traits that are needed in livestock herding dogs, than in guide dogs or military and police dogs. However, an Australian survey found that breeders and handlers of Australian herding dogs valued trainability, motivation, confidence and friendliness in their working dogs, while excitability was a 'Goldilocks' trait that needed to be present but not too strong (Early et al., 2019). Additionally, 54% of 864 dogs that were reported as having been dismissed from training by Australian herding dog handlers were disqualified due to a lack of natural working instinct or ability (Arnott et al., 2014b). Such working instincts are thought to be modified forms of wild canine hunting behaviours that have been retained in many modern working dogs, such as livestock herding dogs and hunting dogs (Lord et al., 2017). The behaviours take forms such as farm dogs stalking and chasing stock, pointers and setters focusing intensely towards prey animals, and retrievers tracking and grabbing killed prey. The complete hunting behavioural pattern is described in Table 2-1. Livestock herding dogs have retained the first four stages of the hunting sequence, stopping before injuring or killing stock. These behaviours are reinforced during training, with stalking and chase behaviours being reinforced and directed, and behaviours that may injure the stock usually being discouraged (McConnell and Baylis, 1985). However, dogs such as Queensland Blue Heelers and Kelpies are sometimes trained to chase and bite cattle to encourage them to move

(Coppinger and Coppinger, 2014). Dogs that do not display the natural hunting behavioural sequence cannot be trained as herding dogs, however if the appropriate instincts are present the dogs are highly motivated to perform them and need to be taught to direct and restrain their behaviour (McConnell and Baylis, 1985). During training of herding dogs, the dogs are given extensive obedience training and taught commands that instruct them which direction to move, as well as when to stop or to move forward (Cavanagh, 1991; Dalton, 1996; Lithgow, 1991; McConnell and Baylis, 1985). In this way handlers can control and direct dogs' innate behaviours, while the work itself is used as a reward for the desired behaviour (Payne et al., 2015).

Table 2-1: The canine hunting sequence. Adapted from Coppinger and Coppinger (2001) and Lord et al. (2017).

Stage	Name	Explanation
1	Orient	The prey is discovered and the predator orients towards it
2	Eye	The predator stares at the prey
3	Stalk	The predator carefully moves closer to the prey
4	Chase	The predator chases the prey at speed
5	Grab-Bite	The predator uses its teeth to grab and hold the prey
6	Kill-Bite	The predator uses its teeth to kill the prey
7	Dissecting-Bite	The predator uses its teeth to dissect and consume the prey

It is important to note that no matter how good a dog's innate behaviours are, proper socialisation, training and experience are essential for it to become a useful working dog (Butler, 1999; Cavanagh, 1991; Coppinger et al., 1987; Dalton, 1996; Lithgow, 1991). A sheep guardian dog that is not socialised with sheep at a young age will not see them as social companions and may show aggressive behaviours towards them as an adult (Coppinger et al., 1987; Coppinger and Coppinger, 2001). Similarly, a young dog that shows strong instincts appropriate for stock herding will not become a useable working dog without extensive obedience training to teach it to work according to the direction of its handler (Butler, 1999; Cavanagh, 1991; Dalton, 1996; Lithgow, 1991). The importance of training is highlighted by the high value Australian herding dog handlers put on trainability in their working dogs (Early et al., 2019). Additionally, effective dog training and work is dependent on the skills of the handler and the communication between dog and human (McGreevy et al., 2017). In Australian stock dog handlers, personality traits have been linked to the likelihood of using certain techniques in training, the level of understanding of how training affects the dogs, and the likelihood of participating in herding trials (Payne et al., 2015). In addition, dog owners with a higher level of conscientiousness were likely to have a higher rate of successfully trained dogs (Arnott et al., 2014b). Thus, it is thought that effective working dog behaviour is dependent on a mixture of instinctual behaviours, appropriate socialization at an early age, thorough training and excellent communication with a skilled handler before a dog can be relied upon to carry out its given task.

2.4 Population features and husbandry of New Zealand working farm dogs

2.4.1 Types of dogs

In New Zealand, farmers generally divide working dogs into two groups based on the way they interact with stock (Dalton, 1996; Oliver et al., 2009; Redwood, 1980; Rennie, 1984). Heading dogs work silently, relying on positioning and 'eye' (see Table 2-1) to head off, gather and redirect stock, while Huntaways use their powerful bark to drive or 'hunt' stock forward (Oliver et al., 2009, p. 11). In addition, some farmers use Handy dogs, which are allrounders characterised by their ability to carry out the work of both Heading dogs and Huntaways, although often with less skill and refinement than a more specialised dog (Redwood, 1980, p. 45; Rennie, 1984, p. 12). Most accepted definitions of what a breed of animal is focuses on the visual appearance of the animal (Langer, 2018). While New Zealand Heading dogs and Huntaways can easily be recognised by appearance, there is a great deal of variation in their coats and body types and they are classed by working ability rather than pedigree. Any dog that displays the correct abilities can be used as a Heading dog or Huntaway on farm, although in practice they are bred in separate lineages. New Zealand working farm dogs can be added to a stud register based on proven ability in competitive herding trials (New Zealand Sheepdog Trial Association, 2018) and the Huntaway has in recent years been acknowledged as a breed and given an entry with Dogs New Zealand (formerly the New Zealand Kennel Club) (Dogs New Zealand, 2013). However, efforts have been made to preserve their working ability and prevent dogs from being bred based on physical appearance alone. The breed standard specifies that Huntaways are only to be registered based on recorded working ability with the New Zealand Sheepdog Trial Association, and that they are not to participate in dog shows.

No census or systematic analysis has been done to determine the total number working farm dogs in New Zealand, although it has been estimated that there are around 200 000 dogs working sheep and beef stock (Cogger and Sheard, 2017). The New Zealand working farm dog population consists of around 50% Huntaways and 40 – 50% Heading dogs, with the remainder consisting of various other types of herding dogs such as Handy dogs, crossbreeds, Bearded Collies and Australian Kelpies (Cave et al., 2009; Jerram, 2013; Singh et al., 2011).

2.4.2 Sex distribution and neutering

Studies of working farm dogs in New Zealand have found that males make up of 54% to 59% of the population (Cave et al., 2009; Jerram, 2013; O'Connell et al., 2019; Singh et al., 2011). Varying degrees of overrepresentation of male dogs is also reported in military, police and sled racing dogs (Moore et al., 2001; Sinn et al., 2010; Tiira et al., 2020; von Pfeil et al., 2015; Worth et al., 2013). The reasons why certain classes of working dogs are more likely to be male are not known. However, there may be a general perception among trainers and handlers that male dogs perform better than female dogs in certain types of work. For example, males dogs are thought to be more aggressive than female dogs in general (Hart and Hart, 2017; Lockwood, 2017). When considering that livestock herding is a form of hunting behaviour and as such aggressive in nature, it may be that male working farm dogs are more likely to become successful workers than females. Additionally, some owners may prefer males for practical reasons such as to avoid problems related to oestrus and unwanted pregnancies.

Five to six percent of working farm dogs have been reported as being neutered, with generally more females being neutered than males (Cave et al., 2009; Jerram, 2013). This is much lower than that reported in other types of working dogs where, depending on the type of work, large proportions of the populations tend to be neutered (Caron-Lormier et al., 2016; Hoummady et al., 2016; Moore et al., 2001; Tiira et al., 2020; Tomkins et al., 2011). None of the studies cited provided information on how decisions were made around neutering of dogs, and no data is available on why most farm dogs are left entire. However, anecdotally it has been said that some farmers feel that neutering could impair dogs' working ability. Another, possibly more likely, reason for not neutering farm dogs is that dog owners want to breed dogs that are proven to be good workers. The quality of a dog may not be apparent until it is two or three years old or more, preventing owners from neutering young dogs. Additionally, some dog owners may feel that the cost of neutering in terms of money, time and lost work during recovery is not justified by the potential benefits. However, more information is needed on why farm dogs owners choose to not neuter their dogs, and whether neutering has any effect on the health and welfare of working farm dogs.

2.4.3 Housing

To date two studies have examined how working farm dogs in New Zealand are housed. A survey of farm dogs in the Manawatu-Wanganui region found that dogs were housed individually, with 95% housed in purpose built enclosed shelters with runs (Jerram, 2013). Eighty-eight percent of these runs were caged areas attached to a box while 12% consisted of a chain attached to the shelter. Twenty-two percent of dog shelters contained bedding, and of these 17% had had the bedding changed in the 12 months before the survey was carried out. Eighteen percent of shelters had been cleaned in the same

12 month period. Bedding consisted of a variety of materials including sheep's wool, straw, blankets, carpet and a vehicle floor mat. Ninety-eight percent of dogs had access to water in the shelter and 69% of dogs had their food placed on the floor of their shelter. A second study collected less detailed information, but reported that a majority of dogs were housed in non-movable shelters (90% of dogs) (O'Connell et al., 2019). Eighty-four percent of dogs enrolled in the study by O'Connell et al had kennels with raised slatted floors and 13% had kennels with raised solid floors. Although not reported in the published article, the study also found that 89% of farm dog owners cleaned the dogs' kennels at least once yearly (O'Connell, 2012). No further information is available about the construction or quality of farm dog shelters, or the specific housing needs of working farm dogs.

Although the Code of Welfare for dogs issued by the New Zealand government contains minimum requirements and recommended best practice for housing dogs, including working dogs (National Animal Welfare Advisory Committee, 2018), it is uncertain what data these recommendations are based on. General recommendations for appropriate housing for dogs exist, for example for working and laboratory dogs (Gaines, 2008; Prescott et al., 2004; Rooney et al., 2009). As many of the specific recommendations around kennel construction and environmental enrichment are based on dogs housed in institutional settings, they are difficult to transfer directly to working farm dogs. However, the Code for Welfare requires that dogs are housed in fully shaded, dry and ventilated kennels, that they are provided with protection from extreme cold or heat and given the opportunity to keep warm in cold weather (National Animal Welfare Advisory Committee, 2018). Additionally, dogs must be given access to water and separate areas for urination and defection at all times, and waste must not be allowed to accumulate in the area where the dog is kept. In addition to these minimum requirements, a range of best practice recommendations are given. For example these include recommendations that kennels should be draught free, that dogs should be provided with bedding if they are housed on hard surfaces, and that housing should provide both protection from poor weather and shade on hot days. More data is needed to determine whether freestanding outdoor kennels such as those recorded by Jerram (2013) and O'Connell et al. (O'Connell et al., 2019) meet these best practice recommendations. If kennels are susceptible to drafts through for example having slatted floors, are un-insulated and/or don't contain appropriate bedding, it may be difficult for dogs to maintain their body temperatures, especially overnight in winter. Increased energy expenditure due to thermoregulation can depriving dogs of energy they could use at work, and worst cause them to lose body weight. Providing some type of soft, warm bedding to dogs is highly recommended (Prescott et al., 2004; Rooney et al., 2009), as it is an effective way to insulate kennels against low temperatures, provides the dog with somewhere comfortable to rest and can act as environmental enrichment. Additionally, bedding helps prevent the formation of callouses and sores that can develop on pressure points such as dogs' elbows and hocks

(Prescott et al., 2004). However, in order to make recommendations about whether current housing for working farm dogs are appropriate, more data is needed on how working farm dogs are commonly housed are and how housing affects their health and welfare.

2.4.4 Nutrition and feeding

Working farm dogs are usually fed once daily on a combination of commercial rations, meat and offal sourced on farm (Jerram, 2013; O'Connell et al., 2019; Singh et al., 2011). Jerram (2013) found that 17% of farmers in the Manawatu-Wanganui region fed their dogs less than once daily. However, O'Connell et al. (2019) and Singh et al. (2011) both found that 97% of farm dog owners reported feeding their dogs daily. To determine whether current feeding practices are adequate, more detailed information is needed about the dogs and their energy expenditure during work, and about the size and composition of meals. In comparison to active pet dogs, endurance work such as stock herding has been assessed to generate a moderate to high increase in energy expenditure (Wakshlag and Shmalberg, 2014). A study in New Zealand used accelerometry activity monitors to investigate energy expenditure and global positioning system (GPS) trackers to measure distance travelled by 52 working farm dogs during peak and off-peak work periods (Singh, 2013). It was found that dogs travelled around 10 km daily during off-peak periods and 20 km daily during peak periods. A study of Australian farm dogs recorded an average of 30 km travelled per dog per day during a peak work period, with one dog travelling 68 km on a single day (Early et al., 2016). While Early et al.'s results indicate that Australian farm dogs may travel longer distances than New Zealand dogs, their study was smaller than that carried out by Singh and involved data collection during a single week of peak work on only one farm. It is possible that there were individual dogs in Singh's study that travelled similar distances during their peak work periods. However, New Zealand working dogs were estimated to use a mean of around 168 kilocalories per kg bodyweight$^{0.75}$ (kcal/kg BW$^{0.75}$) per day during peak work and 128 kcal/kg BW$^{0.75}$ per day during off-peak work (Singh, 2013). Estimated peak work requirements were slightly higher than those of racing greyhounds in training (Hill et al., 2000) and lower than hunting dogs working for around three hours in cold weather (Ahlstrøm et al., 2011), while off-peak energy requirements were only slightly higher than those of an active pet dog (Wakshlag and Shmalberg, 2014). These energy requirements seem inconsistent with the long distances farm dogs were recorded to travel, which suggest a moderate to high increase in workload in comparison to a pet. The equation used to calculate energy expenditure in working farm dogs was developed using only six dogs with a small range of body weights and was not validated using a separate set of dogs with known energy expenditures (Singh, 2013). As such, it is difficult to use Singh's results to compare working farm dogs to other populations of dogs where more research has been carried out. If Singh's estimation of energy expenditure is an underestimation, general feeding recommendations for endurance racing dogs such as sled dogs in training may be applicable to stock herding dogs in heavy work. If however, Singh's estimation is correct, the energy expenditure is closer to that of racing greyhounds. However, greyhounds are sprinters that use large proportions of their energy during short bursts of speed while both Singh and Early et al. found that working farm dogs work for long periods with activity spread throughout the day. The types of diets recommended for racing greyhounds may therefore not be appropriate to farm dogs despite a similarity in energy output. While both Singh (2013) and Early et al. (2016) contributed interesting data about workload in working farm dogs, the dogs' energy requirements are still uncertain and more research is needed to determine whether current diets commonly fed to working dogs are suitable.

In addition to increased activity during peak work, ambient temperature and terrain profile influence the daily energy requirements of working farm dogs. Both low and high temperatures cause dogs to expend more energy on thermoregulation, with high temperatures causing them to pant and low temperatures causing shivering and increased metabolic rates in order to keep them warm (Auld et al., 1980; Hellstrom and Hammel, 1967; Sugano, 1981). As mentioned above, many working farm dogs may be housed in poorly insulated kennels and are as such susceptible to energy loss during hot or cold weather. The quality of the dog's kennels and whether they are provided with bedding material and coats in cold weather should therefore be accounted for when estimating energy requirements for working farm dogs.

When attempting to determine whether the current common diets of meat and commercial dog food is appropriate for working farm dogs, a number of factors must be considered. Feeding such dogs exclusively on low cost commercial foods formulated for pet dogs is probably not ideal since such foods often have low energy density in comparison to for example high fat meat (Hill et al., 2009). The lower the energy density of a food, the greater the volume of food needed to meet energy requirements, and dogs with a high energy requirement may not be able to consume sufficient volume, especially if fed once daily. Considering that most working farm dogs are fed once daily they may not be able to eat enough to cover their energy needs if fed low quality food. The formulations of specific commercial diets should be carefully assessed before being used as a main food source. While meat is a good source of energy and nutrients in the form of protein and fat and thus likely to be a good supplement to a commercial diet that may be low in energy, is it also deficient in some essential micronutrients (Hill, 1998). Mineral deficiencies can occur in dogs fed all-meat diets without bone, and it is recommended that such deficient diets should be supplemented in order to restore the proper balance of vitamins and minerals (Wakshlag and Shmalberg, 2014). Some dog owners may feed uncooked meat with bones, but this carries with it a risk of tooth damage from chewing and intestinal blockage if the dog swallows whole pieces of bone. Offal may also be a good source of nutrients, but this seems to be less common among New Zealand farm dog owners than feeding meat. Jerram (2013) reported that 11 of 198 dog owners (6%) fed their dogs offal, and Singh (2011) did not record offal as a separate part of dogs' diets. A possible reason why feeding offal is less popular is that it is a legal requirement in New Zealand to treat offal by 30 minutes of boiling or freezing to below -10^{o}C for a week before using it as dog food (Biosecurity New Zealand, 2018). This treatment requirement is designed to prevent the spread of hydatid tapeworms and it is also recommended to prevent sheep measles (*Taenia ovis* infection in sheep) (OVIS Management, n.d.). While the meat and commercial food combinations fed to many working farm dogs in New Zealand could be adequate if they are of high quality and fed in appropriate amounts, more information about meal compositions and dogs' energy expenditure is needed.

2.4.5 Preventative health

Jerram (2013) and O'Connell et al. (2019) surveyed the owners of working farm dogs on the North Island of New Zealand. Jerram reported that in the previous year 84% of 1194 dogs had been given anthelmintic treatment, 18% had been vaccinated and nine percent had been given a flea treatment. In contrast, O'Connell et al. reported that 95% of 196 dogs in their study were given anthelmintic treatment at least every four to six months, 79% of dogs had been vaccinated at least once and 40% were vaccinated annually, and 64% of dogs were given some type of treatment to control fleas. O'Connell et al. also reported that 81% of farm dog owners took their dogs to be seen by a veterinarian occasionally or only at vaccination, and 15% of owners never took dogs to a veterinarian. If dogs are generally healthy and rarely develop conditions that need veterinary treatment, these numbers are may be reasonable although. However, if the research carried out as part of this thesis shows that working farm dogs have a high occurrence of conditions that require veterinary attention, further investigation may be warranted into what barriers exist to prevent farm dog owners from accessing veterinary treatment for their dogs.

O'Connell et al. (2019) found that 40% of dogs had at least one species of parasite present in their faeces, with half of those dogs being infected with nematodes. The study found no association between the frequency of anthelmintic treatments and the presence of parasite infection. This suggests that while most farm dog owners do treat their dogs with anthelmintics, the treatments are ineffective in treating the infections due to errors in dosing or drug resistance, dogs are reinfected between treatments, or the administered drugs are not targeting all the species dogs are likely to be infected with. In addition to being beneficial to the health of dogs, monthly anthelmintic treatment of farm dogs is recommended for sheep farmers in New Zealand due to the risk of *Taenia ovis* infection in sheep (DeWolf et al., 2014). Possibly, dog owners are focusing on the risk related to *Taenia ovis* infection rather than on reducing parasite infections in general. Alternatively, the presence of parasite infections despite reported treatments could be due to resistance to anthelmintic drugs resistance (Kopp et al., 2008; Raza et al., 2018). Husbandry practices associated with working farm dogs, where dogs are often housed in close proximity and given individual anthelmintic treatments as groups rather than being dosed based on their body weights and parasite burdens, may be favourable to the development of anthelmintic drug resistance (Raza et al., 2018). However, more research is needed to know whether such resistance is a widespread problem in New Zealand dogs.

The vaccination rates in working farm dogs that were recorded by Jerram (2013) and O'Connell et al. (O'Connell et al., 2019) were very different, with Jerram reporting a much lower vaccination rate. However, Jerram did not report how many dogs had been previously vaccinated. There is evidence to suggest that the most common types of vaccines regularly given to dogs may have long term or even lifelong effect (Schultz, 2006; Schultz et al., 2010). As such, dogs that have only been vaccinated as pups may still be protected as adults. Additonally, if infectious diseases were a major problem in the New Zealand working farm dog population, it should be expected that this would have been reflected in the results of a survey of health in farm dogs published by Cave et al (2009). However, this survey of farm dogs in veterinary clinics was conducted over only a 12-month period and may have missed more limited disease outbreaks or hotspots occurring outside the areas covered by participating clinics. Investigation is therefore necessary to determine the prevalence of infectious diseases in the working farm dog population and whether the risk of disease is reduced in farm dogs that are vaccinated regularly throughout their lives.

Similarly to vaccination frequencies, Jerram (2013) and O'Connell et al. (O'Connell et al., 2019) found very different frequencies for flea treatments. O'Connell did not examine whether dogs had fleas or whether treatments had any effect. However, Sheard (2014), using data from the same survey as Jerram, reported that 7 of 1115 dogs (>1%) had a flea infection and 14 (1%) had itchy skin in the course of a year. Similarly, Cave et al. (2009) reported that 23 of 2214 working farm dogs (1%) examined in veterinary clinics had skin parasites, of which six had fleas. While fleas are a health and welfare problem due to the itching and discomfort they cause and the potential pathogens they can carry (Chandra et al., 2017; Kelly et al., 2005), there is currently little evidence to suggest that flea infections or inadequate flea treatments are a significant problem in New Zealand working farm dogs.

The differences seen in results between the studies carried out by Jerram (2013) and O'Connell et al. (O'Connell et al., 2019) may reflect differences in sampling strategies and geographical area. Jerram (2013) randomly sampled farms to survey, while O'Connell (2019) used a convenience sample of dogs owners that participated in a North Island sheepdog trial championship or were associated with a cooperating veterinary clinic. Convenience samples, while common, can introduce biases to a sample that are difficult to detect and account for. For example, dog owners that participate in sheepdog trials are more likely to have vaccinated their dogs as it is a requirement for entry into competition (New Zealand Sheepdog Trial Association, 2018) as the mixing of dogs from various farms and geographical areas is likely to increase the risk of disease in dogs that are used for sheepdog trials. The inclusion of trialling dogs could therefore have caused a bias towards vaccinated dogs in O'Connell et al.'s sample. Additionally, there may have been some geographical differences between the studies. O'Connell et al. recruited mainly farmers who lived in the Waikato region while Jerram interviewed farmers in the Manawatu-Wanganui region only. Thus, some differences seen between surveys may reflect regional differences in dog population and husbandry practices, possibly due to variation in farm types, farm management practices and local customs. However, these differences are likely to be small, as the regions are relatively close to one another on the North Island.

2.5 Health, disease and mortality in working farm dogs

2.5.1 Common conditions in working farm dogs

To date a range of studies and case reports have been published that investigate single injuries and diseases in New Zealand working farm dogs (Bojanić et al., 2019; Harland, 2015; Hughes, 2001; Hughes et al., 1987; Jolly et al., 2002; Nortje et al., 2015; Scrimgeour et al., 2012). While interesting, few of these studies attempt to estimate how common diseases are in the general farm dog population or assess which conditions have the greatest potential to impair dogs' welfare or working ability. In contrast, two studies have been carried out that aimed to describe the prevalence of all types of disease and injury in New Zealand working farm dogs. In the first study Cave et al. (2009) asked staff at 30 participating rural veterinary practices across New Zealand to complete a questionnaire for each working farm dog they saw in the course of one year. Records were obtained for 2214 visits, not counting return visits due to the same instance of illness or injury. It is possible that some of these visits involved the same dogs but different reasons for visiting the veterinary clinic. In the second study Sheard (2014) used data collected by Jerram (2013) during interviews with farm dog owners on 118 farms in the Manawatu-Wanganui region. Dog owners were asked about the dogs that had been present on their property in the previous 12 months and what kind of health events the dogs had experienced in that time. Data was collected regarding 1115 working farm dogs.

Both Cave et al. (2009) and Sheard (2014) divided their results into traumatic injuries and non-traumatic illnesses. Traumatic injuries were found to be common, with 38% of presentations to veterinary clinics related to trauma, and farm dog owners reporting that 25% of dogs had one or more traumatic injury during the course of a year. Both studies found that injuries most commonly involved the skin and musculoskeletal system, and were usually located on the feet and legs of dogs. Where causes of injuries were known, they often involved livestock, vehicles and crossing of fences. Of non-traumatic cases seen in veterinary clinics consisted of 9% gastrointestinal disease, 9% involved the reproductive system and 7% involved the skin (Cave et al., 2009). The most common types of gastrointestinal disease reported were constipation (51 of 200 gastrointestinal cases), gastric dilatation volvulus (GDV; 36 of 200 cases) and acute vomiting and/or diarrhoea (32 of 200 cases). In addition, 6% of dogs seen in veterinary clinics had arthritis and 4% had other musculoskeletal problems including 1% with hip dysplasia. When compared to other farm dogs, Huntaways were overrepresented in cases of constipation, GDV, pyometra/endometritis, vaginal prolapse, vaginal hyperplasia and mammary neoplasia. However, when reported by farmers (Sheard, 2014) the most commonly reported non-traumatic health conditions included low body weight (19% of dogs), followed by arthritis (10%), skin disease (12%) and eye conditions (including blindness) (6%), gastrointestinal conditions (5%), respiratory disease (4%) and problems related to the reproductive systems (3%). When seen as a whole, these studies suggest that the most common types of health problems in working farm dogs are likely to involve illness and injury relating to the musculoskeletal system and skin. Additionally, a large proportion of working dog owners reported concern that their dogs were too thin, although underweight dogs were rarely reported in veterinary clinics.

The studies by Cave et al. (2009) and Sheard (2014) provide excellent data on what types of health conditions are likely to be commonly seen in working farm dogs. However, due to the way data was collected they may also have missed important information. By limiting data collection to those dogs seen in veterinary clinics, Cave et al. (2009) had no way to assess how common the recorded conditions were in the general working dog population as only dogs with problems considered serious enough by the owner to warrant a visit to a veterinary clinic were recorded. Dogs with minor or self-limiting conditions, or those that died before they were seen by a veterinarian would not have been recorded in this study. For example, while many dog owners reported that some of their dogs were underweight, few such cases were seen in clinic, presumably because the owners felt confident that they could manage the situation themselves. Alternatively, the perception of what is a normal or underweight working farm dog may differ between people, and between dog owners and clinicians. While Sheard (2014) did analyse data that was collected from working dogs outside veterinary clinics, by relying on interviews with farm dog owners an increased possibility of error and bias was introduced. While farm dog owners are very knowledgeable about their dogs, they are not trained in veterinary medicine and may miss more subtle clinical signs of illness or misinterpret signs they observe. Additionally, working dog owners were asked to report events from the previous 12 months, making it possible that some events were forgotten and so not reported. Minor health conditions that were not seen in clinics or forgotten by dog owners probably have relatively minor impacts on dogs' immediate health, welfare and working ability. However, it is nonetheless worth recording them as they contribute to a more complete image of the types of illnesses and injuries working farm dogs are susceptible to and because some types of minor injuries can develop into more serious conditions of their effects are repetitive and/or long-lasting.

To fill the knowledge gap left by the currently available studies of working farm dogs, data from clinical examinations should be collected from a large population of working farm dogs, irrespective of their health status. Such a study would provide investigators with more accurate data on the prevalence of disease and injury in the population than owner interviews or data collected from veterinary clinics can provide. Performing clinical examinations on presumably healthy dogs may also uncover information on less serious or subclinical conditions that owners have no way of detecting but which could be important risk factors for future illness or injury. Investigating how such risk factors affect dogs' health and longevity would require the same cohort of working farm dogs to be followed up with one or several clinical examinations over an extended period of time. Such a study requires substantial resources but has the potential to provide excellent data that can be used to improve the health and welfare of working farm dogs.

2.5.2 Body condition in working farm dogs

Despite being common in other dog populations (Courcier et al., 2010; German, 2006; Hoummady et al., 2016; Lund et al., 2006; Mao et al., 2013; McGreevy et al., 2005), obesity is not thought to be a problem in highly active working dogs. In New Zealand, as many as one fifth of working farm dogs were considered by their owner to be underweight (Sheard, 2014). Another study (O'Connell et al., 2019) used a validated scale to rate body condition where one is considered emaciated, four to five is normal and nine is morbidly obese (Laflamme, 1997; WSAVA Global Nutrition Committee, 2013). Of 197 working farm dogs 47% were given body condition scores (BCS) of two or three and another 47% were given scores of four, suggesting that a large fraction of the population are either underweight or at the lower end of the normal range.

Data from other species exist that show associations between body fat and/or lean mass and performance or the risk of disease or injury. For example, in humans US Army recruits and soldiers that were underweight on the body mass index (BMI) had higher risk of musculoskeletal disease and injuries (Hruby et al., 2016; Knapik et al., 2012), while reduced muscle size and strength have been associated with having lower bone mineral density in older adults (Ahedi et al., 2014; Edwards et al., 2013). Reduced bone mineral density causes reduced bone strength and increases the risk of fractures (Ratti et al., 2013). In racehorses, having been in training for longer periods of time was associated with a reduction in body fat mass, while horses classed as elite racers has higher fat-free mass than non-elite racers (Fonseca et al., 2013). In production animals such as sheep and cattle, body condition scores are also commonly used (Kenyon et al., 2014; Roche et al., 2009). Production values such as milk production and rates of conceptions and births have been found to increase as sheep and dairy cows gain bodyweight and BCS (Kenyon et al., 2014; Roche et al., 2009). However, if animals become overweight their production plateaus or starts decreasing. Additionally, a probable link exists between lameness and low body condition in dairy cows, although the mechanism of the effect remains uncertain (Huxley, 2013). The values of BCS at which animals have the highest rates of production or lowest risk of disease vary according to what is being measured (Heuer et al., 1999; Kenyon et al., 2014), making it difficult to recommend that all animals should be within a certain BCS range at all times. While it is well accepted that being overweight is detrimental to health and quality of life in dogs (German et al., 2012; Kealy et al., 2002; Santarossa et al., 2017), little is known about the effects of dogs being underweight. Being underweight is likely to have an effect on the health of working farm dogs, however it is currently unknown what the precise effects are, or at what level of BCS dogs should be considered to be unhealthily underweight. In highly active dogs such as these, differentiating between low levels of body fat due to high levels of athleticism, and low body fat mass due to malnutrition, illness or injury is important.

While body condition scoring in dogs is widely used and has been validated as a reliable way to estimate the quantity of body fat in overweight and obese dogs (Laflamme, 1997; Mawby et al., 2004), BCS not been well validated for use in underweight, lean and/or athletic dogs. Laflamme (Laflamme, 1997)'s study of 255 dogs included no dogs that were given a score of one and Mawby et al. (2004) included no dogs with a score below four in a sample population of 23 dogs. As a result, the utility of BCS when applied to thin or lean dogs is uncertain. In addition to being generally thin or lean, working farm dogs are highly active (Early et al., 2016) and which is likely to cause an increase in muscle mass similar to that observed in race horses in training (Fonseca et al., 2013).

In humans, body mass index (BMI) is a very commonly used estimate of body condition, but it is unreliable for assessing muscular individuals, as people with higher than average body weight due to above average muscle mass tend to be classed as overweight or obese (Nuttall, 2015). A similar problem may occur when applying a score to lean athletic dogs that has been validated on normal to overweight dogs to lean. Specifically, working and sporting dogs may be scored as underweight due to having little subcutaneous body fat despite being highly athletic and muscular. In such athletic dogs, a loss of muscle mass may be a more accurate sign of ill health than a low level of body fat. In humans a loss of lean body mass, including muscle mass, is associated with malnutrition, old age, underlying diseases such as cancer and an increased risk of musculoskeletal injury (Heymsfield et al., 1982; Mareschal et al., 2019; Powers et al., 2017). Additionally, being classed as underweight according to the BMI scale is linked to lowered body functions and impaired bone health, especially in athletes and the elderly (Falagas et al., 2009; Melin et al., 2019; Tenforde et al., 2015). The finding that working farm dogs tend to be on the leaner end of the body condition spectrum and that musculoskeletal disease and injury seems to be fairly common (Cave et al., 2009; Sheard, 2014), makes it reasonable to suggest that an assessment of lean body mass may be a more relevant measure of overall health in working farm dogs than conventional BCS which focuses on body fat mass.

Leung et al. (2018) suggested that the ratio of lean body mass to skeletal size may be a better way to assess body condition in lean working dogs than BCS, and developed a method to calculate lean body mass and skeletal size in Heading dogs and Huntaways based on a six measurements, body weight, age and type of dog. However, the method was developed using 25 dogs, and has not been applied to a larger population of working farm dogs. It is therefore unknown what constitutes a normal level of lean body mass in working farm dogs, or whether high or low values are related to health outcomes.

2.5.3 Musculoskeletal injury and illness

As stated, musculoskeletal injury and disease are among the most commonly reported conditions in many populations of dogs, including working farm dogs (Anderson et al., 2018; Cave et al., 2009; Freeman et al., 2006; Mele, 2007; O'Neill et al., 2013; Sheard, 2014; Singh et al., 2011). Musculoskeletal disorders are a serious issue that affects overall health, welfare and working performance in for example humans and horses in addition to dogs (Bevan, 2015; Burton et al., 2006; Cogger et al., 2008; Mele, 2007; Perkins et al., 2004). Hughes (2001) found that the prevalence of hip dysplasia may be as high as 18% in working farm dogs, with Huntaways being vastly overrepresented amongst the diagnosed cases. However, Hughes chose to study hip dysplasia due to a personal perception that the disorder was becoming more common in Huntaways and recruited dog owners that were actively interested in whether hip dysplasia was present in their dogs. As such, they may have recruited dog owners that suspected that their dogs had a problem in their hip joint, resulting in a study population with a higher prevalence than the general populational. In pet dogs, musculoskeletal disease was the second most common reported cause of dogs dying or being euthanised, after neoplasia (Bonnett et al., 1997; O'Neill et al., 2013). In New Zealand police dogs and UK guide dogs, the most common cause for early retirement was an inability to continue working due to musculoskeletal disease or injury (Caron-Lormier et al., 2016; Worth et al., 2013). In US military working dogs, the most commonly recorded cause of death or euthanasia was degenerative joint disease (Moore et al., 2001). A range of literature is available on musculoskeletal conditions in dogs (for example: Anderson et al., 2020; Ginja et al., 2010; Komsta et al., 2015; Simpson et al., 2019). However, many studies focus on purebred pet dogs and little data is available on the types of musculoskeletal disorders that affect athletic working and sporting dogs. Of the available studies, most focus on injuries obtained during competitive racing (Prole, 1976; Sicard et al., 1999; von Pfeil et al., 2015) or dogs that have died or been retired from work (Caron-Lormier et al., 2016; Hoummady et al., 2016; Moore et al., 2001; Worth et al., 2013). In working farm dogs, Hughes (2001), Cave et al. (2009), Singh et al. (2011) and Sheard (2014) all report results suggesting that musculoskeletal injury and disease are commonly seen in New Zealand farm dogs. However, Sheard did not find that traumatic injuries or musculoskeletal disease or injury were associated with a higher risk of dying or being euthanised. This lack of association may have been caused by a failure to account for confounding during data analysis, which may have obscured the association between musculoskeletal conditions and the risk of dying. Additionally, Sheard analysed only the risk of dying or being euthanised and did not consider whether dogs were still working or had been retired. It may be that dogs with chronic musculoskeletal diseases and injuries are more likely to be retired from work rather than euthanised and as such were not included in Sheard's analysis. Sheard's results, while interesting should therefore be considered critically, and the association between musculoskeletal conditions and retirement or death should be investigated in more detail. Additionally, while there is good reason to believe that musculoskeletal disease and injury may be important health and welfare concerns in working farm dogs, few data are available regarding the specific types and locations of common disorders, the impact these disorders have on dogs' health, welfare and work performance, or whether certain dogs are at higher risk of developing musculoskeletal problems than others. Studies that aim to investigate these areas should aim to collect clinical data from a large population of dogs, independently of whether or not they were seen in veterinary clinics. Additionally, they should be followed up over an extended period of time in order to detect new occurrences of musculoskeletal conditions and which risk factors are associated with such occurrence.

2.5.4 Mortality rates and reasons for death and retirement

Knowing the reasons why working farm dogs die or are retired from work is important for anyone who wants to improve the overall health, longevity and quality of life of working dog populations. Investigating the underlying reasons for death and retirement is likely to expose issues that have strong impacts on the health and welfare of dogs. Cave et al. (2009) reported what types of health events caused working farm dogs to be examined at veterinary clinics and how many clinic visits resulted in the dog being lost through death, being euthanised or being retired. Eleven percent of visits resulted in dogs being recorded as lost, including eight percent where the dog died or was euthanised. Note however, that the authors had no way to record dogs that may have died or been retired after veterinary treatment had been completed. Trauma was reported as the cause of 32% of dogs that died, were euthanised or were retired, with injuries caused by stock or trauma involving motor vehicles being by far the most common. Non-traumatic causes of death included gastrointestinal disease (13% of lost dogs), musculoskeletal disease (7%) and reproductive system disease (6%). Singh et al. (2011) asked farm dog owners how many dogs on their farms were euthanized in the course of a year, but did not record how many dogs died in total. The most commonly reported causes of euthanasia were degenerative joint disease in old dogs (40% of euthanized dogs), unsatisfactory working performance (18%) and trauma associated with livestock (15%). Due to the way their data were collected the results reported by Cave et al. and Singh et al. are incomplete and difficult to apply to recommendations about care and husbandry in working farm dogs. However, when considered as a whole the results point towards traumatic injuries sustained on farm as common causes of premature death in working farm dogs. Additionally, Singh et al. reported that musculoskeletal disease was a common cause for euthanasia in older dogs. While seen less frequently in veterinary clinics, musculoskeletal disease was also a common cause for loss in the study by Cave et al. Musculoskeletal disease and injury have been recorded as being common causes of death in both pet and working dogs and of retirement from work in guide, police and military dogs (Bonnett et al., 2005; Caron-Lormier et al., 2016; Egenvall et al., 2005, 2000; Hoummady et al., 2016; Moore et al., 2001; O'Neill et al., 2013). Given the potential of musculoskeletal conditions to shorten the lives of dogs in a range of populations, and the high activity levels of working farm dogs, there is reason to hypothesise that musculoskeletal abnormalities may be an important risk factor for death, euthanasia and retirement in working farm dogs.

Sheard (2014) investigated risk factors related to euthanasia and death in working farm dogs, though the study did not record specific reasons for death or whether dogs died naturally or were euthanised. Univariate logistic regression analysis was used to examine whether the risk of death in working farm dogs during the course of one year was associated with a range of factors. In a population of 1115, 167 dogs (15%) were reported to have died. The study found that the risk of death was highest in dogs that were below two years or above seven years of age, were partially trained or retired, were a part of a team of 15 or more working dogs on farm or had had one or more non-trauma health event in the 12-month study period. However, being considered to be underweight or having had an axial or limb fracture was associated with a reduced risk of death. In light of Cave et al. (2009) and Singh et al. (2011) reporting traumatic injury and musculoskeletal disease as common causes of death or euthanasia, the results of Sheard's study are surprising. A reason for this mismatch in results may be that Sheard's analysis does not include a multivariable model which could have accounted for confounding and interactions between different risk factors. For example, the protective effect seen as a result of being considered underweight or having a fracture may be caused by these dogs having been rested and given less challenging work and therefore being at lower risk of further injury. If dogs' workload had been considered the apparent protective effect of being injured may have been removed. The study also relied on owners accurately recalling and reporting events from the previous 12 months, and no veterinary examinations of dogs were done. It is possible that many of the dogs that were reported by owners to be underweight are lean but in good physical condition when considering the requirements of their work and as such are at less risk of injury and death compared to other farm dogs. While current evidence suggests that many working farm dogs are potentially underweight (Leung et al., 2018; Singh et al., 2011), an association between body condition and health, retirement or mortality has not yet been investigated. A longitudinal study that collects health data from working farm dogs repeatedly over an extended period of time would be able to investigate which factors were present or absent prior to dogs developing illness or injury, and the association between health and death or retirement could be investigated in more detail than was possible with the cross-sectional data analysed by Sheard. No such longitudinal study has been carried out to date.

A higher risk of death was observed in working farm dogs that were retired and/or above 7 years of age and in young dogs and dogs still undergoing training (Sheard, 2014). This increased risk of death in young dogs may represent dogs being removed from work during training. Singh et al. (2011) reported that 18% of euthanised dogs were euthanised due to unsatisfactory working performance, while Australian farm dog owners and handlers reported that a mean of 20% of dogs they acquired did not become successful working farm dogs (Arnott et al., 2014b). More than half of the Australian farm dogs were reported as being lost from work due to a lack of natural working ability. While Arnott et al. (2014b) and Early et al. (2019) have begun to investigate which traits owners value in their working farm dogs, little is known about what constitutes optimal working performance in these dogs. A better understanding of working performance in farm dogs may provide an opportunity to improve rearing and training methods and reduce the number of dogs that are dismissed due to poor working ability.

Another possible reason for the observed increase in risk of death in young dogs (Sheard, 2014) may be that young dogs are generally at higher risk of injury. An increased risk of traumatic injury has been observed in young, insured Swedish dogs (Egenvall et al., 2005), possibly because young and inexperienced dogs are less experienced and thus less able to assess risks than adult dogs. Although traumatic injuries were not found to significantly increase the risk of death in Sheard's (2014) study, if young dogs have a higher rate of injury than adults this may contribute towards the increased risk of death that was observed in dogs that were young and undergoing training.

Sheard (2014) did not find any differences in the risk of death between males and females or between Heading dogs and Huntaways. Hughes (2001) found that hip dysplasia was more common in Huntaways than in Heading dogs, and Cave et al. (2009) found that there were differences between Heading dogs and Huntaways in the prevalence of certain types of illness and injury. These results have not been investigated further, except for the study carried out by Sheard which did not follow dogs over time in order to investigate risk factors or account for confounders. Caron-Lormier et al. (2016) and Moore et al. (2001) examined sex and breed differences in death and retirement in guide dogs and military dogs respectively. Both found significant breed and sex differences in the rates of loss due to specific conditions, including cancers and musculoskeletal diseases. Neither used multivariable modelling techniques that could have accounted for confounding in their data, and the differences between the types of dogs and the work they are trained to do makes it difficult to know whether the results are relevant when considering working farm dogs. Strong effects on mortality by breed, sex and neuter status have also been observed in a range of studies of pet dogs (Bonnett et al., 2005; Bonnett and Egenvall, 2010; Egenvall et al., 2000; O'Neill et al., 2013), although again the relevance of these studies to working farm dogs is questionable. However, while the current evidence is conflicting, there is a possibility that there are important dog type or sex differences in the occurrence of conditions that increase the risk of retirement or death in working farm dogs. Knowledge of these differences would be helpful to farmers and veterinarians who care for these dogs as it may enable them to adjust their practices to minimise the chance of injury or disease in at-risk animals. The effect of sex and type of dog on the occurrence of clinical abnormalities and the risk of dogs being lost from work should therefore be investigated in more detail, ideally by using a multivariable modelling approach that can account for confounding and interactions between variables.

Although a great deal is currently known about husbandry practices, common health conditions and reasons for death in working farm dogs, no studies to date have been able to collect clinical health data from presumably healthy dogs or follow a large group of dogs over time. This has limited the possibilities for investigating risk factors that may have been present before the occurrence of injury, disease and loss of dogs from work. Such a study would be able to fill many of the current gaps in knowledge and lay the foundations for future, more targeted studies aimed at preventing and treating common conditions and improving the overall health and welfare of the New Zealand working dog population.

2.6 Conclusion

In addition to giving an overview of epidemiological concepts and techniques used in this thesis, this literature review summarised the origins and behaviours of working dogs and working farm dogs in particular. Additionally, what is currently known about population features, husbandry and health in working farm dogs was summarised and important gaps in our knowledge was highlighted. While much is known about health in dogs in general and working dogs in particular, the nature of this knowledge makes it difficult to apply when assessing optimal care and husbandry practices in working farm dogs. This thesis aims to fill some of the gaps outlined in this literature review by using data collected as part of the TeamMate study. Our aim is to publish our results and to share what we have learned with both the veterinary community and the communities of farm dog owners who contributed to the study.

Chapter 3

Population characteristics and health of working farm dogs on enrolment to the TeamMate project.

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Population characteristics and health of working farm dogs on enrolment to the TeamMate project.

3.1 Abstract

Working farm dogs are invaluable on New Zealand sheep and beef farms. To date no study describing farm dog population and health has included information about incidence of illness and injury, or risk factors affecting health and career duration. This paper describes the methodology and initial results from TeamMate, a longitudinal study that was designed to address this gap. We describe the study population, husbandry practices, and prevalence of clinical abnormalities on enrolment.

Data about the farms, owners, husbandry practices and dogs were collected on farm at approximately 6-month intervals. All dogs over 18 months old and in full work were enrolled. Dogs were given physical examinations by veterinarians. On examination all abnormalities were noted, regardless of clinical significance. Six hundred forty-one working farm dogs and 126 owners were enrolled from the South Island of New Zealand. Forty-nine percent of dogs were Heading dogs (314 of 641) and 48% Huntaways (308 of 641). Median age of dogs was four years (range 1.5 – 14) and median body condition score (BCS) was four on a 9-point scale (interquartile range (IQR) 3 – 5). Fifty-four percent of dogs were male (345 of 641), and 6% (41 of 641) were neutered. Eighty-one percent of owners (102 of 126) fed dogs commercial biscuits and meat sourced on farm. Forty-four percent of dogs (279 of 641) had bedding in their kennel, 14% (55 of 393) had insulated kennels, 69% (442 of 641) had been vaccinated and 33% (213 of 641) were insured. Clinical abnormalities were found in 74% of dogs (475 of 641). Common abnormalities involved the musculoskeletal system (43%, 273 of 641), skin (including scars and callouses; 42%, 272 of 641), and oral cavity (including worn and broken teeth; 35%, 227 of 641).

Our results expand on those from previous surveys and indicate that musculoskeletal illness and injury, and skin trauma are the most commonly seen clinical abnormalities in working farm dogs. These results will provide a baseline for investigation of incidence and risk factors for illness, injury, retirement and death in New Zealand working farm dogs.

3.2 Background

There are over 25,000 sheep and beef farms in New Zealand (Stats NZ, 2013). In 2016, meat and wool exports were worth NZ$6.7 billion, accounting for 14% of New Zealand's total exports of goods. In 2016-17 New Zealand was the third largest wool exporter in the world, producing 9% of the world wool supply (Beef + Lamb New Zealand, 2018; Statistics NZ, 2017). Many of the sheep and beef farmers who supply these products rely heavily on dogs when mustering and moving stock between pastures, and it is often said that the rough New Zealand terrain could not be farmed without the help of dogs (Cogger and

Sheard, 2017). It has been estimated that there are approximately 200,000 working farm dogs in New Zealand, most of them belonging to one of two distinct types of dog (Cogger and Sheard, 2017; O'Connell et al., 2019). These dog types, called Heading dogs and Huntaways, are anecdotally known to be phenotypically distinct and having been bred to perform different types of stock work. However, no data is available to verify the population size, or the differences between the types of dogs.

Maintaining the health of working farm dogs is important for farmers who rely on their assistance, but little research has been conducted about the specific needs of these dogs. Today, husbandry practices are often based on traditional and anecdotal knowledge that is passed between dog owners and trainers or documented in training manuals (Dalton, 1996; Knight, 1984; Oliver et al., 2009). Other sources are studies of health in pet dogs and other types of working dogs such as military and police dogs, assistance dogs for the disabled or racing dogs (Ahlstrøm et al., 2011; Evans and Lewis, 2018; Hoummady et al., 2016; Loftus et al., 2014; Worth et al., 2013). However, advice that is well founded and useful for pet dogs and other types of working dogs may not be applicable to highly athletic working farm dogs that live most of their lives outdoors. Advice on husbandry practices needs to be based on sound evidence that the recommended changes are likely to improve the health, welfare and career longevity of working farm dogs specifically. Currently, such evidence does not exist.

Previous surveys have described sections of the farm dog population (Cave et al., 2009; Jerram, 2013; Sheard, 2014; Singh et al., 2011). Two of these studies reported farm dog health, with Sheard (2014) surveying owners about the health of their dogs in the previous year and Cave et al. (2009) recording farm dog visits to 30 veterinary clinics during the course of one year. Sheard (2014) relied completely on owner reports, which may be unreliable, and did not collect clinical data from the dogs. Cave et al. (2009) analysed records of farm dogs that were seen in veterinary clinics, but had no way to record health events that happened on farm and were not seen by a veterinarian. This will have resulted in an under-reporting of cases that were judged by the owner to not warrant a visit to a veterinary clinic and cases where the problem was resolved or the dog died before being seen by a veterinarian. When taken together the two studies provide valuable data about the health of farm dogs, but they have major limitations, mostly due to sampling bias. Additionally, the authors were unable to record how disease develops over time or investigate risk factors that may affect the likelihood of disease, retirement or death. A longitudinal study collecting clinical data about dogs at several points over a period of time would be able to investigate whether or not certain factors were present before the onset of disease, and whether their presence increased the risk of a dog developing disease. Knowledge about such risk factors would be very useful to farm dog owners and veterinarians making decisions about how to provide the best care for farm dogs.

This paper describes TeamMate, a longitudinal study of 641 working farm dogs on the South Island of New Zealand. TeamMate was designed to accomplish a number of objectives: (1) to gather population data on working farm dogs on the South Island; (2) to identify common husbandry practices; (3) to supplement current knowledge about common injuries and diseases occurring in farm dogs; (4) to gather data regarding the work farm dogs are required to carry out; and (5) to investigate how the above factors interact with, and contribute to, the long-term health and career longevity of working farm dogs. The aims of the present paper are to describe the design, implementation and the population involved in the TeamMate study. Specifically, we describe the farms and dog owners involved in the study. Then, we describe the population of working farm dogs and their feeding, shelter and vaccination status. Lastly, we report the prevalence of abnormalities found on each dog's initial clinical exam on enrolment in the study.

3.3 Methods

3.3.1 Study design

TeamMate was a longitudinal study, aiming to capture data on risk factors that might affect health outcomes and career duration in working farm dogs. To capture data a veterinarian and a technician visited participating dog owners on the farm where they worked. The farm visits were carried out during distinct periods of calendar time which are referred to as 'data collection rounds'. Six data collection rounds were carried out at roughly six monthly intervals over a period spanning May 2014 to the second half of 2018 (Figure 3-1). Because of logistical issues, a small amount of overlap in dates occurred between the third and fourth data collection rounds. At each data collection round, all owners that were enrolled in the study at that point were visited. Owners and dogs were enrolled during the first three data collection rounds, with the last enrolments occurring in May 2016. As some owners moved to new farms during the course of the study, a small number of new farms were enrolled after the third data collection round. After the first and second data collection rounds, adjustments were made to the questionnaires that were used to collect data (see Appendix 1).

At each farm visit, clinical examinations of all enrolled farm dogs were carried out by a veterinarian, and questionnaires were filled out with the help of a scribe. All veterinarians and scribes were trained to ensure data collection was performed in a standardised way, with veterinarians asked to record specific clinical signs rather than make general diagnoses. Training included a run-through of all questionnaires and how they should be completed as well as practical sessions that involved filling in the questionnaires and examining, scoring and measuring farm dogs.

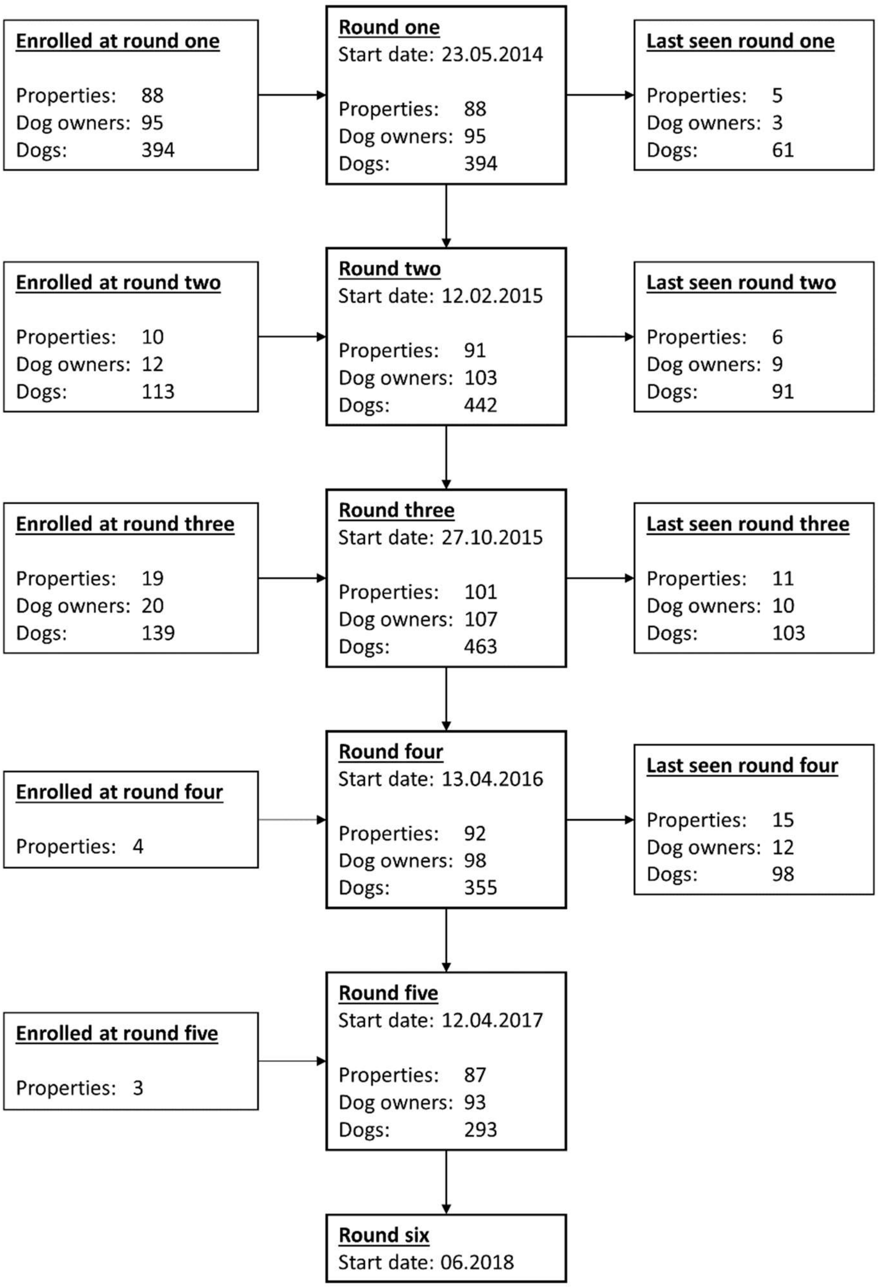

Figure 3-1: Flow chart showing the start dates of each data collection round as well as the number of farms, dog owners and dogs enrolled in TeamMate up to and including the fifth round of farm visits. Additionally, 14 properties, 16 dog owners and 68 dogs missed at least one round of data collection. Note that data for the sixth data collection round was not yet available at the time of writing.

3.3.2 Recruitment

A convenience sample of working farm dog owners was drawn from existing clients of Vetlife, a chain of veterinary clinics on the South Island. Recruitment started in early 2014. The TeamMate study was advertised through clinic newsletters, media coverage, stalls at agricultural shows and personal invitations to those perceived to be interested. Participating dog owners became part of the 'TeamMate Club' and received a five percent discount on premium dog food recommended for working dogs and

10% discounts on certain antiparasitic treatments for dogs, working dog collars, dog coats and bedding. Study results were not shared with owners until the completion of data collection. Owners were free to withdraw at any time, and otherwise remained until the end of the study.

The first time data were collected from an owner, all working farm dogs belonging to that owner that were older than 18 months old and in work at the time of data collection were enrolled in the study. Any new dogs belonging to the owner that met the eligibility criteria were enrolled each time data were collected, up to and including the third data collection round. In other words, dogs that were older than 18 months and had either been acquired between data collection rounds or had reached the age of eligibility since the previous data collection round, were enrolled. Dogs remained until the end of the study or until they died, were euthanized, retired, sold or given away, or the owner withdrew from the study.

3.3.3 Data collection

3.3.3.1 At enrolment

When an owner was first enrolled in the study, they were asked to provide information about themselves, the property they worked on and their working dogs. The exact questions asked about the farm and owner varied slightly between the first, second and third data collection rounds (See Appendix 1 and Appendix 2). Irrespective of data collection round, at enrolment data were collected about the property size, types of terrain present on the property and details of the types and number of stock farmed. On enrolment of owners the following data were collected: age, gender, job title, years of experience working with farm dogs, whether they bred working dogs and if so, what types of dogs and how many litters they had bred in the previous six months, and which types of food they had fed their working dogs during the previous six months.

Owners were asked to provide information about each dog, skeletal size measurements were recorded, and a full physical examination was conducted. As for the farm and owner survey, the questions asked at enrolment varied somewhat between each of the three data collection rounds in which enrolments were carried out (see Appendix 1 and Appendix 2). Irrespective of data collection round, at enrolment data were captured on the age, sex, neuter status, and type of dog as well as vaccination history, skeletal size measurements and, for females, breeding history. Skeletal size measurements consisted of head length, head circumference, front leg length, hind leg length, body length and thoracic girth in centimetres. Detailed definitions of skeletal measures were included on all enrolment questionnaires (see Appendix 1).

When a dog was enrolled, dog owners were asked to provide information about any health conditions that had affected the dog's work in the past, and clinical examinations were carried out by veterinarians. Dogs were weighed and their body condition was scored using a nine-point scale where 1 is underweight, 9 is obese, and 4 to 5 is considered ideal (WSAVA Global Nutrition Committee, 2013). The physical examination included visual inspection of coat, skin, eyes, ears, teeth, footpads and nails; manual palpation of legs, tail, muscles, joints, mammary glands, testes, lymph nodes and abdomen; cardiovascular and respiratory examination with a stethoscope; and trot up to check for lameness. Range of motion was assessed in all major limb joints and the spine.

The ways in which dogs had been trained to work with stock was recorded (see Table 3-3 for descriptions of roles), along with the type of terrain they worked on and the types and species of stock the dog worked with (sheep, beef cattle, dairy cattle, deer, and other). Owners were asked how they acquired each dog. If the dog was not bred by the current owner, its age and level of training on arrival and any cost in money or trade was recorded. The composition of each dog's most recent meal was recorded. If the dog was currently being given any dietary supplements or medication, the type of supplement or medication was recorded.

During the first data collection round, data were collected regarding the construction of dogs' housing, frequency of feeding, whether each dog had the opportunity to scavenge, the types of food and water bowls used, the source of water, the modes of transport used for working dogs, where antiparasitic drugs were purchased, and whether the dog owner or the owner's employer paid for the feeding and veterinary treatments of working dogs. After the first data collection round, most of these questions were dropped, and questions related to housing were simplified and re-worded (see Appendix 1 and Appendix 2).

3.3.3.2 <u>At follow-up</u>

At follow-up, dog owners were again asked to provide information about the size and terrain of the farm, how many and which types of stock were present and what types of food they had fed their working dogs since the previous data collection round (see Appendix 1 and Appendix 2). Data collection was not repeated for information such as the dog owner's age, gender, job title or experience.

At follow-up, most of the data that were collected at enrolment were collected again (see Appendix 1 and Appendix 2). If a dog had died, been retired or left the property between data collection rounds this was recorded and when possible the reason was noted. From the third round of data collection onwards, follow-up data were also recorded about neuter status, insurance, and council registration of all enrolled working dogs, as these may have changed between farm visits. Information collected at follow-up visits did not include data on vaccination status, working roles, the terrain a dog worked on or skeletal size measurements.

3.3.4 Classification of type of dog

Dogs enrolled in TeamMate were classified based on the description given by the owner. The three most common groups were Heading dogs, Huntaways and Handy dogs. Dogs described by the owner as Beardies were classed as Huntaways, as 'Beardie' is a common term used to describe rough coated Huntaways. Dogs described as collies or Border Collies by the owner were classed as Heading dogs. Dogs classed as Handy dogs are dogs that can do the jobs of both Heading dogs and Huntaways, and were either described as such by their owner or were described as mixed dogs with one or both of the two main dog types in their parentage. A very small number of other types of dogs, mainly Kelpies, were listed by their reported breed.

3.3.5 Coding of clinical abnormalities

Abnormalities noted on clinical examination were systematically categorised using alphanumeric codes based on the examining veterinarian's notes. Each code consisted of a letter signifying the body system involved and up to five numbers signifying the location, symmetry, type and cause of the abnormality (see Appendix 3). Coding was carried out by a single veterinarian and checked by another person with training in veterinary health. Codes that were unclear or incomplete were re-checked by a veterinarian. In this paper, types of abnormalities seen in fewer than 10 dogs were generally classified as 'Other'.

3.3.6 Data analysis

The data presented here were recorded on the enrolment of properties, dogs and owners to the study. As we are presenting data for descriptive purposes, no significance testing was carried out. Data were analysed using R version 3.6.0 (R Core Team, 2020). Figures were generated using ggplot2 version 3.1.1 (Wickham, 2016) within R, except Figure 3-1 which was constructed in Microsoft PowerPoint 2016. Data were managed using Microsoft Access 2016.

Ninety-one dogs whose owners were clients of one clinic were found to have a 50% lower prevalence of recorded abnormalities on enrolment to the study than the overall population mean. As it was felt that abnormalities in these dogs were likely to have been missed due to the high workload put on the staff of this particular clinic, and the group of dogs was large enough to skew our results, we made the decision to remove dogs whose owners were clients of this clinic from the dataset.

3.4 Results

Data collection for TeamMate was carried out over a period spanning May 2014 to the second half of 2018 (Figure 3-1). Enrolment of dog owners and dogs was completed in May 2016. In total 126 owners associated with 116 farms participated in the study and 641 working farm dogs were enrolled.

3.4.1 Farming properties and dog owners

All farms were located in Otago and Canterbury, on New Zealand's South Island (Figure 3-2).
Table 3-1 summarises the number of farms, dog owners and dogs by types of terrain and stock present on the property. The median property size was 1511 ha (IQR = 501 – 4500 ha). Stock types and numbers were reported for 115 farming properties. The total number of stock animals on farm ranged from 12 to 36 000 animals, with a median of 4320 stock animals per farming property (IQR = 2220 – 6350).

Eighty-four percent (106 of 126, 95% confidence interval (CI) = 78% – 91%) of working farm dog owners were male, 58% (66 of 113, 95% CI = 49% – 67%) were the farm owner, 19% (22 of 113, 95% CI = 12% – 27%) were the farm manager and 19% (21 of 113, 95% CI = 11% – 26%) were employees. Sixty-three percent (75 of 120, 95% CI = 54% – 71%) had participated in training relating to farm dogs. Figure 3-3 shows the owners' age ranges and years of experience working with farm dogs. At the time of enrolment the median number of dogs per owner was four (range 1 – 9).

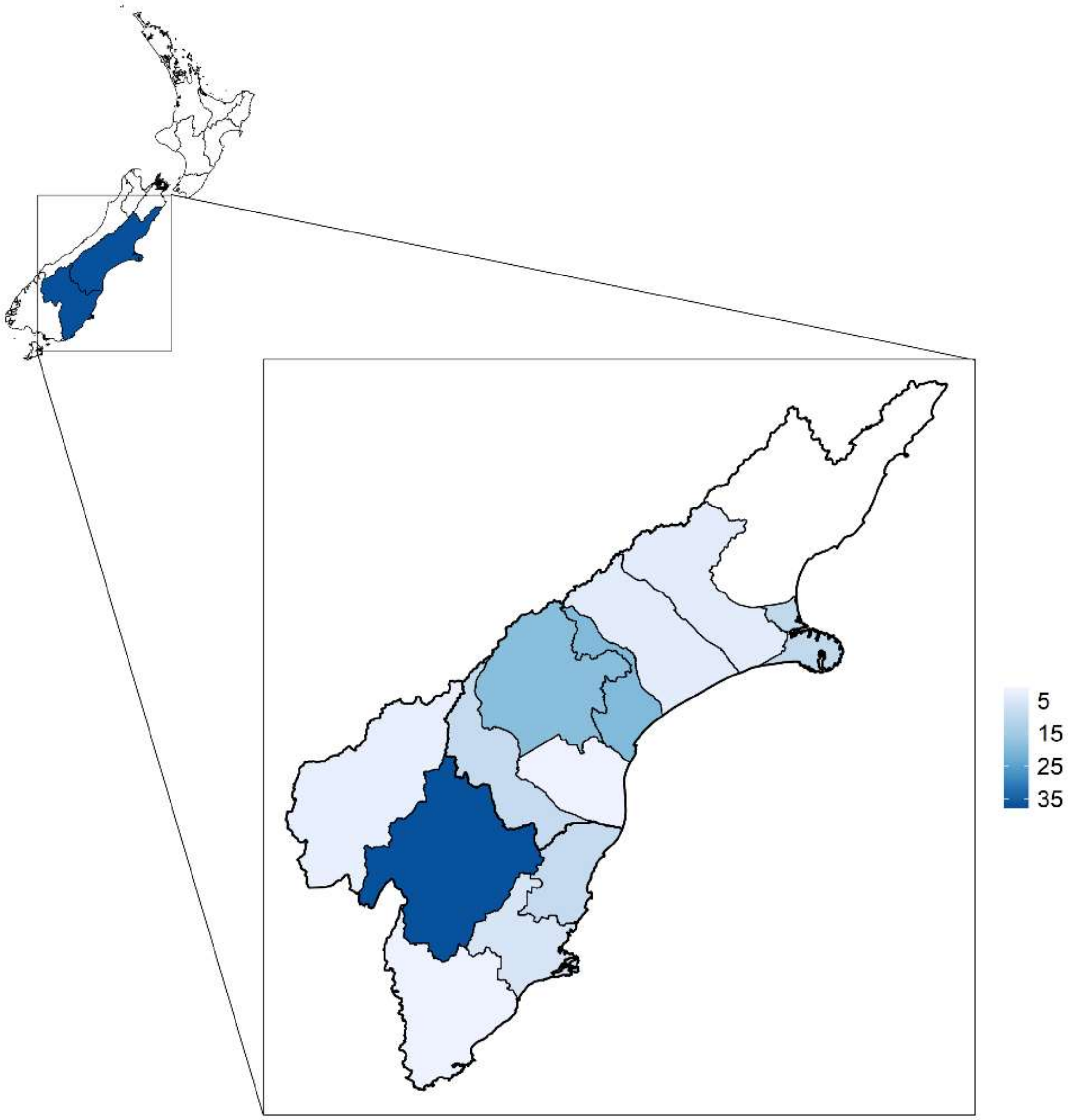

Figure 3-2: Map of New Zealand with the regions of Canterbury and Otago expanded. Shaded blue areas show the study area, with a darker shade indicating more farming properties. The study area is located between approximately -46 and -43 degrees longitude. The files used to generate this map were sourced from Stats NZ (2019) and licensed by Stats NZ for re-use under the Creative Commons Attribution 4.0 International licence.

Table 3-1: Number and percentage of farms, owners and dogs stratified by terrain and type of stock present and combinations of stock present. Data were collected from 641 dogs, 126 dog owners and 116 farms that participated in TeamMate. Combinations of stock that were seen on fewer than 10 farms were combined and listed as 'Other'

	Farms		Owners		Dogs	
Property variables	n	% (95% CI)	n	% (95% CI)	n	% (95% CI)
Terrain						
Both flat and steep	61	53 (43 – 62)	70	56 (47 – 64)	350	55 (51 – 58)
Flat only	34	29 (21 – 38)	34	27 (19 – 35)	159	25 (21 – 28)
Steep only	20	17 (10 – 24)	21	17 (10 – 23)	18	18 (15 – 21)
Type of stock present						
Sheep	111	96 (92 – 99)	121	96 (93 – 99)	16	96 (95 – 98)
Beef cattle	104	90 (84 – 95)	114	90 (85 – 96)	581	91 (88 – 93)
Dairy cattle (dry)	20	17 (10 – 24)	21	17 (10 – 23)	116	18 (15 – 21)
Deer	17	15 (8 – 21)	23	18 (12 – 25)	107	17 (14 – 20)
Other stock present	10	9 (4 – 14)	12	10 (4 – 15)	63	10 (8 – 12)
Combinations of stock						
Sheep and beef cattle	74	64 (55 – 73)	78	62 (53 – 70)	400	62 (59 – 66)
Sheep, beef cattle and dairy cattle (dry)	13	11 (5 – 17)	13	10 (5 – 16)	75	12 (9 – 14)
Sheep, beef cattle and deer	10	9 (4 – 14)	15	12 (6 – 18)	66	10 (8 – 13)
Other combinations of stock	19	16 (10 – 23)	20	16 (9 – 22)	100	16 (13 – 18)

Percentages do not add up to 100% due to incomplete recording of data and because most properties, dog owners and dogs were associated with more than one type of stock.

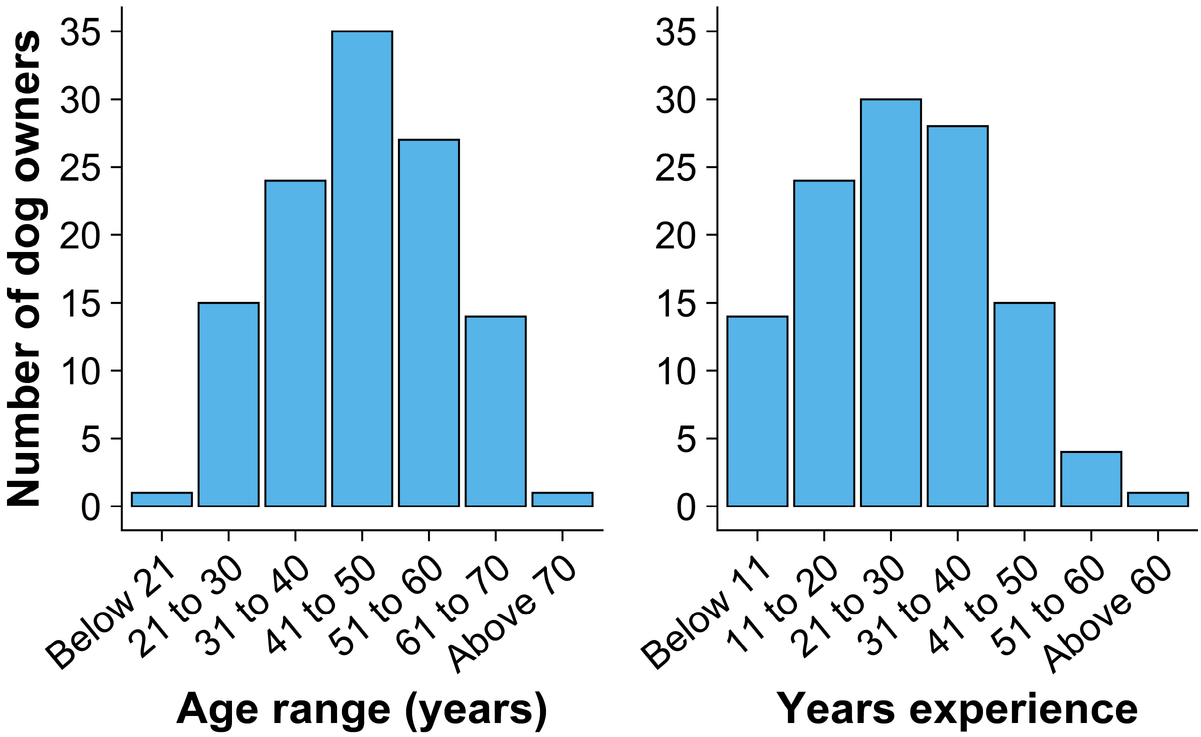

Figure 3-3: Left: Bar chart showing the number of dog owners stratified by age range (n = 117). Right: Bar chart showing the number of dog owners stratified by years of experience working with farm dogs (n = 116). Data were collected from working farm dog owners who participated in TeamMate.

3.4.2 Farm dogs

3.4.2.1 Population features

Population features of all dogs enrolled in TeamMate are summarised in Table 3-2. The median age of enrolled dogs was four years (IQR = 2 – 6). Mean body weight across all enrolled dogs was 26 kg (n = 608, SD = 6), with some differences seen between types of dogs (Figure 3-4). Median BCS was four out of nine (n = 634, IQR = 3 – 5), with a range of one to seven.

More females than males were neutered (Table 3-2). In females, 15 dogs were reported to have been neutered due to medical issues such as vaginal prolapse, pyometra or problems with pregnancy or whelping, four to prevent unwanted pregnancies and two due to their temperament. It should be noted that though seven female dogs were reported to have been neutered due to ‘prolapse’ or ‘vaginal prolapse’, these cases are more likely to be mis-identified cases of vaginal hyperplasia. In fact, one case was reported as ‘Prolapse / vaginal hyperplasia’. Four males were reported to have been neutered due to unspecified behavioural issues, four to prevent fighting and unwanted mating, three due to prostate disease and one to both stop mating and correct an unspecified body weight issue. Six females and one male had no recorded reason for being neutered.

The main modes of work New Zealand working dogs are trained to carry out are outlined in Table 3-3, and the distribution of working roles between the Heading dog and Huntaway types of dog is seen in Table 3-4. Note that 'Heading dog' and 'Huntaway' refers to the type of dog, while 'Head' and 'Hunt' refers to specific tasks carried out by working farm dogs. While the naming of the dog types is related to the work these dogs normally do, there is an amount of overlap in the tasks dogs in this dataset have been trained to carry out.

Table 3-2 shows the origins of all dogs in the study. Of the 466 dogs that had been acquired from another person, money was exchanged for 216 or 46% (95% CI = 42% – 51%). One hundred eighty-two of the remaining dogs were given at no cost and 51 dogs were traded. Trades involved alcohol (typically cases of beer), exchanging for another dog, or various other items. The median age at acquisition was 12 weeks (n = 466, IQR = 8 – 104). Fifty-four percent (n = 250 of 466, 95% CI = 49% – 58%) of the dogs had received no training prior to arriving with their current owner, 22% (n = 102, 95% CI = 18% – 26%) had been partly trained and 19% (n = 90, 95% CI = 16% – 23%) were fully trained. Twenty-four dogs had no record of their level of training on arrival. Across all purchased dogs in which money was exchanged the median price was NZ$800 (n = 216, range = NZ$26 to NZ$8000). Figure 3-5 illustrates the range of purchase prices stratified by the dog's level of training at the time of purchase. The majority of dogs were sold with no training and these, with the exception of a few outliers, were usually sold at relatively low prices.

3.4.2.2 <u>Husbandry practices and feeding</u>

Table 3-5 summarises a range of variables related to husbandry and housing of enrolled dogs. Of 311 dogs that did not have bedding in their kennel five were noted to have rejected the bedding provided to them and 13 to have bedding in winter. Six of the 333 dogs that were reported to not wear a coat were reported to have rejected it.

Table 3-6 shows the types of food dogs had been fed in the six months prior to enrolment in the study, and Table 3-7 shows what combinations of foods dogs were fed at their most recent meal prior to enrolment. 'Meat sourced on farm' refers to livestock, and occasionally game animals, that have been killed and butchered on farm.

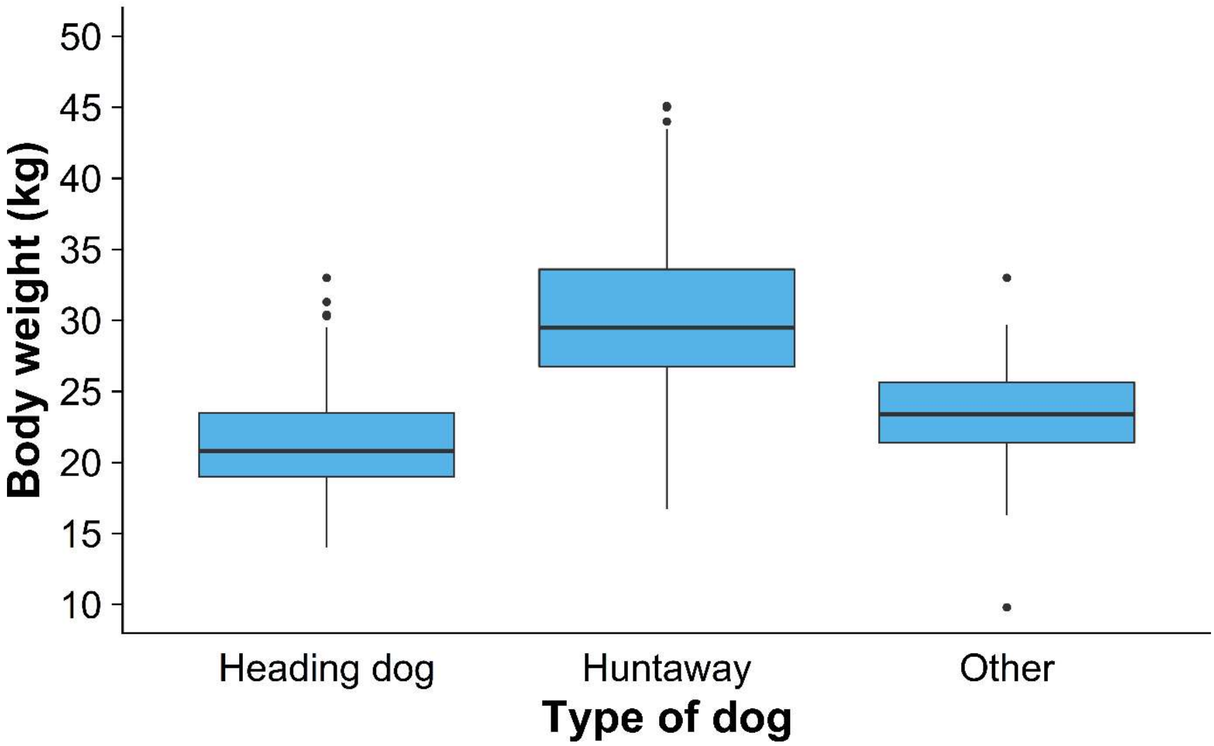

Figure 3-4: Boxplots showing the recorded body weights of 298 Heading dogs, 299 Huntaways and 19 dogs of other types. Data were collected from working farm dogs that were enrolled in TeamMate.

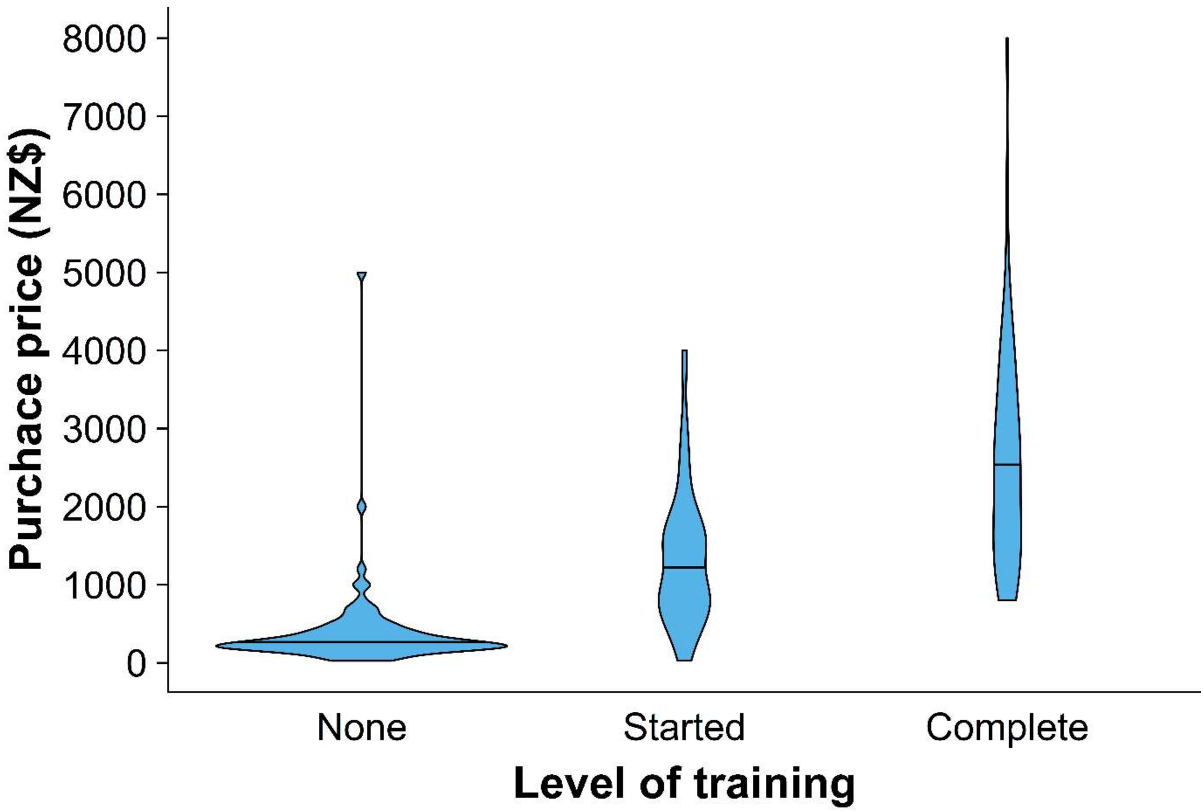

Figure 3-5: Violin plot, with the mean indicated, showing the purchase price of 200 working farm dogs stratified by level of training. Dogs that were acquired at no cost or had unknown purchase price or training level were not included in this plot. Data were collected from working farm dogs that were enrolled in TeamMate.

Table 3-2: Number and percentage of dogs stratified by type of dog, sex and neuter status, age and source of the dog. Data were collected from 641 working farm dogs enrolled in TeamMate.

Population features	Dogs	Percentage (95% CI)
Type of dog		
Heading dog	314	49 (45 – 53)
Huntaway	308	48 (44 – 52)
Handy dog	13	2 (1 – 3)
Kelpie	3	0 (0 – 1)
Other mixed breed	2	0 (0 – 1)
Unknown	1	0 (0 – 0)
Sex and neutering		
Female entire	250	39 (35 – 43)
Female neutered	29	5 (3 – 6)
Female neuter status unknown	17	3 (1 – 4)
Male entire	305	48 (44 – 51)
Male neutered	12	2 (1 – 3)
Male neuter status unknown	28	4 (3 – 6)
Age range		
1.5 to 3 years	291	45 (42 – 49)
3.1 to 5 years	143	22 (19 – 26)
5.1 to 7 years	94	15 (12 – 17)
7.1 to 10 years	92	14 (12 – 17)
Above 10 years	21	3 (2 – 5)
Source of dog		
Obtained from another breeder	466	73 (69 – 76)
Bred by current owner	148	23 (20 – 26)
On loan	1	0 (0 – 0)
Not recorded	26	4

Table 3-3: An overview of the modes of work commonly done by New Zealand working farm dogs. Dogs can be trained to carry out one or several modes of work.

Mode of work	Description
Head	The dog circles around to the head of the herd and uses its positioning to gather, stop and redirect animals. This type of work is typically, but not exclusively, carried out by Heading dogs.
Hunt	The dog uses its bark and position to apply pressure to the herd from behind in order to move the animals forward. This type of work is typically, but not exclusively, carried out by Huntaways.
Yard work	Any work done in stockyards and runs.
Catch	Separating one or several specific animals from the herd.

Table 3-4: Number and percentage (with 95% CI) of Heading dogs (n = 314) and Huntaways (n = 308) stratified by the ways in which they were trained to move stock. Data were collected from 641 working farm dogs enrolled in TeamMate. Percentages do not add up to 100% as many dogs were trained to carry out more than one mode of work.

	Heading dogs		Huntaways	
Mode of work	n	% (95% CI)	n	% (95% CI)
Head	291	93 (90 – 96)	81	26 (21 – 31)
Hunt	17	5 (3 – 8)	284	92 (89 – 95)
Yard work	52	17 (12 – 21)	253	82 (78 – 86)
Catch	132	42 (37 – 48)	44	14 (10 – 18)
Not reported	17	5	16	5

Table 3-5: Number and percentage (with 95% CI) of working farm dogs (n = 641) stratified by health management, registration status and housing. Data were collected from 641 working farm dogs enrolled in TeamMate. Details about kennel construction were obtained in relation to 393 dogs that were enrolled during the first round of farm visits. Percentages do not add up to 100% because of incomplete recording of data.

Variables	Dogs	Percentage (95% CI)
Vaccination status		
Only vaccinated as pup	290	45 (41 – 49)
Never vaccinated	77	12 (9 – 15)
Interval other than yearly	61	10 (7 – 12)
Yearly	58	9 (7 – 11)
Sporadically	33	5 (3 – 7)
Owner unsure of vaccination status	65	10 (8 – 12)
Dog insured		
Yes	213	33 (30 – 37)
No	373	58 (54 – 62)
Council registration		
Yes	418	65 (62 – 69)
No	128	20 (17 – 23)
Wears a coat		
Yes	154	24 (21 – 27)
No	333	52 (48 – 56)
Bedding in kennel provided		
Yes	279	44 (40 – 47)
No	311	49 (45 – 52)
Kennel construction		
Source of kennels		
Commercial	266	68 (63 – 72)
Home–made	120	31 (26 – 35)
Kennel type		
Motel with individual run	282	72 (67 – 76)
Kennel with chain	104	26 (22 – 31)
Other	3	1

Table 3-5: cont.

Kennel elevated from ground		
Yes	362	92 (89 – 85)
No	19	5 (3 – 7)
Kennel insulated		
Yes	55	14 (11 – 17)
No	320	81 (78 – 85)

Table 3-6: The numbers and percentages of dog owners stratified by the types of foods they reported to have given to their working farm dogs during a 6–month period. Data were collected from 126 working farm dog owners participating in TeamMate. Note that percentages do not add up to 100% because many owners fed more than one type of food.

Food fed to dogs	Owners	% (95% CI)
Meat	107	85 (79 – 91)
Source		
Sourced on farm	105	83 (77 – 90)
Purchased	16	13 (7 – 19)
Treatment		
Frozen	100	79 (72 – 86)
Fresh	27	21 (14 – 28)
Offal	28	22 (15 – 29)
Cooked	25	20 (13 – 27)
Fresh	1	1 (0 – 2)
Commercial dog food	113	90 (84 – 95)
Dry dog food	111	88 (82 – 94)
Wet dog food	54	43 (34 – 51)
Other commercial food	27	21 (14 – 29)
Not recorded	8	6 (2 – 11)

Table 3-7: The number and percentage of working farm dogs stratified by the types of foods comprising their most recent meal at the time of their enrolment to the study. Data were collected from 641 working farm dogs enrolled in TeamMate. Combinations of foods that were fed to fewer than 10 dogs are combined and listed as 'Other combinations'.

Most recent meal	Dogs	% (95% CI)
Meat only	242	38 (34 – 42)
Dry commercial food only	207	32 (29 – 36)
Meat and dry dog food	85	13 (11 – 16)
Dry and wet dog foods	25	4 (2 – 5)
Wet commercial dog food only	14	2 (1 – 3)
Meat, dry and wet dog foods	13	2 (1 – 3)
Dry and other commercial foods	10	2 (1 – 3)
Other combinations	30	5 (3 – 6)

3.4.2.3 Clinical examination

The prevalence of abnormal findings in each of the main categories, and the prevalence of abnormalities in Heading dogs and Huntaways can be seen in Table 3-8. For those dogs in which at least one abnormality was recorded, the median number of abnormalities per dog was three (IQR = 1 – 4). Note that recorded abnormalities in this study include anything that deviates from the ideal, including signs of previously healed injuries and normal wear that do not necessarily represent reduced health or welfare at the time of examination. As no clear differences were seen between Heading dogs and Huntaways in the prevalence of the major types of abnormalities, the remaining results are presented for the entire population without stratification by type of dog.

Twenty-nine percent of dogs (183 of 641, 95% CI = 25% – 32%) had at least one musculoskeletal abnormality in the hind limbs, 20% of dogs (130 of 641, 95% CI = 17% – 23%) had an abnormality in the front limbs and 7% of dogs (44 of 641, 95% CI = 5% – 9%) had an abnormality in the spine or tail. Lameness on trot was observed in 12% of all dogs (83 of 641, 95% CI = 10% – 16%) or 26% of dogs with a musculoskeletal abnormality (78 of 272, 95% CI = 21% – 31%). Table 3-9 and Table 3-10 show the prevalence of a range of musculoskeletal abnormalities in the forelimbs and hind quarters (including the tail), and the number of those dogs that were also lame when trotted up. Twenty-three dogs (n = 641, 4%, 95% CI = 2% – 5%) had abnormalities relating to the ribs and spine (excluding the tail) that could not be categorised as belonging to the front or hind part of the body. They are therefore not represented in the tables. Twenty-one dogs (n = 641, 3%, 95% CI = 2% – 5%) showed signs of pain on manipulation of the spine. Ten of these 21 dogs were also lame on trot-up (48%, 95% CI = 26% – 69%). One dog was recorded to have a swelling at the sacroiliac joint and to also be lame in the hind quarters. Additionally, one dog had an abnormal curvature of the lumbar spine, and one dog was recorded to have a protruding 13th rib on the left side. These two dogs were not observed to be lame.

Table 3-11 shows the prevalence of the different types of skin, eye and reproductive system abnormalities. Fifty-eight dogs (n = 641, 9%, 95% CI = 7% – 11%) had a callous and/or a healed scar with no other skin abnormality present. Ninety-three percent of dogs with skin callouses had them on the legs (93 of 100, 95% CI = 88% – 98%). Of dogs with a healed scar, an open or healing wound or both, 65% (100 of 153, 95% CI = 58% – 73%) had them on the face or ear, 35% (53 of 153, 95% CI = 27% – 42%) on the legs, 11% (17 of 153, 95% CI = 6% – 16%) on the torso, 8% (12 of 153, 95% CI = 4% – 12%) on the foot (including nails) and one on the tail. Types of skin abnormalities categorised as 'Other' included six dogs with missing nails, eight with poor coat condition, three that were missing part of an ear, two with pruritus, and one dog that had abnormal wear of the nails on one foot.

Table 3-12 shows the prevalence and placement of recorded clinical abnormalities relating to the teeth. Abnormalities classed as 'Other' included eight dogs with periodontitis or tooth abscesses, three dogs were observed to have a focal enamel defect and one had several retained juvenile incisors. Additionally, three dogs had gingivitis and two dogs had soft tissue injuries in the mouth.

Ocular abnormalities categorised in Table 3-11 as 'Other' included four dogs with conjunctivitis, two with evidence of uveitis, and one with signs of both conjunctivitis and uveitis. Four dogs had tumours related to the meibomian gland, seven were blind or had reduced vision, two had brown discolouration of the iris, two had corneal ulcers, two had one missing eye, two had conjunctival discharge, and one dog had a unilateral deformity of the third eyelid.

Nineteen females and one male dog were recorded to have mammary tumours. In females, reproductive system abnormalities classed in Table 3-11 as 'Other' included nine females with mammary hyperplasia, two dogs with an extra nipple, one dog with vaginal discharge eight weeks post whelping, and one dog was recorded to have vaginal prolapse. As mentioned above, the case reported as vaginal prolapse is likely to be a mis-characterised case of vaginal hyperplasia. In males, six dogs were cryptorchid, three had testes of unequal size, one had an enlarged prostate, one had scar tissue on the penis and one dog was described as having 'small, soft testicles'.

Four dogs had one swollen popliteal lymph node, three had one or two swollen prescapular lymph nodes, one had one swollen mandibular lymph node and one dog had one swollen inguinal lymph node. Four dogs had an unclassified heart arrhythmia and two had a heart murmur. One dog had been diagnosed with a diaphragmatic hernia following an accident and one had a slight unilateral wheeze on auscultation. Three dogs had umbilical hernias, one dog had an anal gland abscess and one was reported to have haematuria.

Table 3-8: The number and percentage (with 95% CI) of dogs that were recorded to have at least one abnormal clinical finding, stratified by body system. Numbers and percentages are shown for the entire population (n = 641) along with numbers and percentages of the two main types of dog: Heading dogs (n = 314) and Huntaways (n = 308). Data were collected from 641 working farm dogs that were enrolled in TeamMate. Percentages do not add up to 100% as many dogs were recorded to have more than one type of clinical abnormality.

	All dogs			Heading dogs			Huntaways		
Type of abnormality	n	%	(95% CI)	n	%	(95% CI)	n	%	(95% CI)
Musculoskeletal	272	42	(39 – 46)	121	39	(33 – 44)	143	46	(41 – 52)
Skin	272	42	(39 – 46)	129	41	(36 – 47)	138	45	(39 – 50)
Oropharyngeal	227	35	(32 – 39)	122	39	(33 – 44)	96	31	(26 – 36)
Ocular	66	10	(8 – 13)	35	11	(8 – 15)	30	10	(6 – 13)
Reproductive	45	7	(5 – 9)	15	5	(2 – 7)	27	9	(6 – 12)
Lymph nodes	9	1	(0 – 2)	2	1	(0 – 2)	6	2	(0 – 3)
Heart	6	1	(0 – 2)	5	2	(0 – 3)	1	0	(0 – 1)
Hernia	3	0	(0 – 1)	2	1	(0 – 2)	1	0	(0 – 1)
Respiratory	2	0	(0 – 1)	1	0	(0 – 1)	1	0	(0 – 1)
Gastrointestinal	1	0	(0 – 0)	1	0	(0 – 1)	1	0	(0 – 1)
Urinary	1	0	(0 – 0)	1	0	(0 – 1)	0	0	
Other	3	1	(0 – 1)	3	1	(0 – 2)	0	0	
Any abnormality	476	74	(71 – 78)	230	73	(68 – 78)	235	76	(72 – 81)

Table 3-9: The number and percentage (with 95% CI) of working farm dogs with reported musculoskeletal abnormalities in the front quarters, and the number and percentage (with 95% CI) of dogs with musculoskeletal abnormalities that were also lame in the front quarters. Data were collected from 641 working farm dogs that were enrolled in TeamMate. Types of clinical abnormalities that were recorded in fewer than 10 dogs are combined and listed as 'Other'.

	Number of dogs		Lame front leg(s)	
Anatomical location and type of abnormality	n	% (95% CI)	n	% (95% CI)
Shoulder				
Reduced range of motion	15	2 (1 – 4)	2	13 (0 – 31)
Other	9	1 (0 – 2)	2	22 (0 – 49)
All dogs with shoulder abnormalities	23	4 (2 – 5)	4	17 (2 – 33)
Elbow				
Reduced range of motion	11	2 (1 – 3)	2	18 (0 – 41)
Other	25	4 (2 – 5)	5	20 (4 – 36)
All dogs with elbow abnormalities	31	5 (3 – 6)	6	19 (5 – 33)
Carpals				
Crepitus	10	2 (1 – 3)	4	40 (10 – 70)
Reduced range of motion	52	8 (6 – 10)	10	19 (9 – 30)
Hard swelling	11	2 (1 – 3)	2	18 (0 – 41)
Other	16	2 (1 – 4)	5	31 (9 – 54)
All dogs with carpal abnormalities	69	11 (8 – 13)	15	22 (12 – 31)
Metacarpals				
Other	4	1 (0 – 1)	0	0
All dogs with metacarpal abnormalities	4	1 (0 – 1)	0	0
Front digits				
Hard swelling	14	2 (1 – 3)	1	7 (0 – 21)
Other	16	2 (1 – 4)	4	25 (4 – 46)
All dogs with front digit abnormalities	26	4 (3 – 6)	4	15 (2 – 29)

Table 3-10: The number and percentage (with 95% CI) of working farm dogs with reported musculoskeletal abnormalities in the hind quarters (including tail), and the number and percentage (with 95% CI) of dogs with a musculoskeletal abnormality that were also lame in the hind quarters. Data were collected from 641 working farm dogs that were enrolled in TeamMate. Types of clinical abnormalities that were recorded in fewer than 10 dogs are combined and listed as 'Other'.

	Number of dogs		Lame hind leg(s)	
Anatomical location and type of abnormality	n	% (95% CI)	n	% (95% CI)
Hip				
Reduced range of motion	59	9 (7 – 11)	12	20 (10 – 31)
Painful	43	7 (5 – 9)	15	35 (21 – 49)
Other	8	1 (0 – 2)	4	50 (15 – 85)
All dogs with hip abnormalities	88	14 (11 – 16)	21	24 (15 – 33)
Stifle				
Crepitus	19	3 (2 – 4)	5	26 (7 – 46)
Reduced range of motion	18	3 (2 – 4)	5	28 (7 – 48)
Hard swelling	32	5 (3 – 7)	6	19 (5 – 32)
Other	13	2 (1 – 3)	4	31 (6 – 56)
All dogs with stifle abnormalities	62	10 (7 – 12)	16	26 (15 – 37)
Tarsals				
Reduced range of motion	27	4 (3 – 6)	8	30 (12 – 47)
Hard swelling	12	2 (1 – 3)	4	33 (7 – 60)
Other	10	2 (1 – 3)	1	10 (0 – 29)
All dogs with tarsal abnormalities	43	7 (5 – 9)	9	21 (9 – 33)
Tail				
Reduced range of motion	12	2 (1 – 3)	1	8 (0 – 24)
Other	12	2 (1 – 3)	2	17 (0 – 38)
All dogs with tail abnormalities	22	3 (2 – 5)	3	14 (0 – 28)
Hind digits				
Other	19	3 (2 – 4)	4	21 (3 – 39)
All dogs with hind digit abnormalities	19	3 (2 – 4)	4	21 (3 – 39)
Metatarsals				
Other	6	1 (0 – 2)	1	17 (0 – 46)
All dogs with metatarsal abnormalities	6	1 (0 – 2)	1	17 (0 – 46)

Table 3-11: The number and percentage (with 95% CI) of working farm dogs with reported abnormal findings associated with the skin, eyes and reproductive systems. Data were collected from 641 working farm dogs that were enrolled in TeamMate. Types of clinical abnormalities that were recorded in fewer than 10 dogs are combined and listed as 'Other'. Note that dogs could be recorded to have more than one clinical abnormality.

Type of abnormal finding	Dogs	% (95% CI)
Skin		
Callous	100	16 (13 – 18)
Scar	98	15 (13 – 18)
Laceration	68	11 (8 – 13)
Inflammation	31	5 (3 – 6)
Mass	30	5 (3 – 6)
Alopecia	28	4 (3 – 6)
Infection	12	2 (1 – 3)
Other	21	3 (2 – 5)
Eyes		
Opacity	37	6 (4 – 8)
Scarring	10	2 (1 – 3)
Other	25	4 (2 – 5)
Reproductive system		
Mammary tumour	21	3 (2 – 5)
Other	24	4 (2 – 5)

Table 3-12: The number and percentage (with 95% CI) of working farm dogs that were recorded to have clinical abnormalities related to the teeth. Types of abnormalities are shown stratified by location in the mouth as well as combined. Data were collected from 641 working farm dogs that were enrolled in TeamMate. Types of clinical abnormalities that were recorded in fewer than 10 dogs are combined and listed as 'Other'. Note that dogs could be recorded to have more than one tooth abnormality.

	Front teeth	Back teeth	General	All locations	
Type of abnormal finding	n	n	n	n	% (95% CI)
Tooth fracture(s)	84	13	7	104	16 (13 – 19)
Tooth wear	55	8	17	80	12 (10 – 15)
Tooth / teeth missing	36	2	4	42	7 (5 – 8)
Tartar	2	3	21	26	4 (3 – 6)
Malocclusion	1	1	17	18	3 (2 – 4)
Tooth discolouration	9	1	1	11	2 (1 – 3)
Other	8	4	0	12	2 (1 – 3)

3.5 Discussion

The aim of the TeamMate project is to investigate health, career duration and loss of dogs over time. This initial paper describes the 641 working farm dogs that were enrolled in the study, their owners' feeding and husbandry practices, their work, population features, and prevalence of abnormal findings on clinical examination.

Dogs were almost equally divided between males and females, and almost all dogs belonged to the Heading dog and Huntaway types, with only 19 of the 641 enrolled dogs classified as another type. We saw a clear division in the types of work done by Heading dogs and Huntaways, with Heading dogs mostly used to head and Huntaways mostly used to hunt. The differences seen in working roles between dogs described as Heading dogs and Huntaways in this study were expected, as these dogs are generally used for different types of stock work (Cogger and Sheard, 2017; Dalton, 2010a, 2010b; Knight, 1984; Oliver et al., 2009). However, there was a degree of overlap, suggesting that the division of work is not the only criteria used to define a dog as a Heading dog or Huntaway. Heading dogs and Huntaways do not have defined phenotypes, pedigrees or genetics in the way that conventional dog breeds do. Consequently, we made the decision to avoid using the word 'breed' when referring to them. Although Heading dogs and Huntaways can be recognised based on appearance, their phenotypes are said to vary widely (Cogger and Sheard, 2017; Dalton, 2010a, 2010b). Generally, Heading dogs resemble short-haired Border Collies, from which they are thought to descend. They are mainly trained to 'head' and often to 'catch' which puts them at closer proximity to stock than Huntaways when moving stock in open areas (see Table 3-4 for definitions of work). Huntaways tend to be heavier than Heading dogs (Figure 3-4), and have different colouring and more variability in coat length. They are trained to use their loud barks to drive or 'hunt' stock, and they are often used in yard work, which is a more confined environment. Huntaways are used for fine manoeuvring of stock less often than Heading dogs. Instead, they are used to apply pressure from behind and keep the herd moving while Heading dogs direct where they should go. When used as teams, Heading dogs and Huntaways can move large herds very effectively across long distances. However, the differences in the ways they work may put them at risk of developing different types of injuries. While no major differences between types of dogs were seen in the prevalence of clinical abnormalities, this will be more re-examined when analysing data on the incidence of new abnormalities on follow-up and rate of dogs being lost from the workforce.

Seventy-five percent of dogs had at least one abnormal finding on clinical examination. Musculoskeletal system, skin and teeth abnormalities were by far the most common, and were recorded in a higher proportion of dogs than in the surveys by Sheard (2014) and Cave et al. (2009). This is to be expected, as TeamMate was deliberately designed to capture all abnormalities in dogs and not just ones that were clinically significant at the time the data were collected. The earlier surveys recorded instances of illness or injury that were serious enough that owners thought to report them at a later date, or took the dogs to be seen by a veterinarian. Unlike these surveys, in TeamMate the term 'abnormality' encompasses any change to a dog, including healed scars, callouses and minor tooth wear that are unlikely to be considered a problem by the owner, or to directly impact on dogs' health and welfare. However, these abnormalities illustrate the most common types of problems working farm dogs are likely to acquire, and they may be contributing factors to subsequent disease, retirement or death.

Several veterinarians participated in data collection, creating a possibility that different individuals assessed and described similar types of abnormalities in in different ways. However, in order to minimise bias in the data, veterinarians were asked to describe physical signs rather than to give overall diagnoses. While differences in data collected by different veterinarians are impossible to rule out, we have worked to minimised the risk of bias through our data collection, coding and data entry procedures. Additionally, a random sampling procedure may have resulted in a sample that was more representative of the farm dog population as a whole. However, in order to avoid a low response rate and to enable data collection to be carried out in a timely manner, a convenience sample of existing Vetlife clients was chosen.

Thirty percent of dogs in TeamMate were given a body condition score of three or below which places them in the 'under ideal' range according to the World Small Animal Veterinary Association (WSAVA Global Nutrition Committee, 2013). This is in general agreement with Sheard's data that dog owners considered one in five of their dogs to be underweight (Sheard, 2014). However, in Sheard's study no data on body weight or body condition scores were collected that could have confirmed or negated owners' assessments. O'Connell et al. (O'Connell et al., 2019) reports similarly low BCS in their sample population, but did not find a correlation between BCS and the presence of parasites in faecal samples, or dogs' sex, age or housing. It should be noted that body condition scoring for dogs was developed with the aim of estimating body fat in overweight dogs (Laflamme, 1997; Mawby et al., 2004) and is poorly validated for athletic, lean dogs. In such dogs, loss of muscle mass may be a more relevant cause for concern. The ratio of lean body mass to skeletal size may be a better way to assess condition in lean dogs than BCS (Leung et al., 2018), although it remains to be seen which method has the greatest utility. Nonetheless, it has not been established what the ideal BCS or lean mass for a working farm dog is, or whether there are proportions of body fat or lean mass associated with an increased risk of disease or injury. An aim of the wider TeamMate project is to use the longitudinal data to investigate whether BCS and lean mass in farm dogs is related to injury, disease, or loss from work.

Similarly to dogs surveyed by Singh et al. (2011) and O'Connell et al. (O'Connell et al., 2019) most dogs in this study were fed a combination of meat sourced on the farm and commercial dog food, and only one dog owner reported having fed their dogs only meat in the previous six months. However, we were not able to record the amounts of food given, the quality of the food or the ratios of meat to commercial food. As such it is impossible to comment on whether the food given was adequate to their needs. However, un-supplemented meat is deficient in several minerals and vitamins (Hill, 1998), and if it is fed as the main proportion of the diet rather than as a supplement to a complete and balanced diet, it may result in malnutrition. To determine whether current feeding practices are associated with disease, injury or shortened lifespans, more detailed information is needed about the dogs, their energy expenditure and the exact size and composition of their meals. Most dog owners reported that the meat fed to dogs had been frozen, and that offal had been cooked. Working farm dogs are at risk of infection from a range of parasites that could be spread through untreated meat (O'Connell et al., 2019). In addition to regular anthelmintic treatment, freezing or cooking meat and offal that is to be fed to dogs is recommended to reduce the spread of these parasites, especially those that might be spread to livestock (O'Connell et al., 2019; OVIS Management, n.d.).

Over 80% of dogs in this study were housed in un-insulated kennels, less than half had bedding in their kennel and at least half of all dogs did not wear a coat for warmth at the time of enrolment. A dog's energy expenditure can be affected by the quality of its housing, as ambient temperatures have an impact on dogs' energy requirements, both if they are too hot and too cold (Wakshlag and Shmalberg, 2014). Dogs that are housed in warm kennels use less energy on thermoregulation, and consequently have lower energy requirements. The recommended range of ambient temperature in order to maintain health and welfare in laboratory dogs is 20 – 26^{o}C (Prescott et al., 2004). In comparison, temperatures on the South Island can drop to well below 0^{o}C in the winter months (National Institute of Water and Atmospheric Research, n.d.). Additionally, it has been shown that low temperatures are associated with increased levels of stress hormones, while dogs housed in actively heated kennels tend to rest more (Rooney et al., 2009). Though there is a great deal of variety in their phenotypes, most working farm dogs in New Zealand have relatively short, smooth coats that are likely to offer limited protection from cold temperatures. In this respect, comparing them to laboratory dogs such as Beagles is not unreasonable. Due to their athleticism and high activity levels, farm dogs are also likely to have less insulating subcutaneous fat than most laboratory dogs. In addition to helping with thermoregulation, providing appropriate bedding can help with preventing pressure sores on dogs' elbows and hocks (Prescott et al., 2004). Three out of every 20 dogs in this study were reported to have callouses that were probably caused by lying on hard surfaces. It should be noted that in this study some of the questions relating to housing had relatively low response rates, and that some dogs were noted to have rejected the coats and bedding provided to them. Nonetheless, improving the housing for working farm dogs could have a positive effect on their health, welfare and career longevity.

Only six percent of farm dogs were reported to be neutered. Farm dog owners may have a desire to be able to breed from dogs that prove to be good workers, causing them to only neuter dogs if they have a specific reason to do so. The rate of neutering was twice as high in females than in males, with most females having been neutered due to medical issues. In comparison, most male dogs had been neutered to stop unwanted mating and behavioural issues such as fighting. Some dog owners noted that neutering a male was done due to having one male in an otherwise all-female team, which is likely to make it more difficult than usual to isolate females in heat. Cave et al. (2009) found that nine percent of clinic presentations of farm dogs involved a reproductive issue. The majority of these were mismatings, with mammary neoplasia being the second most common. An increased rate of neutering would decrease the rate of mismatings and might also reduce injuries caused by males fighting. However, it is uncertain whether neutering is beneficial for dogs' overall health beyond removing risk directly related to the testes, ovaries and uterus. Most of the reproductive system abnormalities recorded in this study were mammary tumours or mammary hyperplasia. In the past it was believed that neutering reduces the risk of mammary tumours in female dogs, but the evidence supporting this claim is of variable quality (Beauvais et al., 2012; Houlihan, 2017).

In the TeamMate population, only 24% of dogs were vaccinated as adults, from yearly to sporadically, although another 45% were known to have been vaccinated as a puppy. In comparison, a study of 196 working farm dogs on the North Island of New Zealand reported that 53% of dogs were vaccinated annually or every two years (O'Connell et al., 2019). The majority of dogs in O'Connell et al.'s study were recruited from a veterinary practice in the Waikato region, with the remainder being recruited at a North Island sheepdog trial event. Possibly, dog owners in Canterbury and Otago tend to live further from veterinary clinics than those in the Waikato region, making it more difficult for them to get their dogs vaccinated regularly. Additionally, dogs are barred from competing in trial events if they are ill with an infectious disease (New Zealand Sheepdog Trial Association, 2018). This may act as an incentive for owners to vaccinate their dogs.

For TeamMate we did not record the nature of the vaccines administered, though it is assumed the majority of vaccinations cover the core viral pathogens (distemper, adenovirus-2, parvovirus, ± parainfluenza). The duration of immunity elicited by the core vaccines is likely to extend beyond 3 years, and is probably life-long in many animals (Schultz, 2006; Schultz et al., 2010). Thus, it is very likely that a large proportion of dogs are sufficiently immunised against the core viral pathogens. Additionally, as farm dogs in New Zealand rarely move off the farm property, their risk of infection is much lower than in pet dogs. This is reflected in the low prevalence of suspected parvoviral enteritis in the study by Cave et al*.* (2009). Other vaccines that may be given to farm dogs include those protecting against leptospirosis and *Bordetella bronchiseptica*. Leptospirosis is common in New Zealand livestock, and seropositivity is relatively common in unvaccinated working farm dogs (Harland, 2015). In addition, outbreaks of acute tracheobronchitis in working farm dogs have been seen by the authors, notably following trial meetings. Nonetheless, the significance of vaccination status to the health and career longevity of working farm dogs is not known. Depending on the results of future studies, more focus may need to be placed on ensuring appropriate vaccination coverage in working farm dogs.

Nearly 35% of farm dogs in the current study were covered by an insurance policy. This is higher than the 20% insurance coverage reported in Golden retrievers enrolled in a longitudinal study in the United States (Simpson et al., 2017). Additionally, in Australia it has been estimated that about 7% of dog owners have pet insurance (Roy Morgan, 2018), however it has been suggested that this might be an underestimate (Fawcett et al., 2018). Due to the inherent differences between these populations, the validity of these comparisons could be disputed. However, little data is available on insurance rates in dogs, and no such data exists on pet dogs in New Zealand. The comparatively high rate of insurance in farm dogs might be explained by the fact that in New Zealand many insurance policies that cover assets related to farming also include the option to cover working farm dogs (AMP, 2018; FMG, 2019; NZI, 2013).

Over two thirds of participating farm dog owners were aged 30 to 59 years and three quarters reported having between 20 and 40 years of experience working with dogs, suggesting that those who work with farm dogs as adults often start learning at a very young age. A large majority of dog owners in our dataset report being the farm's owner or manager, and very few recorded farms had more than one dog owner associated with it. Many farm managers employ farm hands and shepherds to help with the running of the farm. These shepherds usually own and work with their own team of dogs. As such, there is a possibility that there were dogs and owners working on participating farms that were not enrolled in TeamMate.

One aim of TeamMate was to try to gain a better understanding of the size of the farm dog population in New Zealand. Numbers are available on how many farming operations are present in New Zealand, but not on how many people on those farms own and work with dogs. However, due to the uncertainty surrounding the number of dogs and owners working on enrolled farms, we reported the median number of dogs per participating dog owner, not per farm. Previous studies have been unclear in whether they reported the number of dogs belonging to each owner surveyed or the number of dogs working on each farm. Most gathered data from a single owner on each property and reported the number of dogs per farm (Jerram, 2013; Sheard, 2014; Singh et al., 2011). None mentioned whether or not other owners have worked with their dogs on the same farms. Jerram (2013) and Sheard (2014) analysed data from the same set of dogs, although Sheard included one less farm and 79 fewer dogs. They enrolled dogs from six months of age and included all dogs that had been working on the farm in the 12 months preceding the survey. Jerram reported a median of seven dogs and Sheard a mean of nine dogs per farm. Singh et al. (2011) included all dogs above 12 months of age and reported a median of six dogs per farm. These are all higher than our result of four dogs per owner, but because TeamMate excluded any dog below 18 months of age or that were not in full work, the difference is not unexpected.

A majority of dogs were not fully trained when acquired, being either purchased as young puppies or bred by the current owner. Most dogs came at little or no cost, although some, usually fully trained adults, were occasionally bought for several thousand NZ dollars. Some farmers may want to teach dogs to work according to their own preferences, causing them to prefer self-bred and/or untrained pups over adults trained by others. However, there is no guarantee that a young pup will develop into a useful working dog and this may not be apparent until a substantial amount of time has been spent on training. In this light it makes sense that farm dogs are not seen as having much monetary value until they are older and better trained.

3.6 Conclusions

This paper describes the TeamMate study and initial data collected from dog owners and working farm dogs at their enrolment to the study. We document previously unrecorded information about New Zealand working farm dogs and their owners and expand on previous knowledge about the dog population as well as common husbandry practices and health. Our results largely agree with previous studies while adding details that were not previously known. Further studies will involve tracking incidence rates of illness and injury, and analysis of factors that may be associated with increased risk. We are also interested to know which risk factors are associated with retirement or death of working farm dogs. This knowledge may enable us to develop guidelines for the care and husbandry of working farm dogs, helping dog owners to maintain their working dogs into later life without sacrificing the dogs' welfare or performance.

3.7 Statement of contribution

DRC 16

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Katja Elisabeth Isaksen
Name/title of Primary Supervisor:	Ass. Professor Naomi Cogger
Name of Research Output and full reference:	
Isaksen, K.E., Linney, L., Williamson, H., Cave, N.J., Beausoleil, N.J., Norman, E.J., Cogger, N., 2020. TeamMate: A longitudinal study of New Zealand working farm dogs. I. Methods, population characteristics and health on enrolment. BMC Vet. Res. 16, 1–17. https://doi.org/10.1186/s12917-020-2273-2	
In which Chapter is the Manuscript /Published work:	Chapter 3
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For manuscripts intended for publication please indicate target journal:	
Candidate's Signature:	Katja E. Isaksen
Date:	9/12/2020
Primary Supervisor's Signature:	N. Cogger
Date:	9/12/2020

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Chapter 4

Exploring body condition in a population of lean working farm dogs

Exploring body condition in a population of lean working farm dogs

4.1 Abstract

Working farm dogs have lower overall body condition scores (BCS) than those reported in pet dogs, and owners of working farm dogs in New Zealand report concerns about low body weight in as many as one in five working dogs. BCS commonly is used to assess body fat percentage in overweight and obese dogs, but it is not well-validated in lean, muscular or underweight dogs. We investigated whether BCS was associated with predicted measures of fat and lean body mass in working farm dogs, and explored an alternative measure of body condition based on predicted lean body mass.

A previously published model (Leung et al., 2018) was used to predict lean body mass and corresponding body fat mass of 436 working farm dogs. Although an association was found between predicted body fat percentage and BCS (Adjusted $R^2 = 0.07$, $P(F) < 0.001$), the effect size was lower than in previously published validation studies. In comparison with the 1.4% increase in predicted fat mass per point increase in BCS found in this study, two previously published validation studies found that body fat increased by 5% and 9% per point increase in BCS. Given this low effect size, a loss of lean mass, such as muscle mass, may be more indicative of poor health in working farm dogs than low BCS which attempts to assess fat mass. The ratio of predicted lean body mass to skeletal size is an alternative measure of body condition in working farm dogs. BCS was not found to be significantly associated with this lean mass ratio (Adjusted $R^2 = 0.003$, $P(F) = 0.14$).

Due to the lack of strong effects of either of the tested measures of body composition on BCS, we recommend that BCS should be further validated as a measure of health in lean dogs if it is to continue to be used in clinical practice. Such validation should take care to include dogs with low BCS that are both athletic and non-athletic in order to add knowledge on how to differentiate between these states. Additionally, both BCS and the ratio of predicted lean mass to skeletal size should be investigated further to discover whether they are associated with health outcomes such as illness or injury, retirement or death. As a next step we plan to investigate whether BCS or the ratio of predicted lean body mass to skeletal size are associated with the risk of dogs dying or being retired.

4.2 Introduction

Owners of working farm dogs in New Zealand report concerns about low body weight in as many as one in five working dogs (Sheard, 2014), but whether this is related to health, welfare, and longevity is uncertain. In humans, both low body mass index (BMI) and loss of muscle mass have been shown to be associated with a poor bone health and a higher risk of musculoskeletal injury in athletes (Finnoff et al., 2011; Powers et al., 2017; Tenforde et al., 2015), to have a negative effect on health outcomes in people with a range of diseases (Deutz et al., 2019), and to be associated with increased levels of injury in the elderly (Lang et al., 2010). However, no data is currently available on what proportion of lean mass is indicative of good or impaired health in dogs, and in order to progress research in this area, a valid, reliable, and feasible way to measure body condition in working dogs is needed.

Body condition score (BCS) is often used in veterinary medicine as a simple subjective estimate of the proportion of body fat in individual animals with an aim to assess whether animals are unhealthily under- or overweight (Henneke et al., 1983; Kenyon et al., 2014; Roche et al., 2009). The nine-point BCS scale has been validated by comparing the measured body fat mass in dogs to BCS assigned by veterinarians (Laflamme, 1997; Mawby et al., 2004). Laflamme (Laflamme, 1997) found that mean body fat mass in 255 purebred laboratory dogs increased by an average of over 5% per point of increase in BCS, while Mawby et al. (2004) found that mean body fat mass in 23 pet dogs increased by 9% per point increase. However working farm dogs, have, on average, lower body condition scores than those reported in pet dogs (Chapter 3) and the utility of BCS when applied to lean, athletic dogs is uncertain because it was was established primarily with a view to quantifying obesity and was validated using normal to obese dogs. Laflamme did not report the distribution of BCS scores in their study population and included no dogs that were given a score of one (emaciated), and Mawby et al. included no dogs with a score below four (normal) and three-quarters of their study population were scored six (obese) or above. The common measure of body condition in people (body mass index, BMI), which was also developed with the aim of assessing body fat in people of average build and conditioning, has been shown to be unreliable as an estimate of body condition when applied to lean, muscular people (Nuttall, 2015). BMI is calculated based on height and body weight causing muscular people to have high BMI due to their high muscle mass rather than because of their fat mass. A similar problem may occur when Laflamme’s BCS scale is applied to lean, muscular working dogs, as the scale was not developed to take muscle mass into account.

Leung et al. (2018) suggested that the ratio of lean body mass to skeletal size may be a more appropriate measure for assessing lean body mass in working farm dogs than BCS. They developed a model to predict lean body mass in New Zealand working farm dogs based on a range of physical parameters.

The model was found to be accurate when applied to the same 20 dogs it was developed from, however more studies are needed to determine the utility of the model more generally in the working farm dog population.

The main purpose of this study was, therefore, to compare the use of conventional BCS for estimating body condition with predicted measures of body composition derived using Leung et al.'s model, in a population of working farm dogs. Specifically, we investigated the effect of predicted body fat percentage and predicted lean mass to skeletal size ratio on BCS. Additionally, we explored the distributions of these variables in the same population of working farm dogs, and compared measures of body size in the two common types of working farm dogs in New Zealand; Heading dogs and Huntaways. As the method used to predict lean body mass has not yet been validated, we conducted a sensitivity analysis to explore the variability of possible outcomes within the confidence intervals associated with the model.

4.3 Methods

4.3.1 Study design

The current chapter used data collected from the TeamMate study, a longitudinal study which was described in detail in Chapter 3. To summarize, a total of 126 owners associated with 116 farms participated in the study and 641 working farm dogs were enrolled. All working farm dogs belonging to participating dog owners were enrolled if they were least 18 months old and working with livestock regularly. At each data collection round, including on enrolment, dog owners were visited on the farm where they worked and interviewed to collect information about the dogs' husbandry, feeding, and work, and dogs were physically examined by veterinarians. Physical examinations included a range of physical and subjective measurements, including scoring of dogs' body condition using the system validated by Laflamme (1997) and Mawby et al. (2004), and taking measurements indicative of body size. All veterinarians and scribes were trained to ensure data collection was performed in a standardized way. In the current study, we used data that was collected on dogs' enrolment to the study.

4.3.2 Assessment of data integrity due to implausible or missing data

A set of six morphometric measurements of dogs were recorded at dogs' enrolment to TeamMate. These measurements were used to calculate predicted measures of body composition (See Section 4.3.3). The presence of implausible or missing morphometric measurements were explored to assess whether bias had been introduced into the dataset. The number of missing or implausible values in each variable was counted, and we investigated whether the presence of these values was associated with the veterinary clinic that collected the data collection or the data collection round.

4.3.3 Generating skeletal size scores

A score representing skeletal size was required in order to predict lean body mass using the model developed by Leung et al. (2018) (Table 0-1). The skeletal size of each dog was calculated using scores from a principal components analysis (PCA) of dogs' morphometric measurements. PCA has been used to examine skeletal size and shape in previous studies (Chase et al., 2002; Leung et al., 2018; Sutter et al., 2008). One of the goals of PCA is to simplify and highlight the most important patterns of variability within highly correlated datasets (Abdi and Williams, 2010). The analysis uses the correlation matrix derived from a dataset to generate a set of coefficients and their corresponding, uncorrelated variables. These variables are called principal components. The first principal component is generated in such a way that it accounts for as much of the variance in the data as possible. Further components are created orthogonally, and each account for as much of the remaining variance as possible until all variance has been accounted for. The principal components can be interpreted by examining the sizes and directions of the coefficients. Appendix 4 gives a more detailed explanation of how coefficients are interpreted.

Rather than exploring all aspects of the morphometric data, the aim of carrying out PCA in the current study was to generate scores representing overall skeletal size that could be used in Leung et al.'s model. Previous studies of morphometric measurements in dogs have suggested that the first principal component represents overall skeletal size while further principal components represent aspects of skeletal shape (Chase et al., 2002; Leung et al., 2018; Sutter et al., 2008). We report and interpret the first four principal components of our morphometric data in Appendix 4. PCA was carried out using complete sets of morphometric measurements from 456 dogs enrolled in TeamMate. PCA was done on centred and scaled data using the prcomp() function from the stats package in R version 4.0.x (R Core Team, 2020). The prcomp() function calculates the PCA output by singular value decomposition of the input data matrix.

Following the method by Leung et al. (2018), skeletal size scores were calculated for each dog from the first principal component scores. As the coefficients of the first principal component were all negative, we used the absolute values to ensure that the smallest dogs had the lowest scores. Leung et al. added six to their principal component scores in order to avoid values of less than one, thereby making the skeletal size score more intuitive and avoiding the ratio of predicted lean body mass to skeletal size being inflated in dogs with skeletal size scores between minus one and one. To be able to use their method for calculating predicted lean body mass it was necessary that we performed the same transformation. Due to the mentioned inflation effect one dog in the current study was excluded from the calculation of the ratio of predicted lean body mass to skeletal size due to having a skeletal size score of less than one after transformation. In addition to the results of the PCA, summary statistics of skeletal size scores in Heading dogs and Huntaways can be found in Appendix 4.

4.3.4 Measuring body size and composition

Predicted lean body mass was calculated using an model developed by Leung et al. (2018). The model was developed based on measured values of lean body mass in 20 healthy working dogs and includes measured values for a range of variables including the type of dog, skeletal size score, bodyweight and age (Table 0-1). Dogs that did not have recorded values for the listed variables, or were not either Heading dogs or Huntaways, were excluded from analysis.

Morphometric measurements were used to describe differences in body size between Heading dogs and Huntaways and to generate skeletal size scores for each dog. Measurements were chosen to be representative of skeletal size independently of joint movement or soft tissue cover, and were the same as those used by Leung et al*.* (2018) (Table 0-2). Before analysis, morphological data were assessed for outliers by visual examination of scatter plots and histograms. Outliers that were judged by a veterinary clinician to be physically impossible in any type of dog were assumed to be measurement or transcription errors and deleted. As one of the purposes of recording skeletal measurements was to explore differences between Heading dogs and Huntaways, the type or breed of dog was not considered. Table 0-2 lists the ranges of what were considered to be plausible measurements. Dogs were excluded from analysis if they had one or more missing value in the morphometric measurements.

Table 0-1: Regression model for factors associated with measured lean body mass in 20 working farm dogs as reported by Leung et al. (2018).

Outcome	Variable		Beta-coefficient	95% confidence interval (CI)
Lean body mass	*Intercept*		6.40	2.22 – 10.57 [a]
	Type of dog	(Heading dog)	Ref	
		(Huntaway)	1.91	0.19 – 3.62
	Skeletal size score		0.60	0.03 – 1.16
	Bodyweight (kg)		0.47	0.22 – 0.71
	Age (years)		-0.18	-0.35 – -0.00

[a] The previously unreported 95% CI for the regression intercept was provided by N.J. Cave, one of the co-authors of the study by Leung et al.

Table 0-2: Morphometric measurements taken from working farm dogs, and the range considered to be physically plausible for each measurement. All measurements were recorded in centimetres.

Measurement	Description	Plausible range
Head length	From the level of medial canthus, equidistant between the eyes, to the external occipital protuberance	9 – 20 cm
Head circumference	Circumference at a point equidistant between the eyes and ears – the widest part of the head.	30 – 60 cm
Front leg length	From the proximal edge of the central foot pad to the point of the elbow (olecranon process), with carpus in extension.	20 – 40 cm
Hind leg length	From the proximal edge of the central foot pad to the tip of the hock (dorsal tip of the calcaneal process), with the tarsus in extension	10 – 25 cm
Body length	From the first thoracic vertebrae to the dorsal process of S1.	25 – 65 cm
Thoracic girth	Chest circumference at the level of the xiphoid.	50 – 90 cm

4.3.5 Exploring population trends

Differences in body size and composition between Heading dogs and Huntaways were explored by determining the means and standards deviations for morphological measures and body weights for each type of dog. The median BCS and IQR was determined for each type of dog. Differences between Heading dogs and Huntaways were tested for significance using two-sample Student's t-tests or Wilcoxon rank sum tests, as appropriate, with significance defined as $P < 0.05$.

Body composition in the study population was explored by calculating the means and standard deviations of the predicted lean body mass and the ratio of predicted lean body mass to skeletal size score. Since the type of dog was one of the variables used when calculating the predicted lean body mass, any values that were based on the predicted lean body mass were not examined for significant differences between types of dogs, that is Heading dogs or Huntaways.

A linear regression model was used to investigate whether there was a significant association between dogs' predicted percentage of body fat and BCS as assessed by a veterinarian. Significance was assessed using the partial F-test. Predicted body fat mass was calculated by subtracting predicted lean body mass from the measured body weight. The percentage of body fat to total body weight was then calculated.

4.3.6 Sensitivity analysis of lean body mass prediction

The model reported by Leung et al. (2018) to predict lean body mass has not yet been validated by applying it to an independent population of working farm dogs with known lean body mass. Because of this we wanted to evaluate the impact of uncertainty in the model's intercept and beta-coefficients when applied to our data. Uncertainty in risk analysis and regression model predictions has previously been assessed using Monte Carlo simulations (Austin and Steyerberg, 2015; Cohen et al., 1996; Thompson, 1999). In existing studies, uncertainty has mainly related to the input variables rather than the regression coefficients, but a similar approach can be used in this case. To explore the effect of uncertainty in the model coefficients on the predicted lean body mass, the intercept and each coefficient was replaced by a uniform distribution of randomly drawn values with upper and lower limits equal to the 95% CI and used to predict lean body mass. For example, the model gives a 95% CI of 0.03 to 1.16 for the beta-coefficient of the skeletal size score (Table 0-1). For each iteration of the Monte Carlo simulation a random number between 0.03 and 1.16 was drawn, applied to the skeletal size score and used to calculate the predicted lean body mass. This procedure was simultaneously carried out with the intercept and all other variables included in the model.

A Monte Carlo simulation with 5000 iterations was run and the lean body mass for each dog was recalculated with the new intercept and beta-coefficients. The result was that for each dog there were 5,000 simulated lean body mass estimates. To describe the effect of uncertainty in the beta-coefficients on the predicted lean body mass, we estimated the mean of the predicted lean body mass in the study population if the beta-coefficients were at the lowest of highest ends of their confidence intervals. Additionally, scatter plots with best-fit regression lines were generated for each set of simulated coefficients and lean body mass. The gradient of the lines indicated how influential each variable was on the outcome. A larger range of possible values for the mean predicted lean body mass and a steeper gradient in the scatter plot indicated that a change in value of the coefficient had a stronger impact on the model output.

4.4 Results

There were 641 dogs enrolled in TeamMate, of which 622 Heading dogs or Huntaways were eligible to be included in the current study. One hundred eighty-six of 622 dogs (30%) had missing or implausible data in one or more the variables relevant to this study and were therefore excluded from analysis. In the 436 dogs with complete data, the median age was 4 years (IQR = 2 – 6 years), the mean body weight was 26 kg (SD = 6 kg) and the median BCS was 4 (IQR = 3 – 5). These values were identical when all 622 eligible dogs were included. Table 0-3 lists the number of eligible dogs and dogs with complete data relevant to the study, stratified by type of dog and sex.

Of the 436 dogs with complete data 151 (35%) were assessed as having BCS below 4, indicating underweight (WSAVA Global Nutrition Committee, 2013), 274 (63%) were assessed as BCS 4 or 5, indicating normal weight, and 11 (3%) were assessed as having BCS of above 5, indicating overweight. No dogs were assessed as having BCS above 6.

Table 0-3: The number of dogs of each sex and type of dog that were eligible to be included in the current study, and the subset that had complete sets of data relevant to the study.

Variables		All eligible dogs (n = 622)	Dogs with complete data (n = 436)
Type of dog	Heading dog	314 (50%)	211 (48%)
	Huntaway	308 (50%)	225 (52%)
Sex	Female	284 (46%)	198 (45%)
	Male	338 (54%)	238 (55%)

4.4.1 Data integrity and missingness

One hundred sixty-seven (27%) of 622 Heading dogs and Huntaways enrolled in TeamMate had at least one missing or implausible morphological measurement and were excluded from analysis. The head length measurement had higher numbers of implausible values than other measurements (Figure 0-1). In the course of assessing the data for integrity, associations were found between the presence of missing or implausible values and the data collection round, with data collected during the first round having the highest proportion of implausible morphometric measurements, and data collected during the third round having the highest proportion of missing morphometric measurements (Figure 0-2). Associations were also found between implausible morphometric measurements and the veterinary clinic that carried out the data collection (Figure 0-3). Note that there were large differences between the number of dogs associated with each clinic, with a few clinics managing data collection from a majority of owners and dogs. As reported at the beginning of the results section, the median age of dogs, median BCS and mean body weight did not change after missing and implausible values were removed from the dataset.

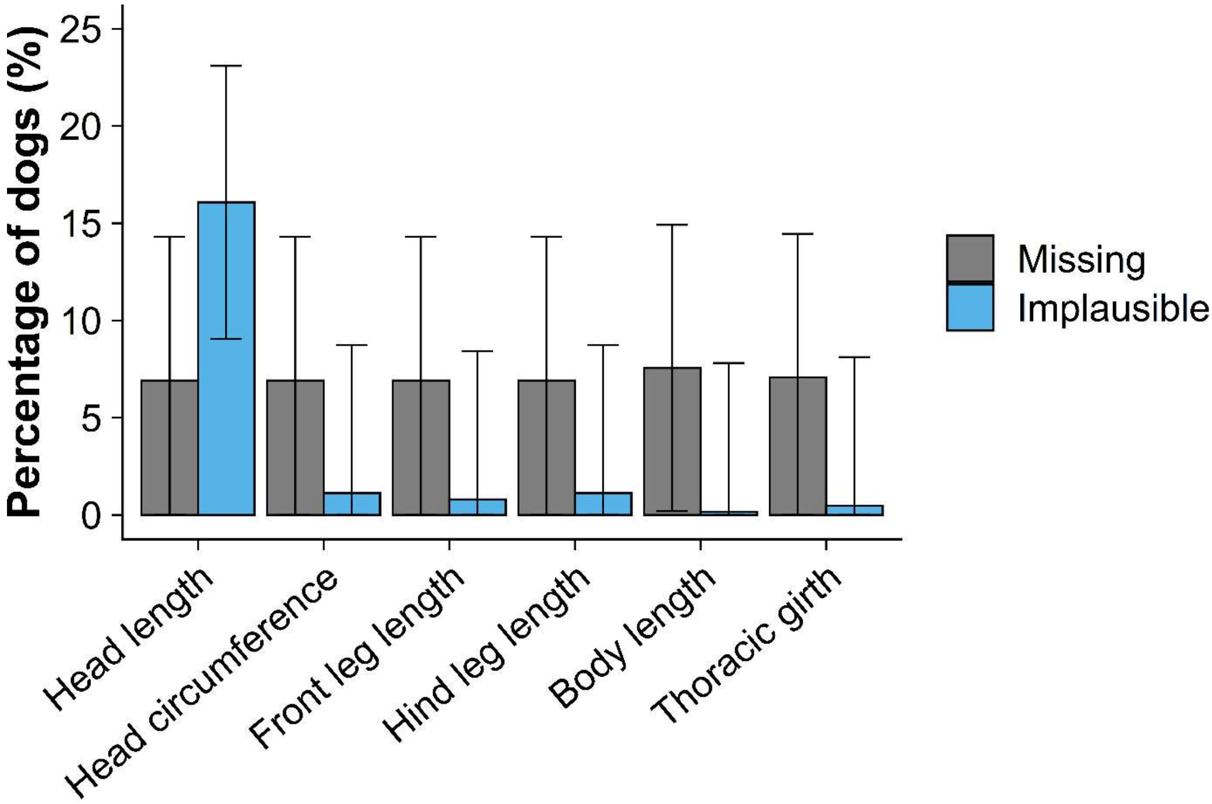

Figure 0-1: Bar chart showing the percentage (with 95% CI) of dogs that had missing or implausible morphological measurements, stratified by the type of measurement. Data from 622 Heading dogs and Huntaways that were enrolled in TeamMate.

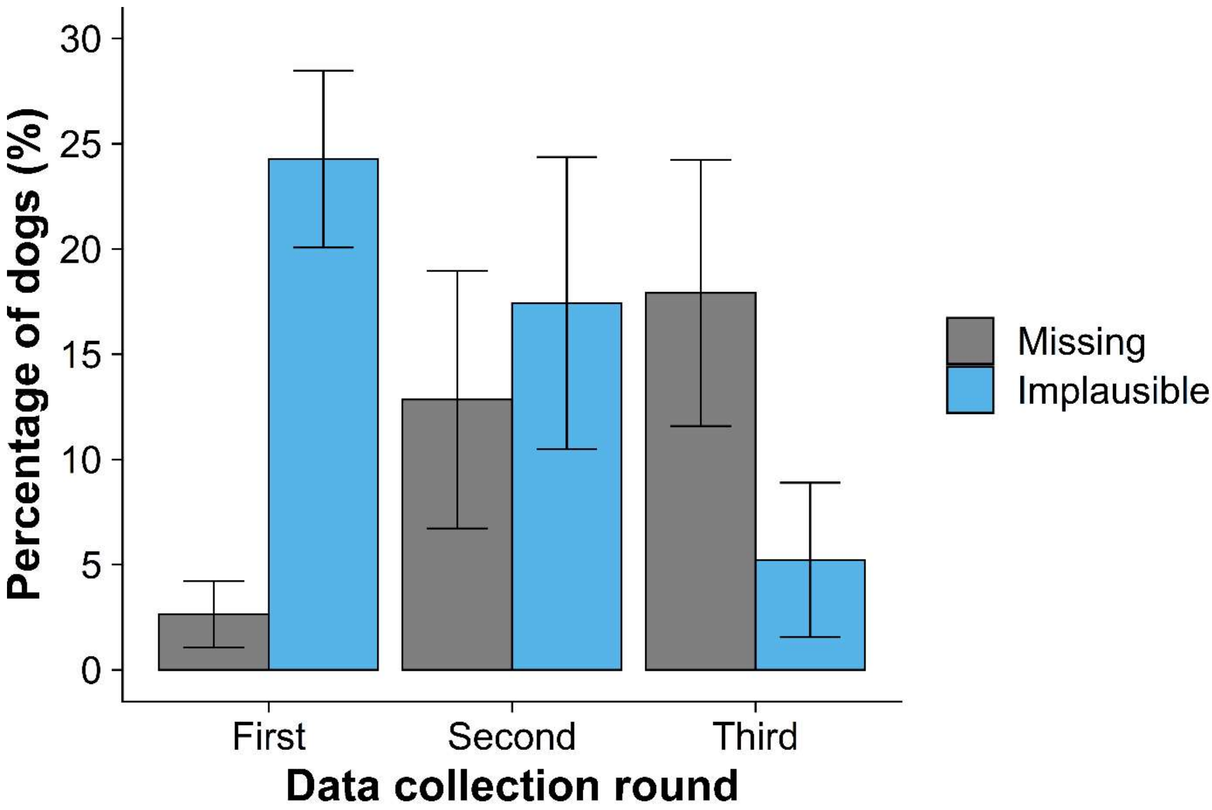

Figure 0-2: Percentage of dogs (with 95% CI) that had at least one missing or implausible morphometric measurement at each data collection round. Data from 622 Heading dogs and Huntaways that were enrolled in TeamMate.

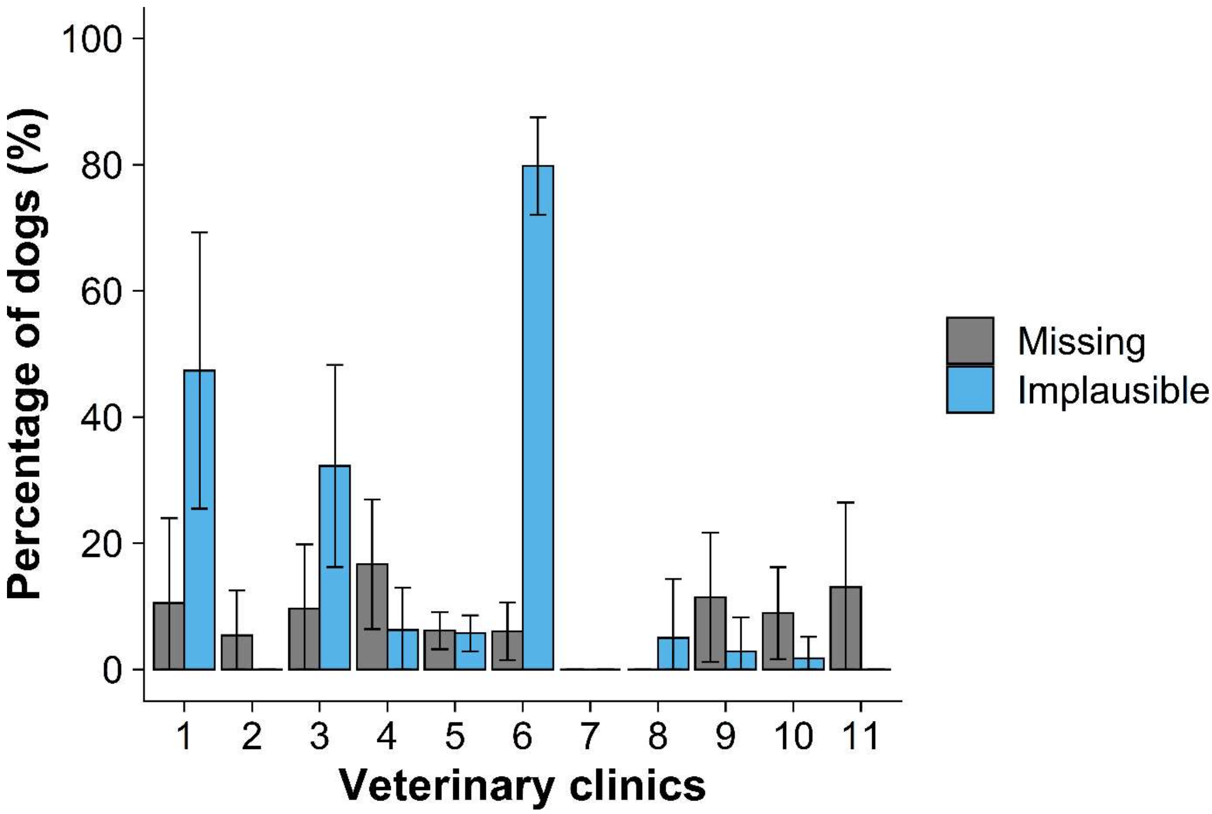

Figure 0-3: Bar chart showing the percentage of dogs that had at least one missing or implausible morphometric measurement, stratified by the veterinary clinic associated with the dog owners. The order of the clinics has been randomized. Data from 622 Heading dogs and Huntaways that were enrolled in TeamMate.

4.4.2 Body size and condition

Heading dogs had lower body weights than Huntaways and were significantly smaller on all recorded morphometric measurements (Table 0-4). However, no difference in the BCS of the two types of dog was seen when testing for significance using a Wilcoxon rank sum test (Heading dogs: median = 4, IQR = 2 – 6; Huntaways: median = 4, IQR = 2.5 – 5.5; $P = 0.13$).

One dog had a skeletal size score below one. Due to the inflation effect mentioned in Section 4.3.4 this dog was excluded from calculations and analysis that involved predicted variables derived from the skeletal size score. Figure 0-4 illustrates the distributions of predicted values related to body condition in working farm dogs. The mean predicted lean body mass was 22.3 kg (SD = 4.8), the mean predicted body fat percentage was 13.0% (SD = 5.0%) and the mean predicted lean body mass to skeletal size ratio was 3.9 (SD = 0.7). The associations between BCS assigned by veterinarians and the predicted body fat percentage or predicted lean mass to skeletal size ratio were assessed using univariable linear regression models (Figure 0-5). A one point increase in BCS was associated with an average 1.4% (95% CI = 0.9 – 1.9%) increase in predicted body fat percentage (Adjusted $R^2 = 0.07$, $P(F) < 0.001$). The predicted lean mass to skeletal size ratio was not found to have a strong association with BCS (Adjusted $R^2 = 0.003$, $P(F) = 0.14$).

Table 0-4: Means and standard deviations (SD) of body weights and skeletal measurements taken from Heading dogs and Huntaways, and the results of Student's t-tests carried out to investigate differences in measurements between the two types of dog. Body weight is given in kilograms and skeletal measurements are given in centimetres. Data from 213 Heading dogs and 227 Huntaways.

	Heading dogs	Huntaways	
Measurement	Mean (SD)	Mean (SD)	*P*(t)
Body weight	21.1 (3.2)	30.3 (5.0)	<0.001
Head length	13.0 (1.3)	14.9 (1.5)	<0.001
Head circumference	38.7 (2.6)	44.8 (3.2)	<0.001
Front leg length	27.5 (2.7)	30.9 (3.3)	<0.001
Hind leg length	14.2 (1.2)	16.1 (1.4)	<0.001
Body length	42.6 (4.0)	46.5 (4.3)	<0.001
Thoracic girth	64.8 (3.9)	71.8 (4.6)	<0.001

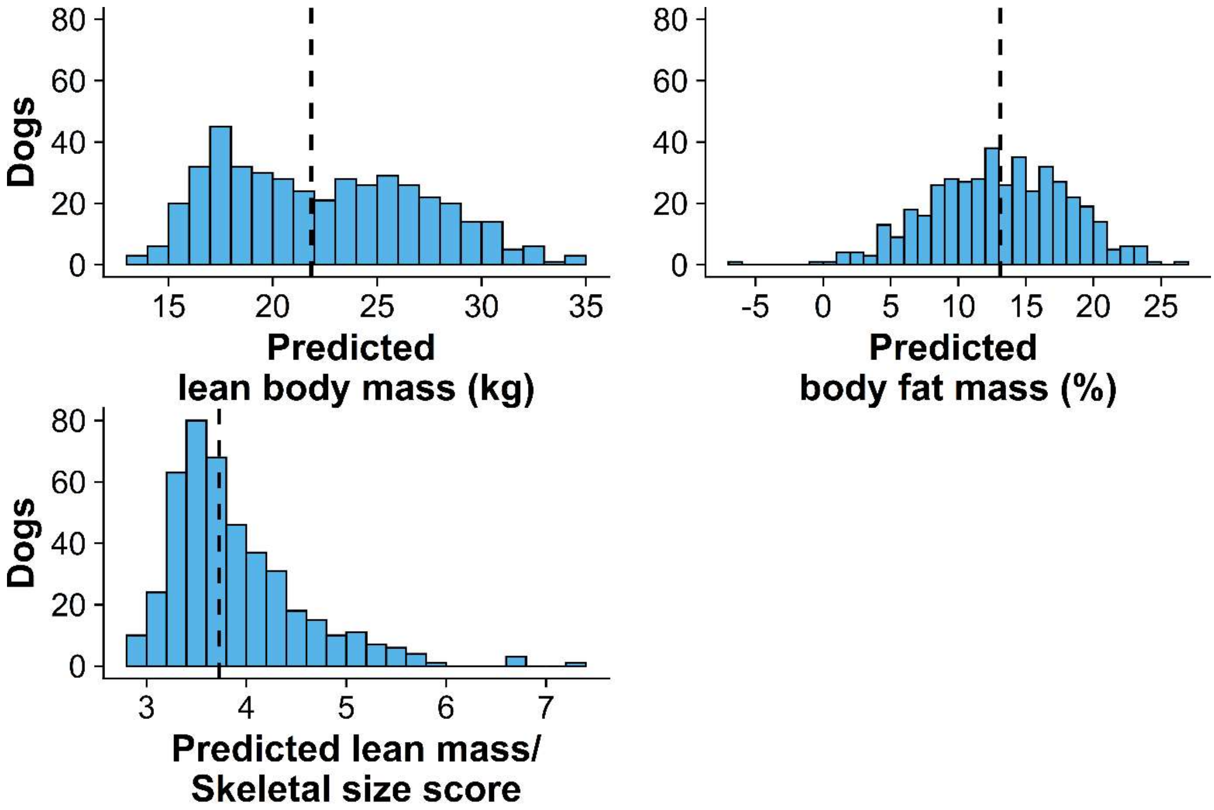

Figure 0-4: Histograms showing the distribution of three predicted values related to body condition in 435 working farm dogs. The dashed lines indicate the means.

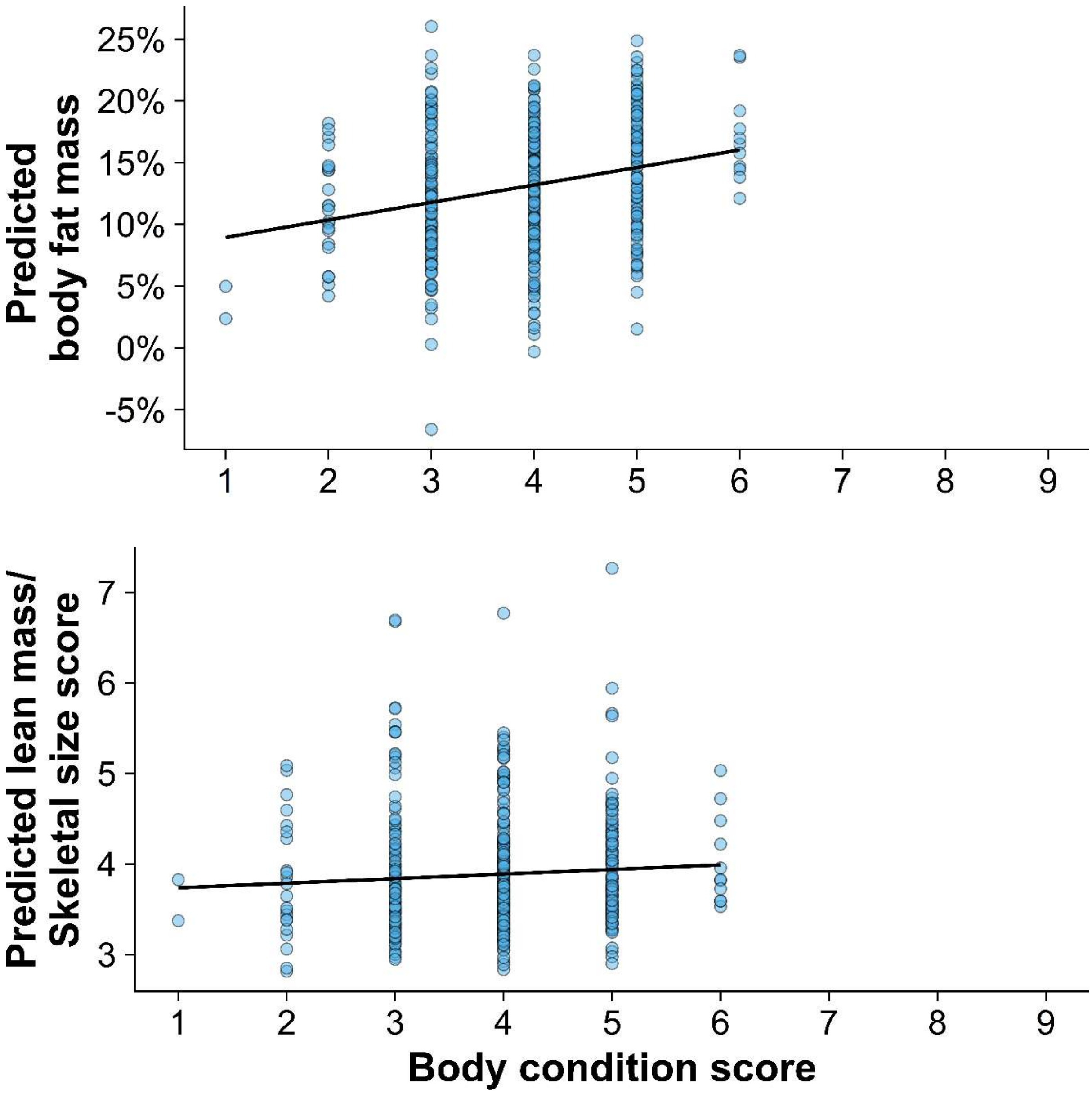

Figure 0-5: Scatter plots with best-fit regression lines showing the associations between body fat percentage and body condition score (top) and lean mass to skeletal size ratio and body condition score (bottom). Data is from 435 working farm dogs.

4.4.3 Sensitivity analysis

Table 0-5 show the relationships between uncertainty in the intercept and beta-coefficients of the predictive model for lean body mass and the simulated lean body mass that was calculated using simulated input values for these coefficients. Changes in the intercept and the body weight coefficient have the strongest effect on the mean simulated lean body mass, as can be seen by the wide ranges of mean simulated lean body mass.

Table 0-5: Ranges of the uniform distributions of input values that were used in the Monte Carlo simulation to predict lean body mass, the ranges of mean simulated lean body mass that were generated when applying the simulated input values to 435 working farm dogs. The regression line gradient indicates the change in predicted lean body mass per one-point increase of the input value.

Input variable	Range of input values (uniform distribution)	Range of mean simulated LBM (kg)	Regression line gradient
Intercept	2.22 – 10.57	17.8 – 26.4	1.04
Skeletal size	0.19 – 3.62	18.7 – 25.4	5.89
Age	0.03 – 1.16	21.3 – 23.0	4.80
Body weight	0.22 – 0.71	15.8 – 28.5	25.85
Type of dog (Huntaway)	-0.35 – -0.00	24.4 – 27.4	0.88

4.5 Discussion

This is the first time body size and body condition has been investigated in a large population of working farm dogs in New Zealand. Dogs were found to be generally lean, both according to BCS and using the using the Leung et al. (2018) model to predict lean body mass in Heading dogs and Huntaways. Although a strong association was found between BCS and the body fat mass predicted by the Leung et al. (2018) model, the effect of predicted body fat percentage on BCS was small, with an increase of only 1.4% body fat mass per point of increase in BCS, corresponding to an average of seven percent difference in predicted body fat percentage across the entire range of BCS scores recorded in this study. In comparison, previous studies have found differences of five percent and nine percent body fat percentage per point increase in BCS, corresponding to 45% and 81% difference in body fat percentage between the highest and lowest recorded BCS (Laflamme, 1997; Mawby et al., 2004). These effects of are much stronger than that detected in this study. Provided that the predicted lean mass provided by Leung et al.'s model is valid, the results of this study suggest that the nine-point BCS scale that is commonly used to assess body fat mass in dogs provides little useful information about changes in body fat percentage when applied to lean, athletic working farm dogs. While there may be meaningful differences in the health of working farm dogs that are given low or high BCS, our data suggests that these differences are probably not linked to large variations in body fat.

Working farm dogs are highly active, athletic dogs with low proportions of body fat and they are likely to be more muscular than the pet or laboratory dogs that were used to validate BCS (Laflamme, 1997; Mawby et al., 2004). BCS was not developed with lean or muscular individuals in mind, and the chart that is commonly used to describe how to assess dogs and assign scores focuses primarily on fat cover over the ribs, vertebrae and pelvic bones (WSAVA Global Nutrition Committee, 2013). The chart makes minimal mention of how to account for musculature beyond noting that dogs given scores of one or two should have some loss of muscle mass. This focus on fat may make it difficult to assign scores to dogs with well-developed musculature but minimal fat cover, causing the spread of scores assigned to farm dogs with similar body fat percentages to be larger than would be expected based on previous studies. This increase in the spread of scores could in turn decrease in the effect size when BCS was analysed in relation to body fat. This may explain the large variation in predicted body fat mass in working farm dogs that were assigned similar BCS (Figure 0-5).

No association was found between BCS and the ratio of predicted lean mass to skeletal size (Figure 0-5). Although BCS was not developed to assess lean mass, this lack of an association reinforces our finding that BCS is a poor indicator of body condition in working farm dogs. However, the Leung et al. model used to calculate the predicted lean mass has not been validated using a larger group of dogs with known lean body mass. Further, it is unknown whether the ratio of predicted lean mass to skeletal size is associated with health outcomes in working farm dogs. This study provides information about the distribution of predicted lean mass to skeletal size ratios that were recorded in over 400 working farm dogs. However, further investigation is necessary to know whether BCS, the lean mass ratio, or both are associated with health outcomes or the risk of injury, disease or loss of dogs from the workforce. If any associations are found, the results may indicate whether BCS or the lean mass ratio can be used as indicators of health in working farm dogs.

Working farm dogs enrolled in this study were predicted to have a mean lean body mass to body weight ratio of 0.87, which corresponds to a body fat mass of 13%. A study of 255 dogs with BCS of two to nine suggested that a healthy proportion of body fat in dogs was roughly 13% to 20% (Laflamme, 1997). However, the study did not describe the criteria used for considering dogs to be healthy. While many studies have been carried out that report on body condition and fatness in dogs, many of them use methods other than BCS to assess obesity. These methods include veterinarians' subjective assessments, the bodyweight of dogs in relation to a breed standard, and novel equations. Studies that report BCS in a cross-section of dogs often select overweight pet dogs for study and do not provide detailed data about dogs that were considered lean or underweight (for example: Courcier et al., 2010; Gates et al., 2019; Kealy et al., 2002; Lund et al., 2006; Mao et al., 2013; McGreevy et al., 2005). However, three studies were found that reported BCS in a cross-section of dogs. Jeusette et al. (2010) reported a mean BCS of 5.7 in 19 dogs, Mawby et al. (2004) reported a mean BCS of 6.1 in 23 dogs and Smith et al. (2018) reported a mean BCS of 5.3 in 141 purebred dogs. In comparison, only three percent of dogs enrolled in TeamMate were scored above six, while almost one third were scored below the four to five range of BCS which is commonly referred to as "ideal" (Table 0-3). While the lack of comparable studies makes it is difficult to make definite conclusions, these results indicate that New Zealand working farm dogs tend to have low predicted proportions of body fat and body condition scores that are on average around one to two points lower than those seen in pet dog populations. When reading this study it should be taken into account that there is a possibility of selection bias being present in our sample of working farm dogs. Dogs and owners were recruited based on owners' perceived interest in participating in the study. As such TeamMate may have recruited owners who take a higher than average interest in the health of their dogs. Such owners may feed and care for their dogs better than other farm dog owners, resulting in our study over-estimating the body condition and health of working farm dogs in general. However, if such selection bias is present it does not invalidate our conclusion that BCS is likely to be a poor predictor of body condition in working farm dogs, or that working farm dogs tend to be leaner than previously studied dogs. We highly recommend further study into how health and body condition can be assessed in lean working dogs.

As mentioned above, the effect of predicted body fat mass on BCS was weak. Although there was a significant association, the adjusted R^2 of the linear regression model was only 0.07 and the mean predicted body fat mass in working farm dogs increased by only 1.4% per one-point increase in BCS. In previous studies that were done to validate BCS as an approximate measure of body fat, mean body fat mass increased with BCS by an average of over 5% per point as measured by dual-energy X-ray absorptiometry (DEXA) (Laflamme, 1997) and by 9% per point as measured by DEXA (Mawby et al., (2004). It is likely that Laflamme and Mawby et al. found larger effect sizes than this study because their sample populations included more dogs with BCS and measured fat mass at the higher end of the scales. However, it is difficult to make comparisons to these studies. Laflamme chose to omit the summary statistics of the sample population and report only the predicted body fat percentages derived from their model, while Mawby et al. had a small sample population consisting of pet dogs that ranged only from four to eight in BCS but a had range of 4 to 41% in measured body fat mass. It may be that we would have found a stronger effect of predicted body fat mass on BCS if our sample population had included more overweight and obese dogs that were also given high body condition scores. However, given the weak effect of body fat on BCS found in this study, further validation studies should be carried out to assess the use of BCS as an indicator of health in lean dogs. Efforts should be made to include lean and underweight dogs in such validation studies, to investigate how athletic and non-athletic dogs with low BCS differ and to investigate how athleticism can be distinguished from underweight caused by illness or malnourishment.

A Monte Carlo simulation was used to assess uncertainty in the model that was used to calculate predicted lean body mass in working farm dogs. Our results suggested that the possible predictions for lean body mass could vary by several kilograms if the true value of one or more of the coefficients lies towards the outer bounds of their 95% CI (Table 0-5). As the Leung et al. model was developed based on data from only 20 dogs the 95% CIs are wide, making the possible effect of inaccuracies quite strong. However, the methodology used to develop the model was based on a highly reliable method of measuring lean body mass (Santarossa et al., 2017), and any uncertainty is mainly a result of the low sample size used by Leung et al. (2018). In order to confirm or deny the utility of the model as a method of estimating lean body mass in working farm dogs, it should be validated using a larger population of working farm dogs with known lean body mass.

Almost 30% of dogs that were eligible to be included in this study were removed from the dataset due to missing or implausible morphometric measurements. The main reason for errors in the measurements, especially of the head length measurement, is thought to be misunderstandings around how to carry out measurements correctly. This assumption is reinforced by the fact that measurement errors were seen to reduce in number in subsequent data collection rounds, as veterinarians became more familiar with the data collection procedure (Figure 0-2). Missing measurements may have several causes. Morphometric measurements were made when dogs were enrolled in the study and were not subsequently repeated as all enrolled dogs were a minimum of 18 months old and presumably fully grown (Chapter 3). In a few cases enrolment questionnaires were not available and the data was therefore not recorded. Additionally, some dogs were mistakenly enrolled before they had reached 18 months of age. Data collected from these young dogs was not entered into the database we used to manage the data until they aged into the study at a later data collection round. Unfortunately, many of these dogs were not re-measured when they were officially enrolled. Additionally, data entry was carried out some time after farm visits, and errors were not discovered in time to ask veterinarians to carry out repeat morphometric measurements on dogs that had missing data. The histograms and scatter plots of the morphometric measurements all indicated normal distributions of data once dogs with missing or implausible measures had been removed. However, it is impossible to rule out that there are measurement errors in the data that affected the results.

4.6 Conclusion

Due to the overall low predicted body fat mass in working farm dogs, lack of validation for BCS in lean dogs and lack of a strong effect of predicted body condition measures on BCS in lean working dogs, we suggest that BCS is a poor measure of body condition in lean athletic working dogs. A possible alternative to BCS may be the ratio of predicted lean mass to skeletal size. This study provides data on the distribution of the ratio in a population of working farm dogs. However, the Leung et al. model used to predict lean body mass should ideally be validated on a larger population of working farm dogs with known body composition. Additionally, it is currently unknown whether the ratio of lean mass to skeletal size or BCS are associated with illness, injury or mortality in lean working dogs, independently of their ability to measure body composition. Investigation is needed on whether measures used to assess body condition are predictive of meaningful health outcomes or risk factors related to retirement and death in working farm dogs. A further study will investigate whether BCS or the lean mass to skeletal size ratio are associated with a risk of death or retirement in working farm dogs enrolled in TeamMate.

Chapter 5

The occurrence of musculoskeletal abnormalities in working farm dogs

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The occurrence of musculoskeletal abnormalities in working farm dogs

5.1 Abstract

Musculoskeletal injury and disease are common in dogs, and a major cause of retirement in working dogs. Many livestock farmers rely on dogs for the effective running of their farms. However, the incidence of musculoskeletal disease has not been explored in working farm dogs. Here we explore the occurrence of musculoskeletal abnormalities in 323 working farm dogs that were enrolled in TeamMate, a longitudinal study of working farm dogs in New Zealand. All dogs were free of musculoskeletal abnormalities on enrolment to the study and were present for at least one follow-up examination. During the follow-up period, 184 dogs (57%, 95% confidence interval (CI) = 52% – 62%) developed at least one musculoskeletal abnormality during 4508 dog-months at risk, corresponding to an incidence rate (IR) of 4.1 dogs (95% CI = 3.5 – 4.7) with recorded abnormalities per 100 dog-months at risk. The most common abnormalities were reduced range of motion and swelling of the carpus or stifle, whilst the hip was the most common site of pain. No major differences in IR between sexes or types of dogs were observed, though Huntaways had a slightly lower rate of carpal abnormalities than Heading dogs (IRR = 0.6, 95% CI = 0.3 – 1.0). Eighty-one of 119 dogs (68%, 95% CI = 60% – 76%) that had a first musculoskeletal abnormality developed a second abnormality during the study period. The most common type of abnormality that was seen in the same dog more than once was reduced range of motion in the carpus (14 of 119 dogs, 12%, 95% CI = 6% – 18%). Although we do not provide data on diagnoses, the high incidence rate of recorded musculoskeletal abnormalities and dogs' high activity mean it is likely that working farm dogs are at a high risk of conditions that could impair their welfare and reduce the lengths of their working careers. Preventing and managing musculoskeletal injury and illness should be a priority for owners and veterinarians caring for working farm dogs.

5.2 Introduction

Musculoskeletal injury and disease is common in many populations of dogs, humans and other species (Anderson et al., 2018; Freeman et al., 2006; Mele, 2007; O'Neill et al., 2013), and can be a serious problem that affects overall health, welfare and working performance (Bevan, 2015; Burton et al., 2006; Cogger et al., 2006). In the UK, the second most commonly recorded cause of death of dogs attending clinical practice was musculoskeletal disorders (O'Neill et al., 2013). In New Zealand police dogs, and UK guide dogs, the most common cause for early retirement was an inability to continue working due to musculoskeletal disease or injury (Caron-Lormier et al., 2016; Worth et al., 2013). In US military working dogs, the most commonly recorded cause of dogs dying was degenerative joint disease (Moore et al., 2001).

Working farm dogs in New Zealand have been found to have a high prevalence of musculoskeletal disease and injury, with over 40% having at least one musculoskeletal abnormality on physical examination (Chapter

3). Additionally, during a 12-month period, 14% of working farm dogs had a non-traumatic musculoskeletal health event and 12% had a traumatic musculoskeletal health event, according to owners (Sheard, 2014). Musculoskeletal disease can be a major cause of reduced quality of life due to its potential to cause pain and limit mobility (Mele, 2007; Rychel, 2010). High levels of activity such as those seen in working farm dogs (Early et al., 2016) can contribute to increased levels of musculoskeletal disease, limiting the dogs' ability to work. Given the reliance of New Zealand farmers on their dogs for the efficient running of their farms (Cogger and Sheard, 2017), and the economic value stock-herding dogs bring to their owners (Arnott et al., 2014a), high incidences of musculoskeletal injury and disease may represent a major economic cost to owners of working farm dogs. Determining what types of musculoskeletal abnormalities are the most common and whether certain dogs are at increased risk of developing musculoskeletal disease could enable veterinarians and dog owners to target preventative measures more accurately. In turn such targeting would improve dogs' health and welfare and ensure that they stay disease-free and able to work for as long as possible.

To date, the incidence of musculoskeletal injury and disease in working farm dogs has not been investigated. The aim of this study was to describe the incidence of different types of musculoskeletal abnormalities recorded in a population of working farm dogs. We anticipated that the incidence of musculoskeletal abnormalities would be associated with the sex and type of the dogs. The incidence of dogs developing musculoskeletal abnormalities is presented, stratified by the types and locations of the abnormalities seen.

5.3 Methods

5.3.1 Study design

TeamMate is a longitudinal study focusing on working farm dogs on the South Island of New Zealand. Chapter 3 describes the study design and data collection procedure in detail, and presents data collected on the dogs' enrolment to the study. To summarize, 641 working farm dogs were convenience-sampled and enrolled in a four-year longitudinal study. All working farm dogs belonging to participating dog owners were enrolled, if they were least 18 months old and working with livestock regularly. In the analysis carried out for the current chapter , we included 323 dogs that did not have a recorded musculoskeletal abnormality on enrolment and that were present for at least one subsequent clinical examination.

Data collection was begun in May 2014. Data was collected approximately every eight to nine months subsequently, and data from five data collection rounds were included in the current study. The fifth data collection round was completed in November 2017.

At each farm visit, including on enrolment, all enrolled dogs were physically examined by veterinarians and dog owners were interviewed to collect information about the dogs' husbandry, feeding, and work. Scribes were responsible for filling in the questionnaires and taking note of any clinical findings. The physical examination included manipulation of all the major joints and encouraging the dogs to trot for a short distance to check for lameness. All physical abnormalities were recorded, irrespective of their clinical significance. All veterinarians and scribes were trained to ensure data collection was performed in a standardized way, with veterinarians asked to record specific clinical signs rather than make general diagnoses. Training included a run-through of all questionnaires and how they should be completed as well as practical sessions that involved filling in the questionnaires and examining, scoring and measuring farm dogs. During training sessions normal range of motion at each joint was demonstrated in healthy working farm dogs.

This chapter presents data from dogs that were enrolled in TeamMate, were free of recorded musculoskeletal abnormalities at enrolment, and were present for at least one follow-up clinical examination

5.3.2 Statistical analysis

Abnormalities noted on physical examination were categorized according to type and location on the body. Anatomical locations and types of abnormalities were included in further data analysis if they were seen in 10% of dogs or more either on enrolment (Chapter 3) or as a first musculoskeletal abnormality following enrolment. The anatomical locations included the carpals, hips, digits and stifles, and abnormalities were categorized as ‘abnormal range of motion’, ‘hard swelling’, ‘painful’, ‘crepitus’, or ‘other’. Lameness on trot was recorded in 12% of dogs on enrolment (Chapter 3). However, we did not include lameness in this study as we cannot know that the underlying cause of lameness is musculoskeletal. For example, dogs may be lame due to injuries to the footpads.

Time at risk to a first recorded musculoskeletal abnormality was calculated using an approximate calculation adapted from that described in Dohoo et al. (2009), with dogs considered as having been withdrawn if they were lost to follow-up for any reason at an earlier date than their owner. The start time at risk was defined as the date on which an individual dog was enrolled in the study. Dogs were considered as no longer being at risk if they were recorded as having a musculoskeletal abnormality, if they or their owner were lost to follow-up for any reason, or they reached the end of the study. Dogs that were recorded as having a musculoskeletal abnormality or were withdrawn were considered as being at risk until the halfway point between the date of their previous examination and the date on which the abnormality or the withdrawal was recorded. Dogs that were not recorded as having any musculoskeletal abnormalities or having been withdrawn were considered as being at risk until the date of their last recorded examination. Time at risk to a second recorded musculoskeletal abnormality was calculated in the same way as the first, except that the start time was considered as being the date on which dogs’ first musculoskeletal abnormality was recorded.

Incidence rate was calculated as the number of dogs that had at least one musculoskeletal abnormality divided by the number of dog-weeks at risk. Note that this is not same as the number of injuries per time period. Dogs may have had more than one recorded abnormality on the same examination. Additionally, single cases of injury or disease were often coded more than once as a reflection of multiple clinical signs. For example, a dog may have swelling, reduced range of motion and pain in the same joint. For these reasons the number of dogs rather than the number of abnormalities were counted.

Incidence rates and 95% CIs were calculated for the first instance of any musculoskeletal abnormality in each dog as well as for the most common types and locations of abnormalities. Specific incidence rates, stratified by sex and type of dog, were calculated for each of the most common joint locations and incidence rate ratios for sex and dog types were calculated with 95% CIs.

Incidence rate was also reported for second occurrences of musculoskeletal abnormalities. The calculation of time at risk included dogs that were recorded as having a first musculoskeletal abnormality and that were present for at least one subsequent examination. The types of abnormalities that were most commonly observed more than once in the same dog are reported.

All data analysis was done using R version 3.6.x (R Core Team, 2020).

5.4 Results

Three hundred twenty-three dogs, belonging to 113 dog owners, did not have a recorded musculoskeletal abnormality on enrolment to TeamMate and were present for at least one follow-up clinical examination. These 323 dogs contributed 4508 dog-months at risk. Table 5-1 shows the distribution of dogs by sex, age group at enrolment, type of dog and the modes of work they had been reported to carry out. The median age at enrolment for both sexes 3 was years (IQR = 2 – 5 years). The median age at enrolment was 3 years (IQR = 2 – 4 years) for Heading dogs, 3 years (IQR = 2 – 5 years) for Huntaways and 4 years (IQR = 3 – 8 years) for other types of dogs. For comparison, the median age on enrolment of all 641 dogs enrolled in TeamMate was 4 years (IQR = 2 – 6) (Chapter 3).

Of 323 dogs, 184 (57%, 95% CI = 52 – 62%) developed at least one musculoskeletal abnormality during 4508 dog-months at risk, corresponding to 4.1 dogs (95% CI = 3.5 – 4.7) per 100 dog-months at risk. Table 5-2 describes the incidence rate of dogs' first recorded musculoskeletal abnormalities following enrolment, stratified by anatomical location and type of abnormality. Table 5-3 and Table 5-4 describes the distribution of incidence rates and rate ratios of the first occurrence of musculoskeletal abnormalities in the most commonly recorded anatomical locations, stratified by sex and type of dog respectively.

Of 184 dogs that were recorded to have had a first musculoskeletal abnormality 119 dogs (65%, 95% CI = 65% – 72%) were present for at least one subsequent follow-up physical examination, and contributed 1144 dog-months at risk. Eighty-one of 119 dogs (68%, 95% CI = 60% – 76%) were found to have a second musculoskeletal abnormality of any type. This corresponds to 7.1 dogs (95% CI = 5.7 – 8.7) per 100 dog-months at risk. Thirty-one of 119 dogs (26%, 95% CI = 18% – 34%) were found to have a musculoskeletal abnormality of both the same type and in the same location on a subsequent examination. The most common abnormalities that were seen in the same dog repeatedly were reduced range of motion in the carpus (14 of 119 dogs, 12%, 95% CI = 6% – 18%) and hard swelling in one or more digits (4 of 119 dogs, 3%, 95% CI = 0% – 7%). All other types of abnormalities were seen repeatedly in three dogs or fewer.

Table 5-1: Population features of the 323 dogs enrolled in TeamMate that did not have a recorded abnormality on enrolment and were present for at least one follow-up examination.

Variables		Number of dogs	% (95% CI)
Sex	Female	151	47 (41 – 52)
	Male	172	53 (48 – 59)
Age on enrolment	1.5 to 2.9 years	101	31 (26 – 36)
	3 to 4.9 years	98	30 (25 – 35)
	5 to 6.9 years	48	15 (11 – 19)
	7 to 9.9 years	30	9 (6 – 12)
	10 years and above	6	2 (0 – 3)
	Not recorded	40	12 (9 – 16)
Type of dog	Heading dog	165	51 (46 – 57)
	Huntaway	148	46 (40 – 51)
	Other	10	3 (1 – 5)

Table 5-2: Number of affected dogs, incidence rate and incidence rate ratio (with 95% CI) of first recorded musculoskeletal abnormalities stratified by the location on the body and type of the first recorded abnormality. Data from 323 dogs that contributed 4508 dog-months at risk. Note that many dogs were recorded as having more than one abnormality on the same examination. Anatomical locations and types of abnormalities were classed as 'Other' if they were recorded in fewer than 10% of dogs on enrolment, or as a first musculoskeletal abnormality following enrolment.

Location	Type of abnormality	Number of dogs	IR / 100 dog-months (95% CI)	
Carpus	Abnormal range of motion*	44	1.0	(0.7 – 1.3)
	Painful	6	0.1	(0.1 – 0.3)
	Hard swelling	9	0.2	(0.1 – 0.4)
	Crepitus	4	0.1	(0.0 – 0.2)
	All carpus	53	1.2	(0.9 – 1.5)
Hip	Abnormal range of motion*	22	0.5	(0.3 – 0.7)
	Painful	18	0.4	(0.3 – 0.6)
	Crepitus	2	0.0	(0.0 – 0.2)
	Other	2	0.0	(0.0 – 0.2)
	All hip	39	0.9	(0.6 – 1.2)
Digits	Abnormal range of motion*	11	0.2	(0.1 – 0.4)
	Hard swelling	5	0.1	(0.0 – 0.3)
	Painful	24	0.5	(0.4 – 0.8)
	Crepitus	5	0.1	(0.0 – 0.3)
	All digits	36	0.8	(0.6 – 1.1)
Stifle	Abnormal range of motion*	7	0.2	(0.1 – 0.3)
	Hard swelling	4	0.1	(0.0 – 0.2)
	Painful	9	0.2	(0.1 – 0.4)
	Crepitus	9	0.2	(0.1 – 0.4)
	All stifle	25	0.6	(0.4 – 0.8)

Table 5-2: Cont.

Location	Type of abnormality	Number of dogs	IR / 100 dog-months (95% CI)
Other	Abnormal range of motion*	41	0.9 (0.7 – 1.2)
	Hard swelling	30	0.7 (0.5 – 1.0)
	Painful	11	0.2 (0.1 – 0.4)
	Crepitus	6	0.1 (0.1 – 0.3)
	Other	8	0.2 (0.1 – 0.4)
	All other	86	1.9 (1.5 – 2.4)
All abnormalities	Abnormal range of motion*	102	2.3 (1.9 – 2.7)
	Hard swelling	56	1.2 (1.0 – 1.6)
	Painful	48	1.1 (0.8 – 1.4)
	Crepitus	21	0.5 (0.3 – 0.7)
	Other	17	0.4 (0.2 – 0.6)
	All abnormalities	184	4.1 (3.5 – 4.7)

*Two dogs were found to have abnormally increased range of motion, one in the shoulder and the other in the tarsus. The remainder had reduced range of motion.

Table 5-3: Number of affected dogs, incidence rate and incidence rate ratio (with 95% CI) of first recorded musculoskeletal abnormalities in a range of anatomical locations, stratified by sex. One hundred fifty-one female dogs contributed 2238 dog-months at risk and 172 male dogs contributed 2270 dog-months at risk.

Location	Sex	Number of dogs	IR / 100 dog-months (95% CI)		IR ratio (95% CI)	
Carpus	Female	24	1.1	(0.9 – 1.3)		
	Male	29	1.3	(1.1 – 1.5)	1.2	(0.7 – 2.0)
Hip	Female	25	1.1	(1.0 – 1.3)		
	Male	14	0.6	(0.5 – 0.7)	0.6	(0.3 – 1.1)
Digits	Female	14	0.6	(0.5 – 0.7)		
	Male	22	1.0	(0.8 – 1.1)	1.5	(0.8 – 3.0)
Stifle	Female	11	0.5	(0.4 – 0.6)		
	Male	14	0.6	(0.5 – 0.7)	1.3	(0.6 – 2.8)
Other	Female	55	1.7	(1.5 – 2.0)		
	Male	65	2.1	(1.8 – 2.4)	1.2	(0.8 – 1.8)
All locations	Female	86	3.8	(3.3 – 4.5)		
	Male	98	4.3	(3.7 – 5.0)	1.1	(0.8 – 1.5)

Table 5-4: Number of affected dogs, incidence rate and incidence rate ratio (with 95% CI) of first recorded musculoskeletal abnormalities in a range of anatomical locations, stratified by type of dogs. One hundred sixty-five Heading dogs contributed 2385 dog-months at risk, 148 Huntaways contributed 1968 dog-months at risk and 10 other types of dogs contributed 155 dog-months at risk.

Location	Type of dog	Number of dogs	IR / 100 dog-months (95% CI)		IR ratio (95% CI)	
Carpus	Heading dog	33	1.4	(1.2 – 1.6)		
	Huntaway	15	0.8	(0.6 – 0.9)	0.6	(0.3 – 1.0)
	Other	5	3.2	(1.8 – 5.9)	2.3	(0.9 – 6.0)
Hip	Heading dog	20	0.8	(0.7 – 1.0)		
	Huntaway	18	0.9	(0.8 – 1.1)	1.1	(0.6 – 2.1)
	Other	1	0.6	(0.3 – 1.2)	0.8	(0.1 – 5.7)
Digits	Heading dog	20	0.8	(0.7 – 1.0)		
	Huntaway	15	0.8	(0.6 – 0.9)	0.9	(0.5 – 1.8)
	Other	1	0.6	(0.3 – 1.2)	0.8	(0.1 – 5.7)
Stifle	Heading dog	14	0.6	(0.5 – 0.7)		
	Huntaway	9	0.5	(0.4 – 0.5)	0.8	(0.3 – 1.8)
	Other	2	1.3	(0.7 – 2.4)	2.2	(0.5 – 9.6)
Other	Heading dog	45	1.9	(1.6 – 2.2)		
	Huntaway	38	1.9	(1.6 – 2.3)	1.0	(0.7 – 1.6)
	Other	3	1.9	(1.0 – 3.6)	1.0	(0.3 – 3.3)
All locations	Heading dog	92	3.9	(3.3 – 4.5)		
	Huntaway	85	4.3	(3.7 – 5.1)	1.1	(0.8 – 1.5)
	Other	7	4.5	(2.5 – 8.3)	1.2	(0.5 – 2.5)

5.5 Discussion

This study confirms that musculoskeletal abnormalities are common in working farm dogs, with almost six in 10 dogs developing at least one musculoskeletal abnormality during the course of the study, at a rate of more than 4 dogs per 100 dog-months at risk. To our knowledge, this is the first time incidence rate of musculoskeletal disease or injury has been reported in a population of working dogs. Musculoskeletal disease and injury cause discomfort, pain and loss of mobility can that have implications for the welfare of the affected dogs and is likely to cause a reduction in working capacity. In the short term this loss of working capacity might put extra strain on the remaining dogs on farm as they are required to fill the gap, or cause productivity issues on farm as the dog owner is unable to move stock efficiently. Additionally, incomplete recovery and lowered fitness, for example following rest, in injured dogs and increased workload in the remaining healthy dogs, can cause further injuries such as tendinopathy, stress fractures and osteochondrosis (Aicale et al., 2018). In the long term, overuse and repeated injuries are risk factors for the development of chronic musculoskeletal disease such as osteoarthritis (Johnston, 1997).

In this study more than two thirds of dogs that had a musculoskeletal abnormality and were present for a subsequent examination were recorded to have a second musculoskeletal abnormality on a later examination, and more than a quarter were recorded as having the same abnormality a second time. The data recorded for this study focused on clinical signs rather than diagnosis, and the lack of advanced diagnostics such as radiographs may have caused some cases of musculoskeletal disease or injury to have been missed or mis-categorised. However, this study only examined broad categories of clinical signs and their locations on the body rather than attempting to assign formal diagnoses. As such, there is no data available on whether repeated observations of abnormalities represent persistent musculoskeletal disease or new injuries in the same location. Either case, however, may be associated with the presence of chronic disease because repeated injuries may lead to chronic conditions such as osteoarthritis (Johnston, 1997).

The carpal joint had the highest incidence rate of abnormalities in this study, and most of these involved reduced range of motion (Table 5-2). This type of abnormality was also, by far, the most common type to be recorded more than once in the same dogs, indicating that this type of abnormality may be more likely to persist over time than other types of abnormalities. However, more detailed data is needed to confirm or negate this assumption. Carpal injuries have been found to be common in racing Greyhounds (Prole, 1976; Sicard et al., 1999), while a study of sled racing dogs suggested that carpal injuries may have been the result of overuse (von Pfeil et al., 2015). Similarly, high activity levels may predispose working farm dogs to carpal injuries. This would explain the high incidence of carpal abnormalities seen in this study. Carpal abnormalities reported in this study rarely involved pain on manipulation, and it is likely that many were the results of minor injuries or changes caused by healing after injury. Dog owners may not consider these injuries serious enough to warrant a visit to a veterinary clinic. Given the effect of chronic musculoskeletal illness on other working dog populations, more research is warranted to quantify the effect of carpal injuries on the health and welfare of working farm dogs. Based on current data, it might be prudent for veterinarians and working dog owners to follow up dogs with carpal injuries and give them the necessary support to prevent and, if necessary, manage chronic musculoskeletal illness.

Except for a slightly higher rate of carpal abnormalities in Heading dogs than Huntaways, no major differences were seen in the rates of musculoskeletal abnormalities between the sexes or types of dogs (Table 5-3, Table 5-4). The 95% CIs of the incidence rate ratios were narrow, indicating that our results are probably quite close to the "true" values in the study population. If this is accurate any differences in the rates of musculoskeletal illness or injuries between sexes or types of working farm dogs are so small that they can probably be disregarded in clinical settings. As the occurrence of musculoskeletal disease and injury is known to increase with age (Mele, 2007; Mey et al., 2020) a possible source of confounding in our results would be if there were pronounced age differences between the sexes or types of dogs. However, age differences between groups was not observed in this population. The small difference seen in the rate of carpal abnormalities could be spurious, or it could be explained by several factors. Heading dogs and Huntaways are phenotypically distinct (Chapter 4), with Huntaways being on average approximately 10 kg heavier than Heading dogs (Chapter 3). Health differences between breeds and phenotypes are commonly seen in dogs (Anderson et al., 2018; Asher et al., 2009; Bonnett et al., 2005; O'Neill et al., 2013). However, Heading dogs and Huntaways also do different types of stock work (Chapter 3), which may put them at risk of different types of injuries. Cave et al. reported that along with automotive accidents, stock-related trauma was reported as a major cause of injury in working farm dogs, and that Heading dogs were over-represented in comparison to Huntaways (Cave et al., 2009). Our data suggests that Heading dogs may be at slightly higher risk of carpal injuries than Huntaways, though further investigation of risk factors related to phenotypes and work in working farm dogs is needed. With carpal abnormalities being the most commonly reported in the population overall, these types of injuries should not be discounted in Huntaways based on the weak difference reported in this study.

No difference in the rate of hip abnormalities was seen between Heading dogs and Huntaways, and the overall incidence rate was around one per 100 dog-months. The majority of recorded hip abnormalities involved reduced range of motion and/or signs on pain, potentially to impairing dogs' mobility and overall welfare. A previous study by Hughes (2001) suggested an 18% prevalence of hip dysplasia in working farm dogs, with Huntaways having a five times higher prevalence than Heading dogs. However, Hughes reports that the majority of dog owners had not noticed lameness in dogs that were scored as having hip dysplasia when examining their radiographs. It has been noted that decisions around management of osteoarthritis and hip dysplasia should not be based solely on radiographs, as they often correlate poorly to the clinical signs shown by the dog (Dycus et al., 2017). Cave et al. (2009) suggested that more Huntaways have hip dysplasia while more Heading dogs have hip luxation. However, the study recorded only 23 cases of hip dysplasia and 31 cases of traumatic injury to the hip in 2214 clinic presentations. In TeamMate, prevalence of hip abnormalities on enrolment was 14% (Chapter 3). The differences seen between these studies can probably be explained by differences in study design, with Hughes possibly recruiting dog owners that were concerned about hip disease in their teams and also relying solely on radiographs for diagnostics. Cave et al. only recorded dogs that were considered by their owners to be ill or injured enough to be taken to a veterinary clinic, and in TeamMate all abnormalities were recorded irrespective of clinical significance. Based on the current data, signs of abnormalities related to the hips may be quite common in working farm dogs. However, it is not clear whether these abnormalities are commonly associated with clinical disease. Physical fitness, including hip musculature, is thought to help prevent joint disease and injury in dogs (Dycus et al., 2017; Farr et al., 2020), and the high activity levels of working farm dogs may therefore help delay the development of serious musculoskeletal disease. More detailed investigation is warranted into whether the hip abnormalities that were recorded during the TeamMate study are associated with conditions such as hind limb lameness and osteoarthritis that can impair dogs' welfare and ability to work.

A problem that occurs as a result of our data collection procedure is that we have no way of knowing whether similar abnormalities observed at different points in time are the results of the same or separate injuries or conditions. For this reason, we chose to carry out a descriptive study that focuses mainly on the first occurrence of musculoskeletal abnormalities. While we do report on second occurrence of musculoskeletal abnormalities, no significance testing was carried out using this data. As we did not analyse the data longitudinally, we were unable to investigate the effect of time-varying factors such as body weight, body condition, workload and diet on the risk of dogs developing musculoskeletal abnormalities. These variables may have acted as confounders on the groups we chose to examine here. For example, differences in body weights between sexes and types of dogs may have had an impact on the incidence rate of certain types of abnormalities. Ideally, these variables should have been analysed using a multivariable modelling approach. Future investigations should examine these risk factors, as they may be useful in determining appropriate husbandry practices necessary to minimize the risk of dogs developing musculoskeletal injury and illness. Future investigation should also examine the effect of musculoskeletal abnormalities on the lifespan and career length of working farm dogs. In combination with the work that has already been carried out, such an investigation will enable veterinarians and dog owners to make decisions about what types of musculoskeletal abnormalities are the most important to prevent and treat in order to ensure that farm dogs lead long and healthy lives.

Due to the fact that data was collected at intervals of several months, we do not have exact data on the time between enrolment and the occurrence of clinical abnormalities, and our calculation of time at risk is an approximation that assumes musculoskeletal abnormalities occurred at the halfway point between examinations. This implies that the recorded musculoskeletal abnormalities occurred evenly distributed between examinations and that they all persisted for long enough to be recorded. However, depending on the type and underlying cause of the abnormalities, they may have occurred at any time after the previous examination and persisted, or they could have occurred within days of the examination and be fully healed shortly after. Additionally, dogs may have sustained and recovered from one or more injuries in between examinations. These injuries would not have been recorded in our data at all. Assuming that recorded abnormalities in our dataset are evenly distributed could therefore be misleading, and we may also have missed a considerable number of less serious injuries. Injuries with a lower or shorter term impact than those recorded here should not be discounted from a welfare perspective, especially if they are numerous and/or repetitive. Additionally, such injuries could have long term consequences if they are repetitive and/or cause changes in tissues or joints. However, the abnormalities that we have reported on in this study, while possibly incomplete, still provide information about the types of injuries that occur and could be used to inform decisions around management and veterinary treatment of working farm dogs.

Another potential weakness of the TeamMate study is the reliance on veterinarians' examination notes to code clinical abnormalities. Several veterinarians participated in data collection, and different veterinarians sometimes examined the same dog at different points in time. This created a possibility that different individuals assessed and described similar or identical abnormalities in in different ways. However, in order to minimize bias in the data, veterinarians were given training in how to carry out examinations in a standardized way and were asked to describe physical signs rather than to give overall diagnoses. While differences in data collected by different veterinarians are impossible to rule out, we have worked to minimize the risk of bias through our data collection, coding and data entry procedures.

While there are several weaknesses that limit our ability to draw conclusions from the current study, this is the first time the incidence of musculoskeletal abnormalities has been investigated in working farm dogs. It is our hope that the study will form the basis for future investigation that can help improve the health and welfare of these hard-working dogs.

5.6 Statement of contribution

DRC 16

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Katja Elisabeth Isaksen
Name/title of Primary Supervisor:	Ass. Professor Naomi Cogger
Name of Research Output and full reference:	
Isaksen, K.E., Linney, L., Williamson, H., Cave, N.J., Norman, E.J., Cogger, N., 2020. TeamMate: a longitudinal study of New Zealand working farm dogs. II. Occurrence of musculoskeletal abnormalities. Front. Vet. Sci. 7, 624. https://doi.org/10.3389/fvets.2020.00624	
In which Chapter is the Manuscript /Published work:	Chapter 5
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90%
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Collated data, analysed data, wrote paper and carried out edits.	
For manuscripts intended for publication please indicate target journal:	
Candidate's Signature:	Katja E. Isaksen
Date:	9/12/2020
Primary Supervisor's Signature:	N. Cogger
Date:	9/12/2020

(This form should appear at the end of each thesis chapter/section/appendix submitted as a manuscript/ publication or collected as an appendix at the end of the thesis)

Chapter 6

Factors affecting the risk of dogs being lost from the workforce.

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Factors affecting the risk of death, euthanasia or retirement in working farm dogs

6.1 Abstract

Working farm dogs are essential to livestock farming in New Zealand and around the world. However, little is known about factors that influence their risk of death or retirement. This paper explores reasons and risk factors for death or retirement in 589 working farm dogs on the South Island of New Zealand. All dogs were enrolled in TeamMate, a longitudinal study investigating health in working farm dogs. To be eligible for enrolment dogs had to be at least 18 months old and in full work. Data were collected on farm approximately every eight to nine months for a period of up to four years. At the time of farm visits, data were collected on work and husbandry practices, and all dogs were given physical examinations by veterinarians. Eighty-one of 589 dogs (14%, 95% CI = 11 – 17%) were lost from the workforce during the study period. Fifty-nine dogs (10%, 95% CI = 8 – 12%) were reported to have died and 22 dogs (4%, 95% CI = 2 – 5%) were reported to have been retired. One-third of dogs that died or were retired did not have an owner-reported reason for loss. Acute injury or illness was the most commonly reported reason for loss, accounting for 22 of 81 dogs that died or were retired (27%, 95% CI = 17% – 37%). Multivariable logistic regression modelling was used to investigate risk factors for dogs dying or being retired after each examination. The best-fit multivariable model showed that age ($P < 0.0001$) and being lame on trot ($P = 0.04$) significantly affected the risk of dogs dying or being retired from work following each examination. Compared to dogs between 1.5 and 2.9 years old, dogs that were ten years or older had the highest risk of dying or being retired (OR = 6.5) while dogs that were three to 4.9 years old had the lowest risk (OR = 0.3). Dogs that were lame were 1.9 times more likely to die or be retired before the next round of data collection than those that did not. The presence of eye abnormalities also increased the risk of loss, however this effect did not reach the level of significance ($P = 0.06$). These results expand our knowledge about important factors that affect the health and welfare of working farm dogs. In particular, appropriate management of the underlying reasons that cause lameness and eye abnormalities may significantly improve the health and welfare of working farm dogs and prevent them from being removed from the workforce before reaching old age.

6.2 Introduction

There are a range of concerns around the health and welfare of working farm dogs. Previous studies have found that farm dogs in New Zealand have a high prevalence of traumatic injury and musculoskeletal illness (Cave et al., 2009; Sheard, 2014). This finding was further confirmed in Chapter 3, and additionally a high incidence of musculoskeletal abnormalities was reported in Chapter 5. Further, owners report concern that as many as 19% of their dogs may be underweight (Sheard, 2014) and around one third of dogs in TeamMate could be considered as underweight if assessed using body condition scoring (Chapter 4). However, it is not known how specific conditions affect the health, welfare and longevity of farm dogs. Additionally, due to a lack of data around what constitutes healthy body condition in highly active, athletic dogs it is difficult to conclude whether or not working farm dogs are clinically underweight (Chapter 4). Determining which factors related to demographics, husbandry or health are associated with the risk of death or retirement in working farm dogs will help researchers, veterinarians and dog owners to decide which areas to focus on when improving dogs' care and husbandry.

Working farm dogs are an essential part of livestock farming in New Zealand and in other parts of the world (Arnott et al., 2014a; Cogger and Sheard, 2017). The loss of a dog from work can be disruptive to the effective running of a farm and put extra pressure on the farmer and the remaining dogs. Knowing which factors are likely to increase dogs' risk of death or retirement can help dog owners and veterinarians to provide appropriate care to ensure that dogs have as long and healthy working lives as possible. Such knowledge may also help inform further research into how the identified risk factors might be avoided. For example, musculoskeletal injury and disease have been reported as common causes of euthanasia and death in working dogs (Caron-Lormier et al., 2016; Moore et al., 2001; Worth et al., 2013), and work has been done into ways of keeping dogs fit and avoiding injury (Farr et al., 2020). However, while cross sectional studies have been carried out into reported reasons for dogs being lost from work, studies that analyse longitudinal data to investigate which factors might put dogs at increased risk of death or retirement are rare. Such risk factor analysis can reveal exposures that make dogs more susceptible to developing the conditions that cause them to be removed from work. Due to this lack of investigation there may be important risk factors that are currently being overlooked by researchers and veterinarians. The aims of this study were to fill this gap in knowledge by investigating risk factors that influenced whether or not dogs died, were euthanised or were retired during the course of the TeamMate study. Additionally, owner reported reasons for death or retirement were reported and compared with the risk factors that were revealed by our analysis.

6.3 Methods

6.3.1 Study design

TeamMate is a longitudinal study focusing on working farm dogs on the South Island of New Zealand. The study design and data collection procedures are presented in detail in Chapter 3. To summarize, a total of 126 owners associated with 116 farms participated in the study and 641 working farm dogs were enrolled. All working farm dogs belonging to participating dog owners were enrolled if they were least 18 months old and working with livestock regularly. At each data collection round, including on enrolment, dog owners were visited on the farm where they worked and interviewed to collect information about the dogs' husbandry, feeding, and work, and dogs were physically examined by veterinarians. All veterinarians and scribes were trained to ensure data collection was performed in a standardized way, with veterinarians asked to record specific clinical abnormalities rather than make general diagnoses. Abnormalities noted on clinical examination were systematically categorized using alphanumeric codes based on the examining veterinarian's notes. In the current study, we included all observations of dogs where no data was missing from the relevant explanatory variables and information was available on whether dogs died or were retired subsequently to the examination. See Figure 6-1 for details on how many observations were excluded and the reasons they were excluded. In total, we included 1360 examinations of 589 working farm dogs in the analysis.

6.3.2 Outcomes - absence, death and retirement of dogs

The outcome variable analysed in this study was whether or not dogs were lost from the workforce through death or retirement. At each farm visit following their enrolment to the study dogs were classified as present or absent. Dogs that were still working on the property but not available for examination on the day of data collection were classified as being present but were not examined. The fates of dogs that were present on the last farm visit made to the owner were recorded as 'working with original owner'. Absent dogs were classified as having been lost from the workforce if the owner reported them as having died or having been retired from work for any reason. Absent dogs that were not dead or retired were not classified as having been lost from the workforce, and their fates were categorised as 'rehomed', 'sold', 'loaned' or 'withdrawn from the study'. Dogs reported as loaned included both dogs that had been loaned out to a different owner and dogs that had been returned to their owner after being loaned. Dogs were occasionally reported as having been retired to a smaller farm. These dogs were assumed to still be working, although in a reduced capacity, and were recorded as having been rehomed rather than being lost from the workforce. Where possible, the reason why a dog was absent was recorded. No data was available on whether health events or conditions that were reported by the owner as being the cause of a dog being absent had been diagnosed by a veterinarian.

Data were analysed to assess the risk of each farm visit and examination being followed by the dog dying or being retired before the next farm visit. Observations where no information was available regarding the further fates of dogs were excluded from analysis. These observations were either the last before a dog owner withdrew from the study or recorded during the final round of data collection.

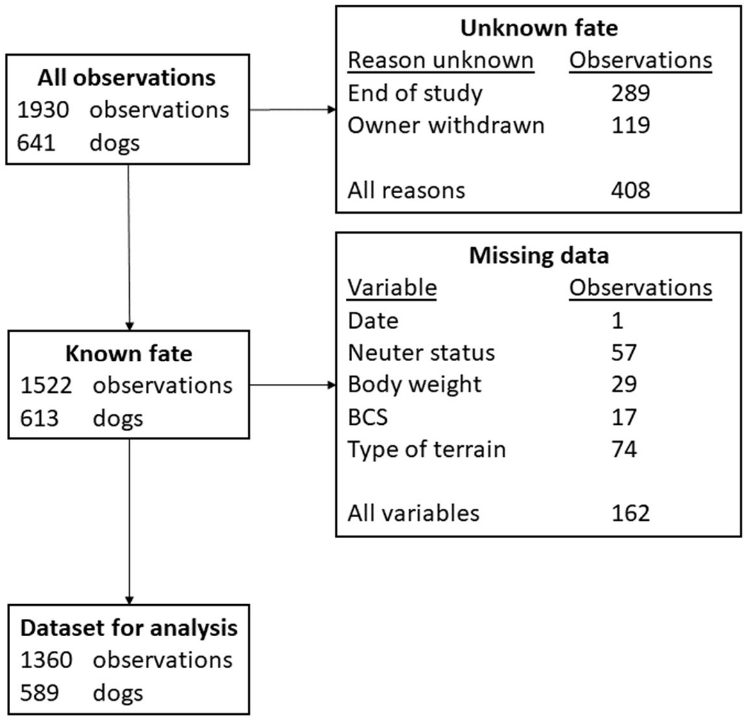

Figure 6-1: Flowchart showing the number of observations that were removed from the analysis due to missing information. As observations could have missing data in more than one variable, the sum of observations with missing data in the different variables do not equal the total number of observations that were removed. Note that dogs that had one or more observations removed could still be present in the dataset.

6.3.3 Explanatory variables

A range of potential risk factors relating to dogs dying or being retired were included in the analysis. These variables are listed in Table 6-1. Clinical abnormalities were analysed according to their overall type (lameness or affected body system) and were included if they were present in 10% of dogs or more on enrolment to the TeamMate study (Chapter 3). Lameness can be caused by a range of factors such as musculoskeletal system disease or trauma such as footpad abrasions. Therefore, despite often being associated with musculoskeletal conditions, lameness was analysed as a separate risk factor.

Examinations conducted on each dog were numbered, with enrolment being Examination 1, and each following examination being numbered sequentially. These examination numbers were included in the analysis to account for the progression of time during the course of the study.

Dog types were classified as ‘Heading dog’, ‘Huntaway’ or ‘other’ based on information provided by the dog owner. More details on the different types of working farm dogs found in New Zealand, how dogs enrolled in TeamMate were classified, their average body weights and which types of work they were recorded to do can be found in Chapter 3.

Body condition was scored using a nine-point numeric scale where 1 is underweight, 9 is obese, and 4 to 5 is considered ideal (WSAVA Global Nutrition Committee, 2013). In addition to body condition scores (BCS), a value for body condition was estimated by calculating the ratio of predicted lean body mass to skeletal size for each dog. The method used was developed by Leung et al. (2018) and further explored in Chapter 4, and involves calculating the predicted lean body mass based on dogs’ body weight, sex, age, skeletal size and whether they were Heading dogs or Huntaways. Skeletal size was determined from the principal components score derived from six skeletal measurements that were recorded from each dog on its enrolment to the study.

Dogs’ ages were measured in one of two ways. On the enrolment of all participating dogs, and on most follow-up clinical examinations the dog owner reported the age of the dog which was recorded. A value for the dog’s age was not recorded at 10% of examinations subsequent to enrolment. In these cases the dog’s age was calculated based on the dog’s reported age at enrolment and the time passed between enrolment and the relevant examination.

Dogs that were enrolled in TeamMate and had information available relating to whether they had died or been retired following at least one examination were eligible to be included in the current study. Data from examinations were excluded if they contained missing observations in any of the variables that were examined as potential risk factors.

Table 6-1: List of explanatory variables that were assessed as possible risk factors for the death or retirement of working farm dogs.

Variable name	Type
Examination	Number of examinations including enrolment.
Characteristics of dogs	Age, sex, neuter status, type of dog, body weight, body condition score.
Variables related to stock work	Type of terrain on property.
Findings on clinical examination	Number of recorded abnormalities, lameness on trot, musculoskeletal abnormalities, skin abnormalities, mouth and teeth abnormalities, eye abnormalities, reproductive abnormalities.

6.3.4 Statistical analysis

The number of enrolled dogs were counted stratified by their fate at the conclusion of the study. Dogs that died or were retired were counted and stratified by the reported reason for death or retirement and their age group on their last examination in the study. Percentages and 95% CIs were calculated for all stratified counts.

The risk of whether or not a dog died or was retired after each next farm visit was analysed using univariable and multivariable binary logistic regression models. Odds ratios were calculated by exponentiating the model beta-coefficients. All models were checked for significance using *P*-values derived from log-likelihood ratio tests (LRT). Potential risk factors were included in the multivariable analysis if the significance of the log-likelihood ratio test was less than $P < 0.2$ during univariable screening. The best-fit multivariable model was developed using backwards single-term deletion, where all potential risk factors were included in the first model tested and the variable with the smallest association with the risk of death or retirement was removed at each step. Backward elimination continued until all variables had a *P*-value for the log-likelihood ratio test of less than 0.10. When interpreting the model outputs only those with a statistical significance of less than 0.05 were considered statistically significant. The examination numbers for each dog were retained in all multivariable models, irrespective of effect size or significance, in order to account for the passing of time from the first to the last data collection round. Pairwise interactions were tested for all variables in the final multivariable model. To account for repeated measures over the course of the study, individual dog and dog owner identification numbers were added to the final multivariable model as nested random effects. The change in model fit caused by adding the random effects was tested using a log-likelihood ratio test.

All continuous explanatory variables were checked for linearity. The log-odds probabilities of dogs being lost were plotted against each continuous variable using a smoothed (loess) line (Dohoo et al., 2009, p. 377). The resulting plot was visually examined for linearity. Additionally a quadratic term was added to the univariable model to allow the regression line to follow a curved path (Dohoo et al., 2009, p. 378). The quadratic term was created by centring and squaring the values of the variable. Centring was done to avoid collinearity with the original predictor. The assumption of linearity was checked by examining whether the quadratic term was significantly associated with whether dogs died or were retired. If the *P*-value extracted from a log-likelihood ratio test was smaller than 0.05 and the smoothed line of the log-odds probabilities had a clear curvature, the assumption of linearity was determined to have been broken. In such cases the explanatory variable was converted to a categorical, removing the assumption of linearity from the model.

To evaluate the quality of fit of the final multivariable model we examined the area under the receiver operator characteristic (ROC) curve. Additionally, the residuals generated by the mixed logistic regression model were checked for outliers that might indicate problems with model fit.

The effect of the predicted lean body mass to skeletal size ratio on the risk of death or retirement was of especial interest to us due to its potential as an alternative to BCS in lean working farm dogs (Chapter 4). As this value was only available in 942 of 1360 observations (70%), we added this variable to the final multivariable model and evaluated how it altered the effects and significances of the risk factors that were retained in the model.

All calculations and data analysis were done using R version 4.0.x (R Core Team, 2020). The values necessary to plot loess smoothed lines for checking linearity of continuous predictors were generated using the loess() function in the car package (Fox and Weisberg, 2019) and the logit() function in the stats package (R Core Team, 2020). Random effects models were fitted using the lme4 package (Bates et al., 2015). The receiver-operator curve was generated and plotted using the pROC package (Robin et al., 2011). The residuals of the final multivariable mixed model were plotted using the qqnorm() and qqline() functions in the stats package.

6.4 Results

In total 1930 observations were recorded from the 641 dogs that were enrolled in TeamMate. Four hundred ninety-three observations were removed from the dataset due to a lack of information about the fate of the dog following the relevant examination, or due to missing data in variables that were examined as risk factors for death or retirement. Figure 6-1 shows how many observations were removed and which variables contained missing values. Full sets of data with no missing observations in the relevant variables (excluding lean body mass to skeletal size ratio) were available for 1360 observations of 589 working farm dogs belonging to 120 dog owners. Table 6-2 shows the distribution of dogs by sex, age group at enrolment and type.

Table 6-2: Population data relating to 589 working farm dogs that were enrolled in TeamMate and included in the current analysis.

Variables		Number of dogs	Percentage
Sex	Female	269	46%
	Male	320	54%
Age on enrolment	1.5 to 2.9 years	179	30%
	3 to 4.9 years	164	28%
	5 to 6.9 years	104	18%
	7 to 9.9 years	107	18%
	10 years and above	35	6%
Type of dog	Heading dog	282	48%
	Huntaway	288	49%
	Other	19	3%

6.4.1 Fates of dogs and reasons for death or retirement

In total, 81 of 589 dogs (14%, 95% CI = 11% – 17%) were lost from the workforce through dying, being euthanised or being retired. Table 6-3 lists the fates of all 589 dogs following the last examinations that were included in this study,

Table 6-4 shows the owner-reported reasons why dogs died, were euthanised or were retired, and Table 6-5 shows the age groups of dogs that died or were retired.

Table 6-3: The fates of 589 working farm dogs enrolled in TeamMate.

Fate of dog	Number of dogs	%	(95% CI)
Working with original owner	427	72	(69 – 76)
Dead or euthanised	59	10	(8 – 12)
Retired from work	22	4	(2 – 5)
Rehomed	32	5	(4 – 7)
Sold	44	7	(5 – 10)
Loaned	4	1	(0 – 1)
Not reported	1	0	(0 – 1)

Table 6-4: Owner-reported reasons for death or retirement of 81 dogs enrolled in TeamMate.

	Died or euthanised n = 59			Retired n = 22			All dead or retired n = 81		
Reported reason	Dogs	%	(95% CI)	Dogs	%	(95% CI)	Dogs	%	(95% CI)
Acute injury or illness	21	36	(23 – 48)	1	5	(0 – 13)	22	27	(17 – 37)
Old age	6	10	(2 – 18)	4	18	(2 – 34)	10	12	(5 – 20)
Chronic injury or illness	8	14	(5 – 22)	1	5	(0 – 13)	9	11	(4 – 18)
Sudden death	8	14	(5 – 22)	–	–	–	8	10	(3 – 16)
Behaviour	6	10	(2 – 18)	0	0		6	7	(2 – 13)
Not reported	10	17		16	73		26	32	

Table 6-5: Age on last examination of 81 dogs enrolled in TeamMate that were reported as having died or been retired from work.

Age on last examination	Died or euthanised n = 59			Retired n = 22			All dead or retired n = 81		
	Dogs	%	(95% CI)	Dogs	%	(95% CI)	Dogs	%	(95% CI)
1.5 to 2.9 years	10	17	(7 – 27)	1	5	(0 – 13)	11	14	(6 – 21)
3 to 4.9 years	6	10	(2 – 18)	0	0		6	7	(2 – 13)
5 to 6.9 years	10	17	(7 – 27)	1	5	(0 – 13)	11	14	(5 – 22)
7 to 9.9 years	18	31	(19 – 42)	4	18	(2 – 34)	22	27	(17 – 37)
10 years and older	15	25	(14 – 37)	16	73	(54 – 91)	31	38	(28 – 49)

6.4.2 Analysis of risk factors for death or retirement

Variables that were found to have an association with dogs' risk of dying or being retired at a level of $P < 0.2$ are listed in Table 6-6. Variables that were found to have P-values above this level are not reported here and were not included for further analysis. The explanatory variables that remained in the final multivariable model all increased the risk of dogs dying or being retired (Table 6-7). Table 6-7 presents the odds ratios calculated from the best-fit multivariable logistic mixed model, and the change in model fit when each of the remaining explanatory variables were removed. Dogs in the youngest and oldest age groups had the highest risk of dying, being euthanised or being retired, with dogs between three and 4.9 years having the lowest risk. Dogs were almost twice as likely to die or be retired if they were recorded as being lame on trot or if they had an eye abnormality. The final multivariable mixed model had an area under the ROC curve of 0.77 (95% CI = 0.71 – 0.82).

6.4.2.1 Predicted lean body mass to skeletal size ratio

Four hundred eighteen of 1360 observations (31%) did not include the data necessary to generate the predicted lean body mass to skeletal size ratio. After removing these observations, the dataset included 942 observations of 416 dogs, of which 55 observations (13%, 95% CI = 10 – 16%) were followed by dogs dying or being retired before the next farm visit. Using this reduced dataset the predicted lean body mass to skeletal size ratio was found to have an adequate association with the risk of dogs dying or being retired to be included in multivariable analysis (P(LRT) = 0.19, OR = 1.1, 95% CI = 1.0 – 1.2) when tested using a univariable model. Table 6-8 shows the results of running the final multivariable model with the addition of the lean mass to skeletal size ratio as an explanatory variable. Here,

Table 6-6: The results of univariable logistic regression models examining the risk of each visit being followed by dogs dying or being retired in relation to a range of explanatory variables. Beta-coefficients (with standard errors (SE)) and odds ratios (with 95% CIs) derived from the logistic regression models and *P*-values derived from log-likelihood ratio tests. Explanatory variables with $P < 0.2$ are reported. Data is from 1360 examinations of 589 dogs, of which 81 examinations were followed by a dog dying or being retired. All dogs were enrolled in the TeamMate project and all observations had recorded values for all tested variables.

		Number (%) of examinations				
Explanatory variables	Level	Working	Died or retired	Beta-coefficient (SE)	Odds ratio (95% CI)	*P* (LRT)
Age category	1.5 to 2.9 years	275 (20)	11 (1)	Ref	Ref	<0.0001
	3 to 4.9 years	402 (30)	6 (0)	-1.0 (-1.5 – -0.5)	0.4 (0.1 – 1.0)	
	5 to 6.9 years	260 (19)	11 (1)	0.1 (-0.4 – 0.5)	1.1 (0.5 – 2.5)	
	7 to 9.9 years	265 (19)	22 (2)	0.7 (0.4 – 1.1)	2.1 (1.0 – 4.4)	
	10 years and older	77 (6)	31 (2)	2.3 (1.9 – 2.7)	10.1 (4.8 – 20.9)	
Number of recorded abnormalities	(count)	-	-	0.2 (0.1 – 0.2)	1.2 (1.1 – 1.3)	<0.0001
Eye abnormalities	No	1188 (87)	62 (5)	Ref	Ref	<0.0001
	Yes	91 (7)	19 (1)	1.4 (1.1 – 1.7)	4.0 (2.3 – 7.0)	
Mouth and teeth abnormalities	No	764 (56)	32 (2)	Ref	Ref	0.0004
	Yes	515 (38)	49 (4)	0.8 (0.6 – 1.1)	2.3 (1.4 – 3.6)	
Lameness on trot	No	1123 (83)	59 (4)	Ref	Ref	0.0005
	Yes	156 (11)	22 (2)	1.0 (0.7 – 1.3)	2.7 (1.6 – 4.5)	

Table 6-5: cont.

Explanatory variables	Level	Number (%) of examinations: Working		Died or retired		Beta-coefficient (SE)		Odds ratio (95% CI)		P(LRT)
Reproductive system abnormalities	No	1194	(88)	68	(5)	Ref		Ref		0.005
	Yes	85	(6)	13	(1)	1.0	(0.7 – 1.3)	2.7	(1.4 – 5.1)	
Musculoskeletal abnormalities	No	674	(50)	28	(2)	Ref		Ref		0.001
	Yes	605	(44)	53	(4)	0.7	(0.5 – 1.0)	2.1	(1.3 – 3.4)	
Neuter status	Entire	1189	(87)	68	(5)	Ref		Ref		0.01
	Neutered	90	(7)	13	(1)	0.9	(0.6 – 1.2)	2.5	(1.3 – 4.7)	
Visit number	(count)	-		-		0.3	(0.2 – 0.4)	1.3	(1.1 – 1.6)	0.01

Table 6-7: Results of the final multivariable logistic mixed model showing the effect of a range of explanatory variables on the risk of examinations being followed by dogs' dying or being retired. Individual dogs and dog owners were defined as nested random effects. Data used in the final model is from 1360 observations of 589 dogs, of which 81 observations were followed by the dog dying, being euthanised or being retired. All dogs were enrolled in the TeamMate project.

Explanatory variables	Level	Odds ratio (95% CI)		*P*(LRT)
Examination number	(count)	1.2	(1.0 – 1.6)	0.08
Age category	1.5 to 2.9 years	Ref		<0.0001
	3 to 4.9 years	0.3	(0.1 – 0.9)	
	5 to 6.9 years	0.8	(0.3 – 2)	
	7 to 9.9 years	1.5	(0.7 – 3.3)	
	10 years and older	6.2	(2.8 – 13.9)	
Lameness on trot	No	Ref		0.04
	Yes	1.8	(1.0 – 3.2)	
Eye abnormalities	No	Ref		0.06
	Yes	1.9	(1.0 – 3.6)	
Dogs and dog owners (random effects)				1.0

Statistical significance was determined using the log-likelihood ratio test.

Table 6-8: Results of the final multivariable regression model with the addition of the ratio of lean body mass to skeletal size added as an explanatory variable. Due to missingness data is from 942 observations of 416 dogs where a value for lean mass to skeletal size was available. Fifty-five observations were followed by the dog dying, being euthanised or being retired. All dogs were enrolled in the TeamMate project.

Explanatory variables	Level	Odds ratio (95% CI)		*P*(LRT)
Lean body mass to skeletal size ratio	(continuous)	1.1	(0.9 – 1.2)	0.36
Examination number	(count)	1.3	(1.0 – 1.8)	0.05
Age category	1.5 to 2.9 years	Ref		<0.0001
	3 to 4.9 years	0.3	(0.1 – 1.2)	
	5 to 6.9 years	1.1	(0.4 – 3.2)	
	7 to 9.9 years	2.2	(0.8 – 5.9)	
	10 years and older	9.3	(3.3 – 26.5)	
Lameness on trot	No	Ref		0.10
	Yes	1.8	(0.9 - 3.6)	
Eye abnormalities	No	Ref		0.25
	Yes	1.6	(0.7 - 3.5)	

Statistical significance was determined using the log-likelihood ratio test.

6.5 Discussion

This is the first time the risk of death and retirement from work has been examined in a population of working farm dogs. Of the 14% of enrolled dogs that were reported to have died or been retired, almost three times as many died or were euthanised rather than being retired (Table 6-5). Nearly three quarters of dogs that were lost from the workforce were seven years or older on their last examination. Of dogs that were retired three-quarters were ten years or older. Depending on body size, dogs can generally be considered as being senior at six to seven years of age and geriatric at around nine to 11 years (Bellows et al., 2015). Our results indicate that working farm dogs tend to keep working into their senior and possibly geriatric years, and that a little over one quarter of farm dogs are retired.

Age group, lameness and the presence of eye abnormalities had the strongest effects on the risk of death, euthanasia or retirement in working farm dogs (Table 6-7). However, acute injury or illness was the most commonly reported reason for dogs being lost from the workforce (Table 6-4). Despite this apparent mismatch in results, the high proportion of dogs being lost due to acute injuries or illnesses can plausibly be linked to our analysis on risk factors. Dogs that are lame, have poor eyesight or are suffering from age-related reduction in musculoskeletal function are probably less able to cope with the physical demands of their work, putting them at increased risk of serious acute injuries that can cause them to be retired or euthanised. For example, such dogs may be less able jump over obstacles such as fence lines or avoid being hit by vehicles or stock. Additionally, young dogs have been shown to require veterinary treatment for acute injuries more often than older dogs (Bonnett and Egenvall, 2010), possibly due to their lower levels of training and higher excitability. Heightened risk due to youth or seniority might be counteracted through age appropriate adjustments to dogs' training and workload. Additionally, prevention and effective treatment of the underlying causes of lameness and conditions that could cause a loss of eyesight should be a priority for veterinarians and working dog owners. Doing so will not only improve dogs' health and welfare but could additionally prevent dogs from having serious injuries that cause them to be lost from the workforce prematurely. However, there is currently no data on how dog owners currently work to counteract injury and disease in their dogs, or whether there are specific areas where improvements to common practices could be made.

Being lame almost doubled the risk of farm dogs being lost from the workforce. Due to the physical requirements of the work farm dogs do this is to be expected, particularly if the lameness is long-lasting and cannot be effectively treated. Lameness can be a sign of musculoskeletal pain and stiffness in dogs, and conditions such as cranial cruciate ligament disease and joint dysplasia are common causes of lameness in dogs (Anderson et al., 2020). However, dogs can also be lame from other causes such as, for example, trauma to the footpads. Because we did not incorporate diagnoses in our data, we do not know what caused the lameness that was recorded in dogs enrolled in this study, and musculoskeletal abnormalities were analysed as a separate risk factor from lameness. When analysed, the presence of musculoskeletal abnormalities were not found to have a significant effect on the risk of dogs being lost from the workforce despite the significant effect caused by lameness, and the likelihood that many cases of lameness were caused by underlying musculoskeletal conditions. One reason for this apparent discrepancy may have to do with how we chose to analyse our data. In this study we examined what effect risk factors had in the months immediately following each observation of a dog. As musculoskeletal disease often develops over long periods of time before they progress to cause pain or lameness, it may be that our analysis considered too short periods of time to detect the effect of musculoskeletal abnormalities on working farm dogs. However, it is likely that musculoskeletal injury and disease is the underlying cause of many the recorded cases of lameness in this study. Research into what types of disorders commonly cause lameness in working farm dogs would be helpful. The results of such research may enable dog owners and veterinarians to treat these conditions more effectively, and delay or prevent dogs from developing lameness that could cause them to be removed from work.

The discrepancy between the effects of lameness and musculoskeletal abnormalities on dogs being lost from work may also have other reasons. Decisions about whether to euthanise or retire working farm dogs are made by their owners, presumably based on their needs on farm and their perception of the performance, health and welfare of their dogs. Many of the most common types of musculoskeletal abnormalities recorded for TeamMate, such as reduced range of joint motion, crepitus and joint pain (Chapters 3 and 5), are likely to be difficult for dog owners to discover. As such these abnormalities probably do not affect owners' decisions on whether to remove dogs from work until they are serious enough to cause dogs to become lame. Lameness and related problems with joint stiffness or pain can cause dogs to have difficulties with for example jumping up and down from vehicles or across fences, and to have reduced working performance (Mills et al., 2020). A study of military working dogs found that dogs were more likely to have signs of spinal disease if they were reported by their handlers to have developed problematic behaviours such as reluctance to jump up onto objects or vehicles, reluctance to perform work tasks or to have become aggressive or anxious (Dodd et al., 2020). Such changes in movement, behaviour and performance in working farm dogs are easier for dog owners to notice than subtle musculoskeletal changes, especially when they know their dogs intimately and rely on them to be able to work. However, if dogs have already developed persistent lameness and joint pain that is affecting their performance it is often difficult or impossible to reverse the underlying causes (Rychel, 2010). However, if musculoskeletal abnormalities can be detected and treated early enough the development of irreversible disease can sometimes be slowed down. Providing farm dog owners with the necessary skills to detect musculoskeletal abnormalities before they progress to cause lameness could enable them to seek veterinary treatment early enough to prevent more serious injury or disease from developing. For example, farm dog owners could be trained in how to detect subtle changes in joint motion or signs of pain in their dogs, and to recognise changes in behaviour and performance that may indicate pain or discomfort. Helping farm dog owners to recognise early signs of musculoskeletal disease in their dogs could help them to make informed decisions around treatment, retirement and euthanasia. However, further study is needed to investigate whether the risk of lameness and musculoskeletal injuries is inherent in the jobs working farm dogs do or whether there are areas where husbandry and owner knowledge levels can be improved in practice.

Having an eye abnormality on examination almost doubled dogs' risk of dying or being retired, although this effect was not significant. However, as a goal of this study is to generate hypotheses for further investigation, we included possible risk factors with *P*-values lower than 0.1 in the final logistic regression model. If the observed eye abnormalities caused dogs' vision to be reduced their working ability may have been affected and they may have been at increased risk of injury when traversing obstacles or working close to stock animals on farm. Additionally, dogs with visible abnormalities of the eyes may be removed from work despite having normal vision if owners believe that the abnormalities could impair performance, increase the risk of injury or is a general sign of old age. On enrolment to TeamMate ten percent of dogs had at least one recorded eye abnormality, the majority of which involved lens opacity and scarring (Chapter 3). However, we do not have data to indicate what types of eye abnormalities were associated with dogs being lost from work. Further investigation is needed to shed light on common eye diseases and injuries in working farm dogs and how they affect the dogs' welfare and working ability.

Almost three quarters of dogs that were retired during the TeamMate study did not have a stated reason for being retired (Table 6-4). It may be that the owners did not have any specific reasons to retire these dogs apart from a general opinion that they were old and no longer needed. Unlike working dogs like police, military and guide dogs, it can be difficult to define what retirement means in working farm dogs. In this study we asked owners to report when dogs were no longer used for work, but we had no way to control this. Anecdotally, instead of having a clear cut-off point in either age or health status where dogs are removed from work and moved into retirement, farm dog owners make the decision on whether and how much their dogs should work based on their own knowledge and experience. Often this means that instead of being retired, older dogs' workloads are gradually reduced according to their working capacity and performance, the owners' needs, and the composition of the owners' teams of dogs. If the owner has younger dogs coming up that can replace the old dog satisfactorily, old dogs' workloads will probably be reduced. However, fully trained and experienced older farm dogs can be very valuable to farmers, and owners may be reluctant to retire them as long as they are still able to work. Additionally, working farm dogs are highly motivated to work with stock even as they grow older and some may not be suitable to keep as house pets. As such their owners may feel that their welfare would be impaired if they were not allowed to work. Anecdotally, there were cases in TeamMate where older dogs were noted as being allowed to 'tag along' for work, and dogs as old as 14 were enrolled in the study (Chapter 3). These dogs are still exposed to risk factors related to work and may be at higher risk of injury due to lower physical capacity caused by aging (Bellows et al., 2015). Including such semi-retired dogs in our study population may have caused us to underestimate the number of dogs that would be considered as retired by their owners and to overestimate the number of dogs that die or are euthanised while still an active part of the workforce. However, we felt that excluding semi-retired dogs would be difficult to do in practice due to the lack of a clear definition about what constitutes retirement. We therefore chose to define all dogs that were reported to be still working in any capacity as not retired. Future investigation should be made into how owners of working farm perceive the health and welfare of their dogs, and how they make decisions around whether to retire or euthanise them. Such investigation would shed light on whether there are areas of concern around health and welfare that traditional epidemiological research has not uncovered, and suggest paths of study that could contribute to improving dogs' quality of life.

Despite high activity levels and traumatic injuries being common (Cave et al., 2009; Sheard, 2014), our data indicated that most working farm dogs live and work into old age. Thirty-eight percent of dogs that died or were retired were ten years or older on their last examination in TeamMate, and nearly three quarters were seven years or older. Although younger dogs were also lost from the workforce for various reasons, the vast majority of dogs that died or were retired were those that could be classed as having reached old age. Additionally, with the exceptions of lameness and eye abnormalities, none of the most commonly seen types of clinical abnormalities that were recorded had any significant impact on dogs' risk of death or retirement independently of the effects of age. Although more can doubtless be done to investigate and improve the health and welfare of working farm dogs while they are part of the workforce, there is probably little to be gained in attempting to extend dogs' working careers. However, due to a lack of quality in our data we did not examine factors which may affect the risk of developing disease or lameness, or carry out any assessment on the effects of husbandry practices such as feeding or the quality of housing. Future investigations may focus on these issues, as they are important in allowing owners of working farm dogs to improve the overall health and welfare of their dogs. Additionally, efforts might be made to investigate health and welfare in older working dogs, and how owners make decisions around whether to euthanise or retire dogs whose ability to work is declining.

The effect of age on dogs' risk of dying or being retired was not linear. Instead, the lowest risk was seen in dogs between three and 4.9 years old, rather than the youngest group 1.5 to 2.9 years old (Table 6-7). This is similar to the analysis done by Sheard (2014), which found that dogs that were two years old or younger, or older than seven years old, were the most likely to be reported as having died in a 12-month period. Sheard also found that partially trained dogs were more likely to die than those that were fully trained. Due to differences in behaviour, fitness and training level, young dogs are likely to be exposed to somewhat different risk factors than older dogs, and they may be at higher risk of traumatic injury due to their lack of experience and higher levels of excitability. In Sweden, a study of insured pet dogs found that young dogs have a higher risk of receiving veterinary care due to traumatic injury than older dogs (Bonnett and Egenvall, 2010). Additionally, young and partially trained dogs are sometimes unsuitable for stock work in general or incompatible with their current owner. In Australia, stock dog handlers reported that 20% of acquired dogs failed to become trained working dogs (Arnott et al., 2014b). Of these, 89% were dismissed due to problems around temperament and training with more than half of dismissed dogs being reported to have a lack of natural working ability. While dogs that are simply incompatible with their owner can be rehomed or sold, finding new homes for farm dogs that are generally unsuitable for work is likely to be difficult due to their high activity levels and need for stimulation. Therefore, a proportion of such dogs are probably euthanised rather than rehomed or sold.

Neither body condition score nor the ratio of predicted lean body mass to skeletal size score were found to be associated with the risk of dogs dying or being retired. This should not be interpreted as a lack of risk associated with being clinically under- or overweight. Instead, our evidence indicates that neither representation of body condition is predictive of whether or not dogs die or are retired. It may be that one or both measures are associated with welfare, working performance or other types of health outcomes in working farm dogs. However, in the current study there is little evidence to suggest that either measure is a reliable indicator of overall health in lean, athletic dogs. Given that concern has been expressed that working farm dogs may in general be too thin, more investigation into what constitutes optimal body condition in relation to health in working farm dogs may be warranted.

6.6 Conclusion

This study found that in addition to the effect of age, lameness and eye abnormalities increase the risk of working farm dogs dying or being retired from work. However, as we did not include diagnoses in our data, we cannot be sure which types of underlying conditions are causing the lameness or eye abnormalities observed in these dogs. Further study should be done to investigate causes of lameness and common eye conditions, and risk factors associated with the development of these conditions.

Based on these investigations, working dog owners could be trained in how to prevent and detect such conditions before the health, welfare and working ability of farm dogs is impaired. Additionally, future study into how farmers make decisions about the work, retirement and euthanasia of their dogs may provide valuable insights that can contribute to ensuring the health and welfare of these dogs.

6.7 Statement of contribution

DRC 16

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Katja Elisabeth Isaksen
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Chapter 7

General discussion

General discussion

This PhD thesis used data collected as part of the TeamMate project to investigate questions surrounding health and the risk of death or retirement in working farm dogs. TeamMate was designed to be a longitudinal study with regular farm visits and physical examinations of working farm dogs carried out by veterinarians. After filtering dogs that did not meet inclusion criteria or had incomplete data collected at enrolment, 1930 examinations of 641 working farm dogs remained, with 124 dog owners and staff from 11 veterinary clinics involved. The project was carried out with minimal funding and resources, with the largest contribution being the donation of a substantial amount of time and effort by Vetlife staff over a period of several years. The study has revealed important knowledge and opened up a range of new research possibilities that could benefit working farm dogs and their owners. None of this would not have been possible without the ability of veterinary staff to visit farms and collect data over a large area of the South Island, possibly to the detriment of their normal duties.

This is the first time a longitudinal study has been carried out to investigate health in working farm dogs or, to my knowledge, working dogs in general. The thesis contains four research chapters. Chapter 3 reported population data and the prevalence of clinical abnormalities in working farm dogs on their first examination as part of TeamMate. Chapter 4 investigated body condition and whether conventional body condition scoring as a way of estimating body fat mass is applicable to working farm dogs. A novel method to assess body condition using a predicted measure of lean body mass was applied to the study population. Chapter 5 investigated the incidence rate of new musculoskeletal abnormalities. Chapter 6 investigated risk factors associated with dogs dying or being retired from work. The TeamMate project fills a number of gaps left by previous studies. Specifically, the data from TeamMate is less biased towards serious disorders than the study done by Cave et al. (2009) who collected data from dogs which were brought to veterinary clinics, and we are likely to have presented a more complete picture of the health of working farm dogs than Sheard (2014) who reported health events based on owner reports. When seen in combination with these two previous studies TeamMate provides a comprehensive overview of the most common conditions that are likely to occur in this population.

Based on the data presented in this thesis we can come to a number of conclusions. Overall, our results indicate that the population of working farm dogs that were studied are likely to be lean, and while a majority of dogs had recorded clinical abnormalities on enrolment, many of these were unlikely to have a strong effect on dogs' overall health and welfare. However, musculoskeletal abnormalities were common and working farm dogs may be at increased risk of musculoskeletal illness and injury as a consequence of their work and high activity levels. After accounting for the age of the dogs, the presence of lameness or eye abnormalities was found to increase the risk of dogs dying or being retired, probably because these types of abnormalities can impact on both dogs' risk of being seriously injured and on their working ability and performance.

7.1 Husbandry and care

Chapter 3 reported and discussed housing, husbandry, diet and vaccination status in working farm dogs on their enrolment to TeamMate. The results confirmed previous evidence about how working farm dogs in New Zealand are housed, fed and cared for (Cogger and Sheard, 2017; Jerram, 2013; O'Connell, 2012; Singh et al., 2011). By considering what is known about other populations of dogs, researchers can use this data to make suggestions about where future research should focus and which areas may need improvement. For example, our results indicate that most dogs are fed only once daily and that many are quite lean (Chapter 3, Chapter 4). Additionally, the large proportion of dogs that were reported to not have access to bedding in their kennels may be a cause for concern (Chapter 3). More focus can be put on whether the way dogs are currently fed and housed is adequate to their needs or if improvements can be made. Unfortunately, our data was not complete enough to enable us to investigate how most of these factors affect the risk of working farm dogs dying or being retired. More detailed investigation is needed into how current husbandry practices affect the health and welfare of working farm dogs, and whether there are specific aspects of these practices that could be improved.

7.2 Body condition in farm dogs

A key finding of this thesis is that working farm dogs are generally lean (Chapter 3, Chapter 4), which is to be expected given the athletic nature of their work. However, concern has been expressed that many working farm dogs may be too thin (Sheard, 2014). Conventional body condition scoring (BCS) in dogs aims to assess body fat mass, mainly in overweight dogs. Our analysis suggests that applying conventional BCS to working farm dogs may be inappropriate, probably due to the lack of validation of BCS in lean athletic dogs. Additionally, we did not find any associations between either conventional BCS or the ratio of predicted lean mass to skeletal size and the risk of dogs dying or being retired (Chapter 6). However, as working farm dogs are highly athletic and generally have low body fat mass, we believe that assessing their lean body mass may be a more appropriate way to assess their general health than assessing fat mass. A loss of lean mass can be associated with illness in cats and dogs (Santarossa et al., 2017), and in humans the loss of lean mass, muscle mass and strength have been linked with malnutrition and increased risk of injury and disease (Deutz et al., 2019; Finnoff et al., 2011; Khayambashi et al., 2016; Lang et al., 2010; Leetun et al., 2004; Mareschal et al., 2019; Powers et al., 2017). While we did not find any evidence that the lean mass ratio was associated with dogs' risk of death, euthanasia or retirement, we have so far been unable to investigate whether there are any associations between either BCS or the lean mass ratio and health outcomes such as for example musculoskeletal disease or injury, or infectious diseases. Also, the equation used to generate the lean mass ratio has not been validated on a population of dogs with known lean mass and may therefore be inaccurate. As there is currently little evidence that either BCS or the lean mass ratio are good measures for assessing health in working farm dogs, further exploration of how to assess body condition in working farm dogs, and lean mass in particular, is recommended.

Chapter 4 highlighted our lack of knowledge of how to assess body condition in lean, athletic dogs. The majority of the existing literature on body condition and related health issues in dogs is focused on obesity in pet dogs. Similarly to the way BMI in humans is not applicable to muscular individuals (Nuttall, 2015) our research indicates that BCS is inappropriate when applied to athletic working dogs. Working dogs contribute to human society in a wide range of areas, and there are many jobs that would difficult or even impossible to do without the help of specially trained dogs (Chapter 2). With low body weight and loss of lean body mass having been linked to malnutrition, serious illness and increased risk of injury in populations of both humans and animals, finding a practical way to assess body condition in lean athletic dogs is an area of research that deserves more attention.

7.3 Musculoskeletal abnormalities

Abnormalities that affected the musculoskeletal system, skin, and mouth or teeth were found to have the highest prevalence in the study population (Chapter 3). Many of the abnormalities that were recorded in the skin or mouth, such as healed scars, callouses and chipped teeth, were considered unlikely to have an effect of dogs' immediate health and/or welfare, while musculoskeletal injury and disease can be painful, uncomfortable and are likely to affect dogs' working ability. Data about the incidence of musculoskeletal abnormalities can provide insights into which types of abnormalities occur most commonly. The incidence of musculoskeletal disease or injury in working farm dogs has not previously been studied, and Chapter 5 of this thesis therefore focused on the development of musculoskeletal abnormalities in these dogs. Data were investigated by calculating incidence rates of the most common types of musculoskeletal abnormalities and examining whether there were any clear differences in the incidence rates of males and females or Heading dogs and Huntaways (Chapter 5). Few differences were found, although Heading dogs had a slightly higher rate of carpal abnormalities than Huntaways.

More than half the dogs that did not have any musculoskeletal abnormalities on enrolment to TeamMate developed at least one abnormality during the course of the study (Chapter 5). Over a quarter of these dogs were additionally found to have the same type of abnormality on a subsequent examination. Although we have no data available on whether these abnormalities are associated with the same or different instances of disease or injury, both cases are concerning. Chronic musculoskeletal disease such as osteoarthritis has been found to be associated with repeated injuries in the same location (Johnston, 1997) and musculoskeletal injuries and diseases are common causes of death and retirement in guide dogs, military dogs and police dogs (Caron-Lormier et al., 2016; Moore et al., 2001; Worth et al., 2013). Although the presence of musculoskeletal abnormalities were not found to significantly increase the risk of farm dogs dying or being retired when analysed using a multivariable model (Chapter 6), musculoskeletal injury and disease are likely to affect the overall health and welfare of dogs, and may have indirect influences on lifespan and career length that were not detect in the analysis done for this thesis. Specifically, musculoskeletal abnormalities are very likely to be associated with the underlying causes of lameness in working farm dogs. The presence of lameness on physical examination was found to almost double dogs' risk of dying, being euthanised or being retired (Chapter 6).

Of the abnormalities that were examined in Chapter 5, carpal abnormalities had the highest incidence rate and they were also seen to persist or be repeated more often than other types of abnormalities. Carpal injures have previously been observed to be common in racing greyhounds and sled racing dogs (Guilliard, 1997; Prole, 1976; von Pfeil et al., 2015), and in sled racing dogs it was suggested that they may be the result of overuse during training for a long distance race (von Pfeil et al., 2015). As they are also highly active, working farm dogs are likely to experience some of the same risk factors as racing greyhounds and sled racing dogs. However, due to the different natures of their work, farm dogs are also exposed to different types of risks than racing dogs. For example, working farm dogs work in close proximity to stock animals and commonly need to jump across fences or on and off vehicles. Such activities have been reported to be common reasons for injury in farm dogs (Cave et al., 2009; Sheard, 2014). The precise mechanisms or risk factors for development of carpal injuries in farm dogs have, however, not yet been investigated.

While carpal abnormalities had the highest incidence rate, hip abnormalities had a higher prevalence than carpal abnormalities on enrolment to TeamMate (Chapter 3). This indicates that while carpal conditions occur commonly, hip abnormalities may have longer duration and therefore accumulate more in the population. Another possibility is that dogs with carpal abnormalities are more likely to be retired or euthanised than dogs with hip abnormalities, causing a reduction in the prevalence of carpal abnormalities. Additionally, while carpal pain was rarely recorded, pain was recorded in half of dogs with hip abnormalities, both when counting prevalent and incident cases. The higher occurrence of hip pain suggests that hip abnormalities may have higher impact on dogs' welfare than carpal abnormalities. However, reduced range of joint motion, which was common in both the hip and the carpus, can also cause lameness, discomfort and a reduced ability to perform desired behaviours such as jumping and running, or finding comfortable positions in which to rest. Neither hip nor carpal abnormalities should therefore not be discounted from a welfare perspective. In addition to the immediate impact on dogs' health and welfare, musculoskeletal injuries can have long term consequences, especially if the injuries are repeated or take a long time to heal. In humans it has been found that former athletes are at increased risk of chronic illness such as osteoarthritis later in life (Gouttebarge et al., 2015), and the same principle may apply to highly active working and sporting dogs. Further study is needed into risk factors associated with the development of musculoskeletal injury and disease, and how such abnormalities impact the welfare and working ability of farm dogs.

Ideally, our analysis would have investigated whether the risk of farm dogs developing musculoskeletal abnormalities was affected by exposure to a range of recorded risk factors. However, due to the way our data was collected it was impossible to determine whether identical musculoskeletal abnormalities that were recorded more than once were the same or new occurrences. As a result, we explored only the first occurrences of musculoskeletal abnormalities in working farm dogs, and did not attempt to model risk factors related to dogs developing new abnormalities. However, the incidence of musculoskeletal disease or injury has not previously been examined in working farm dogs and our study provides a starting point and suggestions for future avenues of research.

7.4 Death, euthanasia and retirement in working farm dogs

Fourteen percent of 589 working farm dogs were recorded to have died, been euthanised or been retired (Chapter 6). Young dogs had a slightly elevated risk of being lost from the workforce compared to adults between three and five years old. However, of the dogs that died, were euthanised or were retired during the course of this study almost 40% were ten years or older on their last examination in TeamMate. Improvements to the husbandry and care of working farm dogs is therefore unlikely to increase the career lengths of most dogs. However, such improvements may benefit dogs' health and welfare as they age, and may also prevent younger dogs from being removed from work prematurely.

Irrespective of age group, the presence of lameness on physical examinations were found to almost double the risk of dogs dying or being retired from work before the next examination (Chapter 6). The presence of lameness is likely to affect both owners' perceptions of dogs' working abilities and dogs' risk of traumatic injuries. Owners reported that the most common reasons for loss were acute illness or injury and 'old age'. Being lame can affect dogs' risk of being injured, and may change dog owners' perceptions of older dogs' health and welfare and whether they are likely to continue being good workers. However, a third of dogs that died or were retired had no owner-reported reason for loss. Therefore, care must be taken when drawing conclusions from the owner-reported data. For example, certain reasons for dogs being lost could be less likely to be reported by dog owners, causing our data to be biased. However, independently of owner-reported reasons for loss, investigation is warranted into what underlying conditions caused the lameness that was observed on physical examination in this study, and whether some of them are more likely to cause dogs to die, be euthanised or be retired than others. Possibly, some of these conditions could be prevented or treated, thereby improving dogs' health and welfare and preventing them from being from being lost from the workforce prematurely.

Despite the presence of lameness nearly doubling the risk of working farm dogs dying or being retired, musculoskeletal abnormalities were not found to be significantly associated with dogs being lost from the workforce. However, on dogs' enrolment to TeamMate the prevalence of lameness was over twice as high in dogs that had a musculoskeletal abnormality than in the overall study population (Chapter 3). Musculoskeletal abnormalities also had both high prevalence and incidence in this study population (Chapter 3, Chapter 5). As such it is likely that many instances of lameness were caused by underlying musculoskeletal disease or injury. However, we do not know which underlying conditions cause lameness in working farm dogs or whether musculoskeletal disease or injury are associated with other health and welfare outcomes. Further studies should examine these issues, and also attempt to examine the effects of different types of musculoskeletal abnormalities in more detail, both on dogs' risk of being lost from the workforce and on other outcomes related to overall health, welfare and working performance.

In addition to being lame on trot, having eye abnormalities were found to increase dogs' risk of death or retirement although this association did not reach significance, with a *P*-value of 0.06. However, we chose to retain eye abnormalities in the final model to account for their effect on dogs' risk of death or retirement, and because it is plausible that eye abnormalities have an effect on whether dogs are lost from the workforce. Working farm dogs depend on their eyesight to navigate their environment and to work with stock, and having reduced vision is likely to impair their working ability and increase their risk of injury. More than half the eye abnormalities that were recorded on enrolment to TeamMate involved lens opacity (Chapter 3). While not all common causes of lens opacity in dogs cause reduced vision (Bellows et al., 2015), there is a possibility that dog owners who observe lens opacity in their dogs may remove the affected dogs from work due to concern that they will work less effectively or have a higher risk of injury due to poor eyesight. However, no data is available on what types of underlying conditions caused the recorded cases of lens opacity in TeamMate, or how dog owners make decisions around euthanasia or retirement of working farm dogs. Research into the causes of eye abnormalities in working farm dogs is warranted to determine whether these abnormalities are linked with reduced eyesight, poor health and welfare or owners' decisions to remove dogs from work.

Further investigation into causes of death in working farm dogs may be complicated by the fact that this is potentially a sensitive issue that some dog owners may be unwilling to discuss. Anecdotally, there is increased public concern for the welfare of working farm dogs in New Zealand and public perception is not always purely positive. This could cause some dog owners to be reluctant to discuss the reasons why dogs died or were euthanised. Such reluctance is one possible explanation for why almost one fifth of dogs that died during the course of the TeamMate study had no recorded cause of death or euthanasia (Table 6-4), especially if the reasons for euthanasia could be perceived as unnecessary by the general public. There could be many reasons why dog owners choose to euthanise dogs, ranging from behavioural and performance issues, having more dogs than they need or have resources to maintain, or dogs being critically ill or injured. Dog owners that felt the need to euthanise surplus or poorly performing dogs may be unwilling to report this to researchers. However, it should be considered that there may not always be good alternatives to euthanasia, especially for dogs that are not good workers. Working farm dogs are highly active and require a lot of stimulation, and some may also be anxious or aggressive. Finding good homes for such dogs if they cannot be used to work with livestock may be close to impossible, and dog owners might not have the time or resources to find new homes or to adequately care for dogs that are not working. However, researching causes of death and euthanasia in working farm dogs may help to prevent unnecessary deaths, and if there are significant proportions of surplus or poorly performing dogs that are euthanised, systems may be put in place to help dog owners to reduce the population of surplus dogs and to find new homes for unwanted farm dogs.

The criteria for when working farm dogs should be retired are not defined, making it difficult to carry out research into reasons for retirement in these dogs. Working dogs such as guide dogs and police or military dogs are often retired based on criteria such as veterinary assessment of their ability continue working. In contrast, there are no standards around what qualifies a working farm dog for retirement and the decision is made solely by individual dog owners. As there is no information available about how owners of working farm dogs decide whether or not dogs should be retired from work or euthanised it is difficult to compare reasons why these dogs are lost from the workforce in relation to other types of working dogs. More information is needed around how owners of working farm dogs decide to retire or euthanise their dogs. Although our analysis suggests that the presence of lameness and eye injury or disease in dogs have impacts on dogs' risk of death and retirement, we do not know if this is because signs of reduced mobility and poor eyesight affects owners' perception of dogs' working abilities, if these problems are associated with increased risk of serious injuries, or both. Future research into death and retirement of working farm dogs should focus on the specific reasons why dogs are lost from the workforce and whether these reasons are linked to husbandry or stock work.

In addition to a lack of clarity around the reasons for retirement in working farm dogs, the definition of what retirement entails is also less clear than in other types of working dogs. For example, working dogs such as guide dogs and police or military dogs are usually removed from work completely and either euthanised or moved to a private home become full-time pets, sometimes with their handler. In contrast, retirement for working farm dogs seems to often be a gliding transition where dogs' workloads are gradually reduced according to their working ability. In TeamMate there were several enrolled dogs that were recorded as having been 'retired' to smaller properties, presumably due to the required workload on their current farm being too demanding. Working farm dogs may not be suitable to be rehomed as pets in their old age as they retain the chasing and hunting related behavioural patterns that enable them to do stock work (Chapter 2) and are often not accustomed to living in a home. Working farm dogs are thought to be highly motivated to work and leaving a retired dog alone in their kennel with no activity while the owner and remaining dogs goes to work is likely to seem inhumane to many dog owners. Allowing dogs to work to their ability as long as they do not hinder the smooth running of the farm is probably seen as a better solution than complete retirement. However, what kind of impact this might have on dogs is unknown. It is possible that allowing them to work as long as is practical is the best solution as it gives dogs the opportunity to carry out behaviours that they are highly motivated to do while also filling their need for social interactions with other dogs and humans. However, it may also be that the underlying health issues that cause dogs' working ability to be reduced have a higher impact on their overall welfare than is apparent to their owners, including increasing their risk of chronic disease or serious injury. If the health and welfare of older and semi-retired working farm dogs is impaired, providing dog owners with training in how to detect signs of underlying health issues or impaired welfare could enable them to make better-informed decisions around retirement and rehoming or older dogs. Additionally, work could be done to connect working dog owners with non-profit organisations such as the SPCA New Zealand (2020) or Retired Working Dogs NZ (2020) which can help to find appropriate permanent homes for older working dogs. However, research is needed into the behavioural and welfare needs of working farm dogs, and whether they can be met in dogs that are prevented from working for long periods of time.

The ultimate goal of this thesis was to provide data that allow researchers to focus on the most common problems and prioritise future research, and to ultimately enable veterinarians and working farm dog owners to make evidence-based decisions about husbandry and care. Future research should involve more detailed studies into the links between workload and husbandry practices, the risk of injury and disease, and working performance. In addition, the risk of dogs dying or being retired for specific reasons might be examined in more detail. For example, risk factors related to farm dogs dying due to traumatic injury are likely to be quite different from risk factors related to dogs dying due to gastric dilatation volvulus or being retired due to old age. Additionally, cases of dogs being euthanised or retired involve dog owners making decisions about the fate of the dogs. For example, owners may need to decide whether or not veterinary treatment and recovery of a promising young dog with a serious injury is worth going through, or whether an older dog that is showing signs of reduced stamina and mobility should continue working. Knowing how dog owners assess the working performance and value of their dogs could be very helpful to scientists in deciding where to focus future research, and to veterinarians in deciding how to communicate with dog owners and which treatment options to suggest.

7.5 TeamMate study design

7.5.1 Sample population and bias

The size of the TeamMate project, the large number of people involved in data collection, and the relative lack of resources brings with them some potential biases and inconsistencies. The need to recruit a large number of working farm dogs that would be accessible to Vetlife staff made it necessary to convenience sample our study population. Dog owners could have been randomly chosen from a larger population and asked to participate. However, choosing dog owners randomly was not possible as no publicly available database of farm dog owners exists that can be used as a sampling frame. Additionally, had random sampling been possible it would have carried with it a risk of a low response rate, making it difficult to reach the necessary sample size for data analysis. Instead, farm dog owners were convenience sampled, with the project being advertised through clinic newsletters, media coverage and at agricultural events, and owners that were considered to be interested in the project goals being approached and asked to participate. This approach to recruiting dog owners may have resulted in us recruiting farm dog owners that take a special interest in working farm dogs and have a different attitude towards the care and husbandry of their dogs than dog owners that did not choose to participate. However, randomly sampling dog owners would not have removed this bias, as owners are free to not participate independently of the method used to recruit them. Using a random sample is therefore unlikely to have removed such biases from the sample population.

In addition to the bias introduced by who is likely to participate in studies, participating dog owners may have differed from non-participating owners due to the fact that they knew that their husbandry practices were being recorded (Sedgwick and Greenwood, 2015). Additionally, owners' contact with veterinary staff during data collection and knowledge about the results of clinical examinations may have influenced their later decisions around dogs' workload and husbandry. Anecdotally, one dog owner noted that being part of the study had caused them to think more carefully about how they fed their dogs. As such, it may be that the population of working dogs that was recruited end enrolled to

TeamMate were generally better cared for and in better health than the general population of working farm dogs. Additionally, as reported in Chapter 3, almost eight in ten participating dog owners reported that they were farm owners and/or managers rather than employees, and few properties were associated with more than one dog owner. With a median of over 4000 animals per property it is unlikely that one person would be able to manage most of these farms alone, and we therefore suspect that we failed to recruit a substantial number of employed shepherds on these farms. Employee shepherds may treat their dogs differently from farm owners and managers due to differences in time, resources, responsibilities or other factors. When interpreting our results these possible sources of bias should be considered, especially if they are used as a basis for recommendations around husbandry or veterinary care.

It is important to note that while factors around sampling and participation may have resulted in dog owners that participating in TeamMate treating their dogs somewhat differently than those who did not participate, these differences would be evenly spread through the population. As such we have no reason to believe that they would have changed the results of our analysis. For example, the relationships between dogs' sex or types and their risk of developing musculoskeletal disease are unlikely to be affected by possible changes in behaviour by their owners. While such behavioural changes should be considered when extrapolating our data about husbandry practices to other populations of working farm dogs, they are unlikely to have changed the data that was collected on clinical examinations.

7.5.2 Data integrity

Data collection for TeamMate was dependent on adequate training of data collectors to minimise the risk and impact of human error. Training days were organised where everyone who would be involved in the project were taught how to collect data correctly. While the data that was collected appears to be consistent, errors or misunderstandings in training in addition to the time that passed between training and data collection, may have resulted in mistakes that are difficult to detect However, except for one skeletal size measurement that appeared to have been measured wrongly by some people (Chapter 4), we have no indications that systematic errors in data collection were a significant problem.

Missing points of data are common in all types of research and can constitute a problem, especially If they are thought to introduce bias into the study. In TeamMate, implausible and missing values were especially common in the morphometric data that was used to calculate skeletal size in Chapter 3. Additionally, some variables relating to dog owners' housing and husbandry practices had more missing data than others, especially on follow-up farm visits. While a proportion of the morphometric data was removed due to being implausible, most of the missing data in this study was simply not recorded.

There may be many reasons why questions were answered incorrectly or not answered at all, including random omissions and mistakes, poor questionnaire design, misunderstandings during training or misunderstandings caused by changes made to questionnaires following training. For example, questions related to dogs' housing were included on all data collection rounds. However, the questions were much more detailed during the first data collection round than subsequently. This was intended to reduce the workload for veterinarians and assistants, especially concerning dogs that had been enrolled previously. However, from the second data collection round onwards, the section on housing started by asking whether the dog's shelter had been changed in the previous six months, independently of whether the dog was newly enrolled, and continuing by asking for additional details if the answer was 'yes'. This may have caused data collectors to skip the entire section, also for newly enrolled dogs. Additionally, questions regarding whether dogs wore coats for warmth and whether they had bedding in their kennels were grouped with the questions regarding housing and may therefore also have been skipped if the owner reported not to have changed the dog's shelter. Lastly, housing, bedding and coat use may be perceived as sensitive subjects. Public concern about the welfare of working farm dogs is anecdotally perceived to be increasing and questions around working farm dog welfare have been raised, including whether the shelters used are suitable (Littlewood and Mellor, 2016). As such, veterinary staff may have been reluctant to ask questions that could be interpreted as touching on owners' care for dogs' welfare, especially if the data had been collected previously. Although most of the questions included in TeamMate did not have as many problems surrounding them as those concerning housing, missing observations were found to be a problem that limited the scope and possibly the quality of our analysis, especially in Chapters 4 and 6. However, the descriptive data around diet and housing that was presented in Chapter 3 provides valuable additional details to data collected previously, and can be used as a starting-point into more detailed investigations into the effects of diet and housing on the health and welfare of dogs.

Potential problems involving bias and data integrity could have been minimised by a range of measures, but they would have involved additional time and funding to complete data collection. For example, a small number of veterinarians and assistants could have been paid to carry out data collection full time, and to carry out data entry to the database in real time. This would have allowed data collection to be more consistent due to the smaller number of people involved and the removal of the additional pressure of being asked to both work on the research project and carry out regular work. Additionally, problems with transcribing hand-written questionnaires would have been avoided as the data entry would have been done by the person who filled in the questionnaire. There was no funding available to be able to do this for TeamMate. However, given the rigorous training that was carried out and the general interest in the project and in providing quality data that was expressed by most Vetlife staff, I believe that the majority of the data was collected and recorded in the way that was intended.

7.5.3 Clinical abnormalities

Veterinarians were not asked to provide any diagnoses for symptoms they observed while examining farm dogs. Instead, they were asked to describe any and all abnormalities they observed, including those that had no current impact on the health or welfare of the dogs. This way of recording health had both advantages and disadvantages. The main advantage was that recording clinical signs rather than diagnoses helped to make data collected by different people more uniform and easier to code for analysis. Additionally, it removed a layer of subjectivity on the part of the veterinarian and reduced the risk of misdiagnosis. A disadvantage of recording only clinical signs is that it ignores the ability of veterinarians to make informed judgements about the condition of the dogs, which could have been an advantage of having veterinarians carry out clinical examinations. However, since examinations were carried out on farm with minimal equipment, the scope of diagnoses that veterinarians could make were limited. Asking veterinarians to record diagnoses could have pressured them into diagnosing dogs based on limited information and with less reliability than if they had access to more equipment and facilities. If dogs had been examined in clinical settings such facilities would have been available. However, transporting entire teams of healthy working farm dogs to veterinary clinics would have been a burden on dog owners, especially as many live quite far from their closest Vetlife clinic. This additional burden would probably have resulted in a much smaller number of dogs enrolled, and a higher rate of withdrawals. It may also have resulted in higher levels of recorded illness and injury as dog owners might have been more likely to take their dogs to the clinic if they were worried about the health of one or more of the dogs on their team. A future study with a tighter focus on specific conditions in working farm dogs may conduct data collection in clinic. However, those carrying out such research should keep in mind that asking dog owners to transport their dogs to clinics may generate a bias in their sample population.

Data on each farm visit was collected independently and no attempt was made to determine whether identical clinical abnormalities that were observed in the same dogs on subsequent visits were newly developed or the results of chronic conditions. When analysing the incidence of clinical abnormalities this made it difficult make meaningful conclusions about repeated abnormalities beyond stating that they were recorded. Determining whether repeated abnormalities were new or persistent would have required more frequent follow-up examinations of working farm dogs and may have required veterinarians to make diagnoses based on testing and equipment that is not available on farm. As mentioned above, requiring dog owners to travel to veterinary clinics with their dogs is likely to have resulted in a much lower number of participants and a higher rate of withdrawals. Collecting data from all dogs at six-month intervals proved to be difficult in TeamMate, and decreasing the sampling intervals and carrying out examinations in clinics would probably have resulted in a much lower sample size. This reduction in power may be justified in other types of studies where a higher level of detail in the data is required, but TeamMate had a wide scope and was intended to explore the general health of working farm dogs rather than focusing on specific issues. As such, a large sample size that would provide a range of observations, including less common conditions, was a higher priority than a high level of detail in the collected health data or an ability to link abnormalities to the same underlying causes.

7.5.4 Sampling intervals

Farm visits and data collection were planned to take place at approximately six month intervals. In practice, dogs were examined approximately every eight to nine months (Chapter 5). The main reasons for this increase in time between intervals are logistical. Both veterinary staff and working farm dog owners have very busy work schedules and it may be difficult to find times when all those involved are free. This is exacerbated by the long distances between many of the participating farms and clinics, and the need to coordinate several farm visits in the same area on the same days in order to avoid repeat trips. Additionally, unexpected events can occur both in clinic and on farm that cause visits to be cancelled at short notice. As a result, fewer rounds of data collection were completed than were originally planned, reducing our sample size and the potential power of our analyses. However, as long as data collection is dependent on finding times when farm dogs and their owners are not working, delays in data collection are to be expected. Any future studies that involve data collection on farms need to take such issues into consideration and have realistic expectations of the amount of data that can be collected. In the case of TeamMate, while the initial goal of twice yearly data collection was not fully met, this goal was an ambitious one and the data that was gather was more than enough to meet the needs of the project. After filtering those dogs that did not meet inclusion criteria, were missing basic information such as breed or sex, or were judged to be unreliable, the data collected included close to 2000 observations of 641 working farm dogs. This large dataset enabled us to have a good deal of confidence in the conclusions that were reached from our analysis.

Having sampling intervals of several months caused a number of problems and possible biases in our data. Firstly, dogs may have experienced one or several health events between data collection rounds that were resolved relatively quickly and therefore not recorded in our data. This is likely to have caused us to under-estimate the number of minor and/or quickly resolved illnesses and injuries that occur in working farm dogs, causing our data to be biased towards more serious and longer lasting illnesses and injuries. However, TeamMate was designed to fill gaps left by previous studies and our data should be seen in combination with these. Specifically, the data from TeamMate is less biased towards major diseases and injuries that are likely to be seen in veterinary clinics than the study done by Cave et al. (2009), and data was collected using veterinary examinations rather than owner reports and is therefore likely to present a more complete picture of the health of working farm dogs than the study by Sheard (2014). Additionally, both these previous studies were able to record health data that TeamMate did not, and in combination with this thesis, they provide a detailed overview of the most common types of health events that are likely to affect working farm dogs in New Zealand.

In addition to a bias towards longer lasting clinical abnormalities, the long sampling intervals in TeamMate led to problems in determining the time at risk when analysing the incidence of new abnormalities. In Chapter 5, we calculated the incidence rate of new musculoskeletal abnormalities based on an approximate time at risk for all dogs that were included in the analysis. Dogs that had a new musculoskeletal abnormality were considered to no longer be at risk at the halfway point between the visit on which they were recorded to have a musculoskeletal abnormality and the previous visit. However, it is likely that there were musculoskeletal abnormalities that occurred and were resolved between visits and that were therefore never recorded. The musculoskeletal abnormalities that were recorded were more likely to have been more serious and/or longer lasting, meaning that they were not resolved by the time of the next visit, or they occurred shortly before the visit and were resolved shortly after. Depending on the proportion of acute and chronic abnormalities that were recorded in relation to those that actually occurred in the study population, our calculation of time at risk may therefore be misleading. However, since we do not know the duration of any of the recorded abnormalities we have no way of knowing whether our estimation of time at risk was in fact wrong, or if it was, the size of the error. In addition to shorter follow-up intervals, one way this could have been partially avoided would have been to ask farm dog owners to note the date and type of any sign of injury or illnesses that occurred in working farm dogs between visits. However, such records would be less reliable than the data collected at veterinary examination, and would also be likely to be dependent on a range of unknown factors such as the dog owners' interest in the study, their workload and their general knowledge about dogs and how to detect signs of illness. If injury dates had been provided by dog owners it is therefore likely that it would be difficult to conclusively tie many of their observations to the recorded abnormalities. Additionally, while our calculation of time at risk may be inaccurate to some unknown degree, the same can be said for many epidemiological studies that calculate incidence rates in their study populations. Such calculations are, however, very useful as guides to thinking about which types of conditions are most likely to occur by comparing incidence rates between different types of conditions or exposure groups.

7.6 Dissemination of knowledge

When carrying out scientific research it is important to consider how the new knowledge that was generated can be disseminated to those who can make use of it. The most common way of spreading scientific knowledge is through publishing scientific papers, and three of the research chapters in this thesis have been published so far, all in open access journals. Additionally, our results have been presented at a number of national and international scientific conferences. However, while publication and conference presentations are important, they do not ensure that information reaches the people who can put the knowledge into practice. In the case of TeamMate this mainly refers to rural veterinarians who treat working dogs and livestock farmers who own and use dogs for their work. As part of the project, efforts were made to inform both study participants and veterinary staff involved in data collection of our results through presentations and public meetings that were held in several locations on the South Island (Gibson, 2019). Additionally, one of the original ambitions for the TeamMate project was that the results could be used to generate a set of best-practice guidelines for care and husbandry of working farm dogs. However, the data presented in this thesis, while interesting and useful, are not specific enough to enable us to develop such guidelines. Future studies into specific issues such as housing, diet and training are needed to develop recommendations that can help dog owners, veterinarians and policy makers to determine the best way to care for working farm dogs.

7.7 Further research needs

This thesis has provided valuable new insights into the types of conditions that are common in working farm dogs and will allow scientists and funding bodies to prioritise which areas of research should be focused on in the future. However, more work is necessary to determine the impact and duration of the most common conditions that affect working farm dogs. Conditions that are likely to affect the health, welfare and working ability of large numbers of dogs over prolonged periods of time should be prioritised when allocating funding and resources for research. In this way it is hoped that this thesis can serve as a starting point to more in-depth research being conducted into how conditions that impair the health and welfare of farm dogs can be prevented or treated. For example, with the knowledge that musculoskeletal abnormalities are common in this population and that lameness may double the risk of death and retirement, researchers can be confident that a closer focus on these areas is likely to result in benefits to dogs and their owners. In addition to determining the overall health impact on the working dog population, further research should focus on linking health data and husbandry practices, such as previous injuries, body condition, diet and housing, to the risk of dogs developing serious illness or injury or having impaired welfare and quality of life.

To get the best possible data future studies should follow dogs over time and focus on determining risk factors for and consequences of dogs developing specific conditions. For example, a series of studies with shorter follow-up intervals than TeamMate should focus specifically on what types of injuries or illnesses cause lameness, whether certain conditions associated with lameness are more likely to result in dogs being lost from work, and which risk factors are associated with these conditions. Such studies are likely to be resource-intensive and it may not be feasible to carry them out in a similar way to TeamMate. An alternative to doing repeated farm visits for data collection could include an initial farm visit to enrol dogs, record husbandry practices and baseline health status, followed by frequent short surveys of owners to ask whether dogs have been ill or injured or developed signs of lameness. If dogs develop specific outcomes of interest they could then be examined by veterinarians to determine diagnoses. Such studies will collect less data than TeamMate, but the data that is collected will be more targeted and therefore more useful in subsequent analysis.

Research is also is needed about how dog owners perceive the health and welfare of their dogs and how they make decisions around workload, veterinary treatment, retirement and euthanasia of working farm dogs. Such knowledge may make it easier for farm dog owners and veterinarians to communicate and develop plans for the treatment and care for dogs that meet both the dogs' and the dog owners' needs. Earlier, I suggested that dog owners may be trained to detect subtle signs of pain and disease that can help them to provide early care to sick or injured dogs. Knowing more about how dog owners perceive and make decisions about their working farm dogs could reveal whether they have the practical capacity to improve their husbandry, and if so, areas where increased knowledge and training could be provided.

Currently, there is no practical, validated way to assess whether working farm dogs have a healthy body condition, and it is therefore difficult to determine whether working farm dogs are in good condition or tend to be underweight. More research is needed into how body condition in lean, athletic dogs can be assessed and whether this assessment can be linked to health outcomes. The ratio of predicted lean body mass to skeletal size may be a viable candidate if it can be linked to health in working farm dogs. However, the equation used to predict lean body mass should be validated by applying it to a new population of dogs with known lean body mass. Additionally, the measurements and calculations necessary to assign a ratio score to a dog is more complicated to carry out than conventional body condition scoring, and it may be difficult to convince veterinarians to adopt it. An alternative to the ratio based on lean body mass may be to develop and validate a system for body and muscle condition scoring specifically aimed at athletic, lean dogs. However, any measure of body condition should be linked to specific health outcomes before it is recommended for use. Specifically, research is needed to determine whether loss of body condition is associated with dogs' risk of disease or injury, or whether it is associated with a loss of physical fitness. For example, researchers might develop tests to assess strength and endurance in working dogs and assess whether the results of these tests are associated with measures of body condition or with risk of injury. If associations are found, this knowledge could be used to develop ways that dog owners can assess their dogs' physical condition and fitness and help them maintain dogs at high performance levels. Dogs' workload varies throughout the year and allowing owners to determine whether dogs are at an appropriate level of fitness when entering into a busy farming season could help them carry out their work more effectively and help prevent injuries in their dogs.

7.8 Conclusion

This thesis provides important data about the health and lifespans of working farm dogs. However, more research is needed into how health and welfare can be improved in these dogs, and how recommendations can be carried out in practice. The TeamMate project and this thesis has made an important contribution to the body of knowledge about working farm dogs, and it is our hope that it will act as a stepping stone to more practically aimed research in the future. Working farm dogs are critically important to the livestock industry of New Zealand, and ensuring that they are healthy and have their needs met is a high priority to their owners and to the general population. Although work remains to be done, this thesis has made an important contribution to our knowledge of health in working farm dogs.

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Appendices

Appendix 1: Questionnaires used to collect data for the TeamMate project

DOG INDUCTION QUESTIONNAIRE

DATE: ______/______/2014

OWNER/HANDLER NAME:	**DOG'S NAME**:
PROPERTY NAME:	
MICROCHIP:	**STUDY ID NUMBER:**

BREED:	AGE TO CLOSEST YEAR:
GENDER: ☐ M ☐ F Spayed/Neutered Y / N	IF female: Number of litters __________
IF Spayed/Neutered - WHY?:	Number of mis-mating injections_______
INSURED: Y / N REGISTERED: Y / N	Has she ever had a vaginal prolapse Y / N

WORMING:	☐ The same as other dog _________________(specify name)		
Sheep Measles	Do you treat for sheep measles? Y / N		
How often?	☐ Only as a pup	☐ Once a month	☐ Every _____month(s)
	☐ Sporadically	☐ Never	☐ Don't know
	Where sourced: ☐ Vets ☐ Supermarket ☐ Rural supply store ☐ Ovis Management		
WORMING:	☐ Only as a pup	☐ Once a month	☐ Every _____month(s)
Broad spectrum	☐ Sporadically	☐ Never	☐ Don't know
How often?	Products used:		☐ Don't know
	Where sourced: ☐ Vets ☐ Supermarket ☐ Rural supply store ☐ Ovis Management		

How often is this dog **vaccinated?**	☐ Only as a pup	☐ Sporadically	☐ Once a year	☐ Never	☐Every_____ years(s)	☐ Don't know

TYPE OF WORK: (tick all that apply)	☐ Head	☐ Hunt	☐ Yard
	☐ Catch	☐ Back	☐ Dog trial
IF dog competes at dog trials:	☐ Casual (social, local trials)	☐ Competitive (to accumulate qualification points)	
Land contours worked:	☐ Flat/easy hill	☐ Steep/hill country	
TYPE OF STOCK WORKED: (tick all that apply)	☐ Sheep	☐ Dairy cattle	☐ Beef cattle
	☐ Deer	☐ Other (please specify)	

WHERE ACQUIRED:	
☐ Self bred	☐ Other breeder
	IF NOT self bred, age acquired:
	Level of training when acquired: ☐ Not started ☐ Started ☐ Fully trained
	Cost if purchased:

INDUCTION QUESTIONNAIRE CONTINUED

FEEDING:	☐ The same as other dog ________________(specify name)
What was this dog fed at its last meal? ☐ Meat – Specie(s)______________ ☐ Offal – Species________________	☐ Comm. dry brand(s)________________________ ☐ Comm. wet brand(s)_______________________ ☐ Comm. other brand(s)_____________________
How many days did this dog work stock in the last week? (All or part of a day =1 day)	
How many days was this dog fed in the last week?	
How often is this dog fed:	

In heavy work:	☐ Daily	☐ Every other day	☐ Other (please specify)
In light work	☐ Daily	☐ Every other day	☐ Other (please specify)
On days off:	☐ Daily	☐ Every other day	☐ Other (please specify)

Is this dog fed any supplements?	Y / N	Specify:
Is this dog on any medication?	Y / N	Specify:
Does this dog have the option to scavenge?	Y / N	(always tied up when not working?)
Feed bowl (made of):		Water bowl (made of):
Water source (eg: spring, bore, tank water):		

SHELTER: (take representative photos)	☐ The same as other dog __________________(specify name)	
☐ Commercial or	☐ Homemade	
Run type:	☐ Cage ☐ Chain	☐ Other: ________________________
Run floor:	Elevated: Y / N	How high (approx)?
	☐ Wood ☐ Concrete	☐ Dirt ☐ Other:_________________
Box/Kennel:	What is floor made of?	
	What is cladding made of?	
	Elevated off the ground: Y / N	How high (approx)?
	Insulated: Y / N	Insulation material:

Does this dog have bedding in its kennel?	Y / N	Bedding material:	
Does this dog wear a coat?	Yes: ☐ at work	☐ at night	☐ No

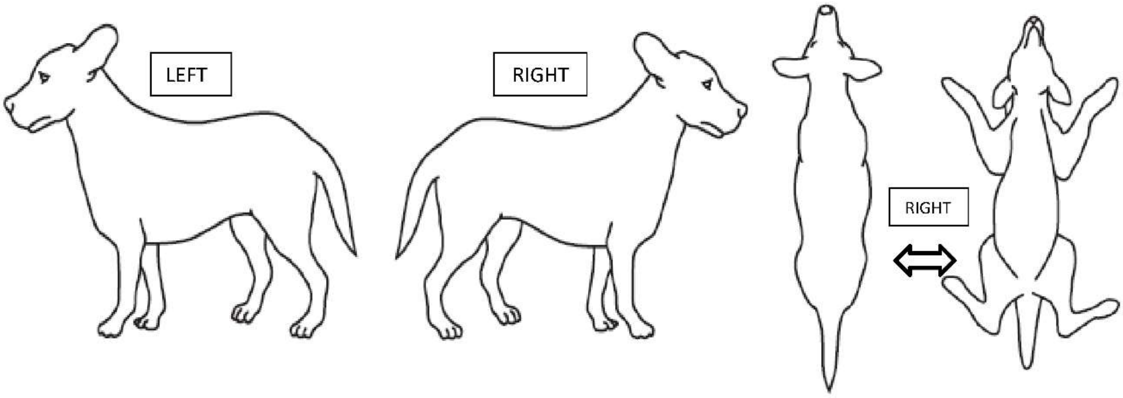
While transported:		☐ The same as other dog __________________(specify name)		
Truck	In cab / on deck	☐ Unrestrained	☐ Tethered	☐ Cage/kennel
Motorbike/Quad	Deck modified* Y / N	☐ Unrestrained	☐ Tethered	☐ Cage/kennel
Trailer	Deck modified* Y / N	☐ Unrestrained	☐ Tethered	☐ Cage/kennel

*modified specifically to reduce hazards which could cause injury to dogs

COSTS - Who pays for:		☐ The same as other dog __________________(specify name)
Vaccination:	☐ Dog owner	☐ Other Please specify:
Worming:	☐ Dog owner	☐ Other Please specify:
Food:	☐ Dog owner	☐ Other Please specify:
Vet bills*:	☐ Dog owner	☐ Other Please specify:

*treatment for illness or injury

PHYSICAL EXAM: Indicate abnormalities on diagrams and explain next page:



PHYSICAL EXAM	Normal	Abnormal		Normal	Abnormal
Skin/Coat	☐	☐	Respiratory	☐	☐
Pads/Nails	☐	☐	Genitourinary	☐	☐
Teeth	☐	☐	Lymph nodes	☐	☐
Ears	☐	☐	Musculoskeletal	☐	☐
Legs/Tail	☐	☐	Sound on trot up (over enough distance to assess if lame)	☐	☐
Cardiovascular	☐	☐	Joint ROM (carpus, elbow, shoulder, tarsus, stifle, hip, **tail**)	☐	☐

OCULAR EXAM – Penlight exam	Normal		Abnormal			Normal		Abnormal	
Menace reflex	L	R	L	R	Iris	L	R	L	R
Palpebral reflex	L	R	L	R	Lens	L	R	L	R
Eyelids (incl TEL)	L	R	L	R		L	R	L	R
Cornea	L	R	L	R		L	R	L	R

WT: kg	**BCS:** /9	**Muscle condition score: (WSAVA scale)** A B C D

Morphometric Measurements:

1. Head length – from level of medial canthus, equidistant between the eyes, to the external occipital protuberance.	cm	**2. Head circumference** - circumference at a point equidistant between the eyes and ears -the widest part of the head.	cm
3. Front leg – From the proximal edge of the central foot pad to the point of the elbow (olecranon process) with carpus in **extension**.	cm	**4. Hind leg** – From the proximal edge of the central foot pad to the tip of the hock (dorsal tip of the calcaneal process with the tarsus in **extension.**	cm
5. Body length - from the first thoracic vertebrae to the dorsal process of S1.	cm	**6. Thoracic girth** – chest circumference at the level of the xiphoid.	cm

Page **3** of **4**

Record details of abnormal findings below:

Describe any previous significant injury or illness that may affect this dog's working life:

SAMPLES TAKEN:
☐ Photos:

		_________ / ___________ /2014
Examiner Signature	Examiner Print name	Date

DOG INDUCTION
QUESTIONNAIRE Round 2

DATE: ______/______/2015

OWNER/HANDLER NAME:	DOG'S NAME:
PROPERTY NAME:	

BREED:	AGE TO CLOSEST YEAR:
GENDER: ☐ M ☐ F Spayed/Neutered Y / N	IF female: Number of litters ________
IF Spayed/Neutered - WHY?:	Number of mis-mating injections________ Has she ever had a vaginal prolapse Y / N

How often is this dog **vaccinated?**	☐ Only as a pup	☐ Sporadically	☐ Once a year	☐ Never	☐ Every_____ years(s)	☐ Don't know

TYPE OF WORK: (tick all that apply)	☐ Head ☐ Catch	☐ Hunt ☐ Back	☐ Yard ☐ Dog trial
IF dog competes at dog trials:	☐ Casual (social, local trials)	☐ Competitive (to accumulate qualification points)	
Land contours worked:	☐ Flat/easy hill	☐ Steep/hill country	
TYPE OF STOCK WORKED: (tick all that apply)	☐ Sheep ☐ Deer	☐ Dairy cattle ☐ Other (please specify)	☐ Beef cattle

WHERE ACQUIRED: ☐ Self bred	☐ Other breeder			
	IF NOT self bred, age acquired:			
	Level of training when acquired:	☐ Not started	☐ Started	☐ Fully trained
	Cost if purchased:			

Morphometric Measurements:			
1. Head length – from level of medial canthus, equidistant between the eyes, to the external occipital protuberance.	cm	**2. Head circumference** - circumference at a point equidistant between the eyes and ears -the widest part of the head.	cm
3. Front leg – From the proximal edge of the central foot pad to the point of the elbow (olecranon process) with carpus in **extension**.	cm	**4. Hind leg** – From the proximal edge of the central foot pad to the tip of the hock (dorsal tip of the calcaneal process with the tarsus in **extension**.	cm
5. Body length - from the first thoracic vertebrae to the dorsal process of S1.	cm	**6. Thoracic girth** – chest circumference at the level of the xiphoid.	cm

***Please attach to Round 2 questionnaire for this dog.**

Page **1** of **1**

TeamMate
The New Zealand working dog project

WORKING DOG QUESTIONNAIRE No.2

DATE: ______/______/2015

OWNER/HANDLER NAME:	**DOG'S NAME:**
PROPERTY NAME:	

Do you have any unregistered dogs at the moment?		
Is THIS dog insured? Y / N If yes, is it insured as: ☐ An individual OR ☐ Under general farm policy		
To what value?		
Male dogs:	Has he been used for mating in the last 6 months?	
	Did this mating result in a pregnancy?	
Female dogs:	Does she come into season regularly? Y / N	How often?
	Has she been in season in the last 6 months?	

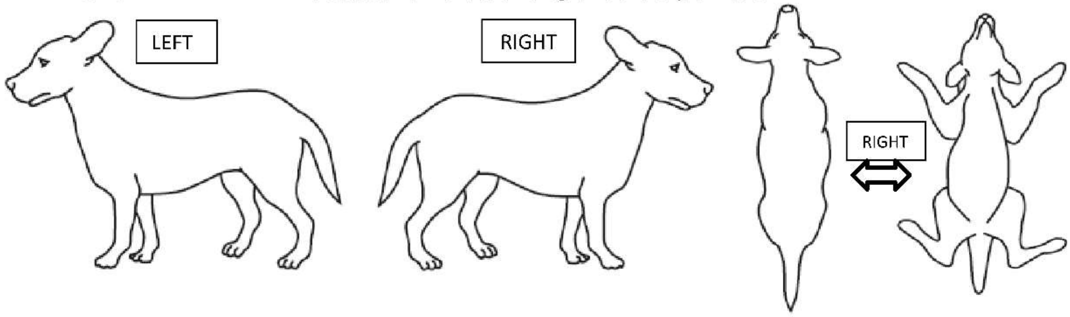
PARASITES:	☐ The same as other dog ________________(specify name)	
When was the last time you treated for sheep measles?		Which product?
When was the last time you treated for intestinal worms?		Which product?
Have you noticed fleas on your dogs in the last 6 months?		
Have you treated your dogs/kennels for fleas since the last exam?		
If so, which products:		

WORKLOAD: Has this dogs workload increased or decreased since the last TM exam?		
Has this dogs work INTENSITY increased or decreased since the last TM exam?		
How many days did this dog work stock in the last week? (All or part of a day = 1 day)		
What type of stock has this dog worked in the last 6 months?		
(tick all that apply) ☐ Sheep	☐ Dairy cattle	☐ Beef cattle
☐ Deer	☐ Other (please specify) ____________________	
WT: kg	**BCS:** / 9	**Muscle Condition score** A B C D
Coat Condition Score 1 2 3	**Coat Comments:**	

FEEDING:		☐ The same as other dog ________________(specify name)
What was this dog fed at its last meal?	☐ Meat – Specie(s)______________ ☐ Offal – Species________________	☐ Comm. dry brand(s)________________________ ☐ Comm. wet brand(s)______________________ ☐ Comm. other brand(s)_____________________
Is this dog fed any supplements?	Y / N Specify:	
Is this dog on any medication?	Y / N Specify:	

SHELTER: Has this dogs kennel/shelter arrangements changed in the last 6 months? Y / N	
Describe if necessary:	Coat? Y / N
Does this dog have bedding in its kennel at this time? Y / N Bedding material:	

PHYSICAL EXAM: Indicate abnormalities on diagrams and explain below:



PHYSICAL EXAM	Normal	Abnormal		Normal	Abnormal
Skin/Coat	☐	☐	Respiratory	☐	☐
Pads/Nails	☐	☐	Genitourinary	☐	☐
Teeth	☐	☐	Lymph nodes	☐	☐
Ears	☐	☐	Musculoskeletal	☐	☐
Eyes	☐	☐	Sound on trot up (over enough distance to assess if lame)	☐	☐
Cardiovascular	☐	☐	Joint ROM (carpus, elbow, shoulder, tarsus, stifle, hip, **tail**)	☐	☐

Record details of abnormal findings below:

Has this dog had any injury(ies) or illness(es) since the last TM exam?

Have any of these caused this dog to miss days it would normally work?

Detail:

		________ / __________ /2015
Examiner Signature	Examiner Print name	Date

TeamMate
The New Zealand working dog project

NEW DOG INDUCTION
QUESTIONNAIRE Round 3

DATE: ______/______/2015

OWNER/HANDLER NAME:	**DOG'S NAME:**
PROPERTY NAME:	

BREED:	COLOUR:	AGE TO CLOSEST YEAR:

GENDER: ☐ M ☐ F Spayed/Neutered Y / N	IF female: Number of litters __________
IF Spayed/Neutered - WHY?:	Number of mis-mating injections_______
	Has she ever had a vaginal prolapse Y / N

How often is this dog **vaccinated?**	☐ Only as a pup	☐ Sporadically	☐ Once a year	☐ Never	☐ Every_____ years(s)	☐ Don't know

TYPE OF WORK: (tick all that apply)	☐ Head ☐ Catch	☐ Hunt ☐ Back	☐ Yard ☐ Dog trial
If dog competes at dog trials:	☐ Casual (social, local trials)	☐ Competitive (to accumulate qualification points)	
Land contours worked:	☐ Flat/easy hill	☐ Steep/hill country	
TYPE OF STOCK WORKED: (tick all that apply)	☐ Sheep ☐ Deer	☐ Dairy cattle ☐ Other (please specify)	☐ Beef cattle

WHERE ACQUIRED: ☐ Self bred	☐ Other breeder			
	IF NOT self bred, age acquired:			
	Level of training when acquired:	☐ Not started	☐ Started	☐ Fully trained
	Cost if purchased/traded for:			

Morphometric Measurements:

1. Head length – from level of medial canthus, equidistant between the eyes, to the external occipital protuberance.	cm	**2. Head circumference** - circumference at a point equidistant between the eyes and ears -the widest part of the head.	cm
3. Front leg – From the proximal edge of the central foot pad to the point of the elbow (olecranon process) with carpus in **extension**.	cm	**4. Hind leg** – From the proximal edge of the central foot pad to the tip of the hock (dorsal tip of the calcaneal process with the tarsus in **extension.**	cm
5. Body length - from the first thoracic vertebrae to the dorsal process of S1.	cm	**6. Thoracic girth** – chest circumference at the level of the xiphoid.	cm

***Please attach to Round 2 questionnaire for this dog.**

WORKING DOG EXAM.3

TeamMate
The New Zealand working dog project

DATE: ______/______/2015

OWNER/HANDLER NAME:	**DOG'S NAME:**
PROPERTY NAME & ADDRESS:	
	ID no.

BREEDING:			
Male dogs:	Has he been used for mating in the last 6 months?		
	Did this mating result in a pregnancy?		
Female dogs:	Does she come into season regularly?	Y / N	How often?
	Has she been in season in the last 6 months?		What month approx?

PARASITES:	☐ The same as other dog ________________(specify name)
When was the last time you treated for sheep measles?	Which product?
When was the last time you treated for intestinal worms?	Which product?
Have you noticed fleas on your dogs in the last 6 months?	
Have you treated your dogs/kennels for fleas since the last exam?	
If so, which products:	

WORKLOAD:			
Has this dogs workload increased or decreased since the last TM exam?			
Has this dogs work INTENSITY increased or decreased since the last TM exam?			
How many days did this dog work stock in the last week? (All or part of a day = 1 day)			
What type of stock has this dog worked in the last 6 months?			
(tick all that apply)	☐ Sheep	☐ Dairy cattle	☐ Beef cattle
	☐ Deer	☐ Other (please specify) ____________________	

FEEDING:	☐ The same as other dog ________________(specify name)	
What was this dog fed at its last meal?	☐ Meat – Specie(s)______________	☐ Comm. dry brand(s)________________________
	☐ Offal – Specie(s)______________	☐ Comm. wet brand(s)______________________
		☐ Comm. other brand(s)_____________________

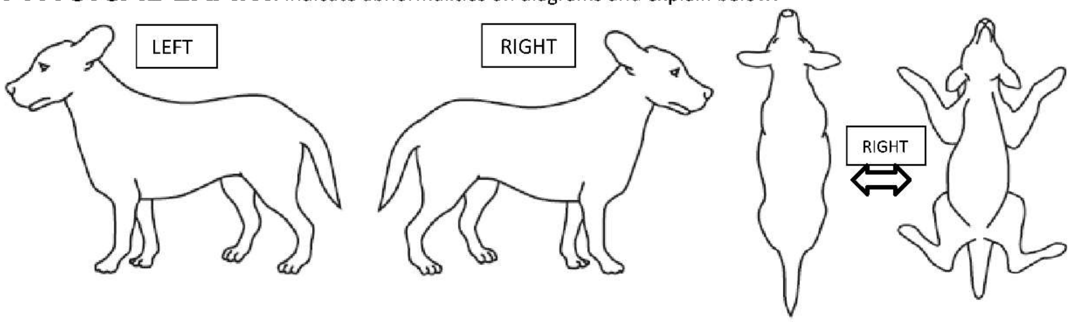
Is this dog fed any supplements?	Y / N	Specify:
Is this dog on any medication?	Y / N	Specify:

SHELTER: Has this dogs kennel/shelter arrangements changed in the last 6 months? Y / N			
Describe if necessary:	Height from ground:	☐ Motel/run	☐ Kennel/chain
Does this dog have bedding in its kennel at this time? Y / N	Bedding material:		
Does this dog wear a coat? Y / N			

WT: kg	**BCS:** / 9	**Muscle Condition score** A B C D
Coat Condition Score 1 2 3	**Coat Comments:**	

Page **1** of **2**

PHYSICAL EXAM: Indicate abnormalities on diagrams and explain below:



PHYSICAL EXAM	Normal	Abnormal		Normal	Abnormal
Skin/Coat	☐	☐	Respiratory	☐	☐
Pads/Nails	☐	☐	Genitourinary	☐	☐
Teeth	☐	☐	Lymph nodes	☐	☐
Ears	☐	☐	Musculoskeletal	☐	☐
Eyes	☐	☐	Sound on trot up (over enough distance to assess if lame)	☐	☐
Cardiovascular	☐	☐	Joint ROM (carpus, elbow, shoulder, tarsus, stifle, hip, tail)	☐	☐

Record details of abnormal findings below:

Has this dog had any injury(ies) or illness(es) since the last TM exam?

Have any of these caused this dog to miss days it would normally work?

Detail:

		_________ / __________ /2015
Examiner Signature	Examiner Print name	Date

Page **2** of **2**

TeamMate
The New Zealand working dog project

WORKING DOG EXAM. No.4

DATE: ______/______/2016

OWNER/HANDLER NAME:	**DOG'S NAME**:
PROPERTY NAME & ADDRESS:	
	ID no.

BREEDING:		
Male dogs:	Has he been used for mating in the last 6 months?	
	Did this mating result in a pregnancy?	
Female dogs:	Does she come into season regularly? Y / N	How often?
	Has she been in season in the last 6 months?	What month approx?

PARASITES:	☐ The same as other dog _________________(specify name)
When was the last time you treated for sheep measles?	Which product?
When was the last time you treated for intestinal worms?	Which product?
Have you noticed fleas on your dogs in the last 6 months?	
Have you treated your dogs/kennels for fleas since the last exam?	
If so, which products:	

WORKLOAD:

Has this dogs workload increased or decreased since the last TM exam?

Has this dogs work INTENSITY increased or decreased since the last TM exam?

How many days did this dog work stock in the last week? (All or part of a day = 1 day)

What type of stock has this dog worked in the last 6 months?

(tick all that apply) ☐ Sheep ☐ Dairy cattle ☐ Beef cattle
☐ Deer ☐ Other (please specify) ____________________

FEEDING:	☐ The same as other dog _________________(specify name)	
What was this dog fed at its last meal?	☐ Meat – Specie(s)______________	☐ Comm. dry brand(s)________________________
	☐ Offal – Specie(s)______________	☐ Comm. wet brand(s)________________________
		☐ Comm. other brand(s)______________________

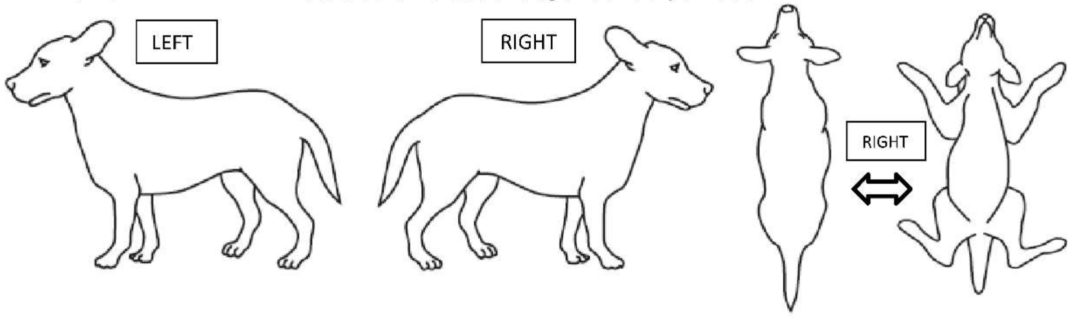
Is this dog fed any supplements?	Y / N	Specify:
Is this dog on any medication?	Y / N	Specify:

SHELTER: Has this dogs kennel/shelter arrangements changed in the last 6 months? Y / N

Describe if necessary:	Height from ground:	☐ Motel/run	☐ Kennel/chain
Does this dog have bedding in its kennel at this time? Y / N	Bedding material:		
Does this dog wear a coat? Y / N			

WT: **kg**	**BCS:** **/ 9**	**Muscle Condition score:** **A** **B** **C** **D**
Coat Condition Score **1** **2** **3**	**Coat Comments:**	

PHYSICAL EXAM: Indicate abnormalities on diagrams and explain below:



PHYSICAL EXAM:	Normal	Abnormal		Normal	Abnormal
Skin/Coat	☐	☐	Respiratory	☐	☐
Pads/Nails	☐	☐	Genitourinary	☐	☐
Teeth	☐	☐	Lymph nodes	☐	☐
Ears	☐	☐	Musculoskeletal	☐	☐
Eyes	☐	☐	Sound on trot up (over enough distance to assess if lame)	☐	☐
Cardiovascular	☐	☐	Joint ROM (carpus, elbow, shoulder, tarsus, stifle, hip, tail)	☐	☐

Record details of abnormal findings below:

Has this dog had any injury(ies) or illness(es) since the last TM exam?

Have any of these caused this dog to miss days it would normally work?

Detail:

Examiner Signature	Examiner Print name	Date
		________ / __________ /2016

WORKING DOG EXAM. No.5

TeamMate
The New Zealand working dog project

DATE: ______/______/2017

OWNER/HANDLER NAME:	**DOG'S NAME**:
PROPERTY NAME & ADDRESS:	
	Heyrex monitor:

BREEDING:			
Male dogs:	Has he been used for mating in the last 6 months?		
	Did this mating result in a pregnancy?		
Female dogs:	Does she come into season regularly?	Y / N	How often?
	Has she been in season in the last 6 months?		What month approx?

PARASITES:	☐ The same as other dog ________________(specify name)
When was the last time you treated for sheep measles?	Which product?
When was the last time you treated for intestinal worms?	Which product?
Have you noticed fleas on your dogs in the last 6 months?	
Have you treated your dogs/kennels for fleas since the last exam?	
If so, which products:	

WORKLOAD:			
Has this dogs workload increased or decreased since the last TM exam?			
Has this dogs work INTENSITY increased or decreased since the last TM exam?			
How many days did this dog work stock in the last week? (All or part of a day = 1 day)			
What type of stock has this dog worked in the last 6 months?			
(tick all that apply)	☐ Sheep	☐ Dairy cattle	☐ Beef cattle
	☐ Deer	☐ Other (please specify) ___________________	

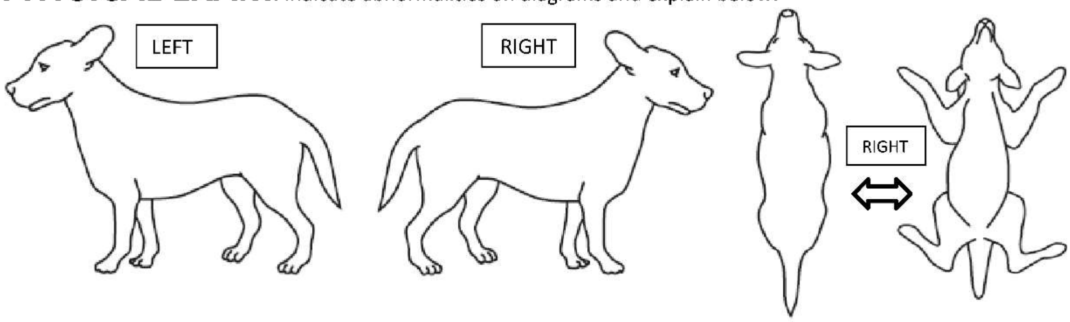
FEEDING:	☐ The same as other dog ________________(specify name)	
What was this dog fed at its last meal?	☐ Meat – Specie(s)_____________	☐ Comm. dry brand(s)______________________
	☐ Offal – Specie(s)_____________	☐ Comm. wet brand(s)______________________
		☐ Comm. other brand(s)____________________

Is this dog fed any supplements?	Y / N	Specify:
Is this dog on any medication?	Y / N	Specify:

SHELTER: Has this dogs kennel/shelter arrangements changed in the last 6 months? Y / N			
Describe if necessary:	Height from ground:	☐ Motel/run	☐ Kennel/chain
Does this dog have bedding in its kennel at this time? Y / N	Bedding material:		
Does this dog wear a coat? Y / N			

WT: kg	**BCS:** / 9	**Muscle Condition score:** **A B C D**
Coat Condition Score **1 2 3**	**Coat Comments:**	

PHYSICAL EXAM: Indicate abnormalities on diagrams and explain below:



PHYSICAL EXAM:	Normal	Abnormal		Normal	Abnormal
Skin/Coat	☐	☐	Respiratory	☐	☐
Pads/Nails	☐	☐	Genitourinary	☐	☐
Teeth	☐	☐	Lymph nodes	☐	☐
Ears	☐	☐	Musculoskeletal	☐	☐
Eyes	☐	☐	Sound on trot up (over enough distance to assess if lame)	☐	☐
Cardiovascular	☐	☐	Joint ROM (carpus, elbow, shoulder, tarsus, stifle, hip, tail)	☐	☐

Record details of abnormal findings below:

Has this dog had any injury(ies) or illness(es) since the last TM exam?

Have any of these caused this dog to miss days it would normally work?

Detail:

Examiner Signature	Examiner Print name	Date
		________ / __________ /2017

OWNER/HANDLER INFORMATION

DATE: ______/______/_______

OWNER/HANDLER NAME:	ID no.
PROPERTY NAME:	
ADDRESS:	
Email Address:	

OWNER/HANDLER:			
Age to closest year:	☐ <20 years	☐ 41-50 years	☐ > 70 years
	☐ 21 - 30 years	☐ 51-60 years	
	☐ 31 - 40 years	☐ 61-70 years	
Gender:	☐ Male	☐ Female	
Job title: (Tick all that apply)	☐ Owner	☐ Manager	☐ Employee
How many years experience do you have working dogs?			
Have you attended any formal dog training courses?		☐ Yes	☐ No
Do you breed working dogs?		☐ Yes	☐ No
How many litters of pups have you bred in the last year?			
Which breed(s)?			
PROPERTY:	Property size in hectares:		
	Contour of farmed land: *Tick all that apply	☐ Flat/Easy hill	☐ Steep/Hill country
Stock numbers:	Sheep:		
	Cattle Beef:	Dairy dry stock:	Dairy milking:
	Deer:		
	Other (please specify):		

Types of foods fed over the last 6 months:			
Meat? Y / N	Specie(s):	☐ Home sourced	☐ Purchased
		☐ Fresh	☐ Frozen
Offal? Y / N	Specie(s):	☐ Fresh	☐ Cooked
Commercial dog	☐ Commercial dry	Brand(s):	
Food? Y / N	☐ Commercial wet	Brand(s):	
	☐ Commercial other	Brand(s):	

List of all dogs over the age of **2 months** owned by you at the property at each visit (not just the dogs in the study):

	Name	Breed	Age	Colour
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Litters of un-weaned pups:

	Bitch's name	Breed of pups	Number of pups in litter	Approx age
1				
2				
3				
4				
5				

OWNER/HANDLER EXAM 2

DATE: ______/______/_2015

OWNER/HANDLER NAME:	ID no.

Have you or are you planning to mate any bitches this season?			
Have you had any litters of pups this year?			
Which breed(s)?			
PROPERTY:	Property size in hectares:		
☐ UNCHANGED	Contour of <u>farmed</u> land: *Tick all that apply	☐ Flat/Easy hill	☐ Steep/Hill country
Stock numbers:	Sheep:		
	Cattle Beef:	Dairy dry stock:	Dairy milking:
☐ **UNCHANGED**	Deer:		
	Other (please specify)		

Types of foods fed over the last 6 months:			
Meat? Y / N	Specie(s):	☐ Home sourced	☐ Purchased
		☐ Fresh	☐ Frozen
Offal? Y / N	Specie(s):	☐ Fresh	☐ Cooked
Commercial dog	☐ Commercial dry	Brand(s):	
Food? Y / N	☐ Commercial wet	Brand(s):	
	☐ Commercial other	Brand(s):	

List of all dogs over the age of 2 months owned by you at the property at each visit (not just the dogs in the study):

	Name	Breed	Age	Colour
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
Litters of unweaned pups:				
	Bitch's name	**Breed of pups**	**Number of pups in litter**	**Approx age**
1				
2				

Continued from previous page if necessary:

	Name	Breed	Age	Colour
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Litters of unweaned pups:

	Bitch's name	Breed of pups	Number of pups in litter	Approx age
1				
2				

NEW OWNER/HANDLER/PROPERTY INDUCTION QUESTIONNAIRE ROUND 3

DATE: ______/______/_______

OWNER/HANDLER NAME:	ID no.
PROPERTY NAME:	
ADDRESS:	
Email address:	

OWNER/HANDLER:			
Age to closest year:	☐ <20 years	☐ 41-50 years	☐ > 70 years
	☐ 21 - 30 years	☐ 51-60 years	
	☐ 31 - 40 years	☐ 61-70 years	
Gender:	☐ Male	☐ Female	
Job title: (Tick all that apply)	☐ Owner	☐ Manager	☐ Employee
How many years experience do you have working dogs?			
Have you attended any formal training courses?		☐ Yes	☐ No
Do you breed working dogs?		☐ Yes	☐ No
How many litters of pups have you bred in the last year?			
Which breed(s)?			

PROPERTY:	Property size in hectares:		
	Contour of farmed land: *Tick all that apply	☐ Flat/Easy hill	☐ Steep/Hill country
Stock numbers:	Sheep:		
	Cattle Beef:	Dairy dry stock:	Dairy milking:
	Deer:		
	Other (please specify)		

Types of foods fed over the last 6 months:			
Meat? Y / N	Specie(s):	☐ Home sourced	☐ Purchased
		☐ Fresh	☐ Frozen
Offal? Y / N	Specie(s):	☐ Fresh	☐ Cooked
	☐ Commercial dry	Brand(s):	
	☐ Commercial wet	Brand(s):	
	☐ Commercial other	Brand(s):	

OWNER/HANDLER/PROPERTY EXAM.3

DATE: _____/_____/2015

OWNER/HANDLER NAME:	ID no.
PROPERTY NAME AND ADDRESS:	

PROPERTY:	Property size in hectares:		
☐ UNCHANGED	Contour of farmed land:		
	*tick all that apply	☐ flat/easy hill	☐ steep/hill country
STOCK NUMBERS:	Sheep:		
☐ UNCHANGED	Cattle beef:	Dairy drystock:	Dairy milking:
	Deer:		
	Other (please specify):		

TYPES OF FOODS FED OVER THE LAST SIX MONTHS:					
Meat?	Y / N	Specie(s):		☐ Home sourced	☐ Purchased
				☐ Fresh	☐ Frozen
Offal?	Y / N	Specie(s):		☐ Fresh	☐ Cooked
Commercial dog food?	Y / N	☐ Commercial dry	Brand(s):		
		☐ Commercial wet	Brand(s):		
		☐ Commercial other	Brand(s):		

Notes:

List all dogs over the age of 2 months owned by you at the property at each visit (not just the dogs in the study):

	Name	Breed HW/HD/BE/HY/KP	Gender M/F	Neutered Y/N	If dog is neutered – why?	Age	Colour	Insured Y/N	Value of insurance	Registered Y/N	Deceased/sold/given away OR OTHER	If deceased/sold/given away – how or why? Or if present but not examined – why?
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												

BREED: HW – Huntaway : HD – heading dog : BE – Beardie : HY – Handy : KP – Kelpie

Any litters of un-weaned pups:

	Bitch's name	Breed of pups	Number of pups in litter	Approx. age
1				
2				
3				

OWNER/HANDLER/PROPERTY **EXAM.4**

TeamMate – The New Zealand working dog project

DATE: _____/_____/2016

OWNER/HANDLER NAME:	ID no.
PROPERTY NAME AND ADDRESS:	

PROPERTY:	Property size in hectares:		
☐ UNCHANGED	Contour of farmed land:		
	*tick all that apply	☐ flat/easy hill	☐ steep/hill country
STOCK NUMBERS:	Sheep:		
☐ UNCHANGED	Beef cattle:	Dairy drystock:	Dairy milking:
	Deer:		
	Other (please specify):		

TYPES OF FOODS FED OVER THE LAST SIX MONTHS:					
Meat?	Y / N	Specie(s):		☐ Home sourced	☐ Purchased
				☐ Fresh	☐ Frozen
Offal?	Y / N	Specie(s):		☐ Fresh	☐ Cooked
Commercial dog food?	Y / N	☐ Commercial dry	Brand(s):		
		☐ Commercial wet	Brand(s):		
		☐ Commercial other	Brand(s):		

Notes:

List **ALL DOGS** over the age of 2 months owned by you at the property at each visit (not just the dogs in the study):

	Name	Breed HW/HD/BE/HY/KP	Gender M/F	Neutered Y/N	If dog is neutered – why?	Age	Colour	Insured Y/N	Value of insurance	Registered Y/N	Deceased/sold/ given away OR OTHER	If deceased/sold/ given away – how or why? Or if present but not examined – why?
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												

BREED: HW – Huntaway : HD – heading dog : BE – Beardie : HY – Handy : KP – Kelpie

Any litters of un-weaned pups:

	Bitch's name	Breed of pups	Number of pups in litter	Approx. age
1				
2				

OWNER/HANDLER/PROPERTY EXAM.5

DATE: _____/_____/2017

OWNER/HANDLER NAME:	ID no.
PROPERTY NAME AND ADDRESS:	
EMAIL ADDRESS: *(So we can send TeamMate farmers information regarding their dogs)*	

PROPERTY:	Property size in hectares:		
☐ UNCHANGED	Contour of farmed land:		
	*tick all that apply	☐ flat/easy hill	☐ steep/hill country
STOCK NUMBERS:	Sheep:		
☐ UNCHANGED	Beef cattle:	Dairy drystock:	Dairy milking:
	Deer:		
	Other (please specify):		

TYPES OF FOODS FED OVER THE LAST SIX MONTHS:				
Meat?	Y / N	Specie(s):	☐ Home sourced	☐ Purchased
			☐ Fresh	☐ Frozen
Offal?	Y / N	Specie(s):	☐ Fresh	☐ Cooked
Commercial dog food?	Y / N	☐ Commercial dry	Brand(s):	
		☐ Commercial wet	Brand(s):	
		☐ Commercial other	Brand(s):	

Notes:

List **ALL DOGS** over the age of 2 months owned by you at the property at each visit (not just the dogs in the study):

	Name	Breed HW/HD/BE/HY/KP	Gender M/F	Neutered Y/N	If dog is neutered – why?	Age	Colour	Insured Y/N	Value of insurance	Registered Y/N	Deceased/sold/given away OR OTHER	If deceased/sold/given away – how or why? Or if present but not examined – why?
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												

BREED: HW – Huntaway : HD – heading dog : BE – Beardie : HY – Handy : KP – Kelpie

Any litters of un-weaned pups:

	Bitch's name	Breed of pups	Number of pups in litter	Approx. age
1				
2				

Appendix 2: Overview of data gathered at each data collection round during TeamMate

Supplementary table 1: Types of data gathered about farming properties, working farm dog owners and working farm dogs enrolled in TeamMate. 'Enrolment only' refers to data that was collected on the enrolment of farms, owners or dogs, but not on follow-up. Due to changes in questionnaire design between the first, second and subsequent rounds of farm visits these are shown separately.

	Time of data collection			
		Data collection round		
Level and type of information recorded	Enrolment only	First	Second	Third and later
General				
Date of visit		x	x	x
Property				
Property name and address	x			
Property size		x	x	x
Stock types and numbers		x	x	x
Dog owner				
Name and contact information	x			
Age, gender, job description	x			
Experience and training	x			
Dog feeding practices		x	x	x
Dog breeding practices		x	x	
Current un–weaned litters		x	x	x
Presence of unregistered dogs on farm			x	
Dogs				
Age, sex, signalment		x	x	x
Fate of dog (if no longer on farm)			x	x
Breeding history (female)	x			
Vaccination history	x			
Neuter status and reason for neutering		x	x	x
Council registration		x		x
Insurance coverage		x	x	x
Type of insurance			x	
Value of insurance			x	x

Supplementary table 1: Cont.

Level and type of information recorded	Time of data collection: Enrolment only	Data collection round: First	Second	Third
Work type, terrain, stock types	x			
Dog source, training level and cost	x			
Body size measurements	x			
Kennel type and elevation		x	x	x
Kennel insulation and building materials		x		
Bedding and coat use		x	x	x
Dog transportation		x		
Employer contributions to dog food, vaccinations and veterinary treatments		x		
Parasite treatments		x	x	x
Parasite treatments source		x		
Recent workload		x	x	x
Meal frequency		x		
Most recent meal composition		x	x	x
Medication or supplements given		x	x	x
Body weight and condition score		x	x	x
Recent breeding performance (males)		x	x	x
Recent oestrus cycle (females)		x	x	x
Medical history		x	x	x
Clinical examination		x	x	x

Appendix 3: Alphanumeric system used to code clinical abnormalities

Body system	Location 1 ABCFHIJKO	Location 2 H	Symmetry ABFHIJK	Descriptor ABEFHJ	Cause HJ	Notes
(A) Oropharyngeal	1. Front teeth (I + C) 2. Back teeth (P + M) 3. Front & Back 4. Soft tissue 5. Bone		1. Single 2. Multiple	0. Other 1. Fracture/Laceration 2. Wear 3. Gingivitis / Tartar 4. Discoloration 5. Infection 6. Missing 7. Cavity 8. Malocclusion teeth 9. Malocclusion jaw 10. Mass		
(B) Ocular	1. Lids 2. Lens 3. Cornea 4. Conjunctiva 5. Iris 6. Whole eye		1. Unilateral 2. Bilateral	0. Other 1. Meibomian gland 2. Cataract 3. Opacity 4. Scar 5. Ulcer 6. Infection 7. Blind / reduced vision 8. Missing 9. Discharge 10. Inflammation		In analysis: Merge cataract/opacity
(C) Cardiovascular				1. Murmur 2. Arrhythmia 3. Other		
(D) Respiratory						
(E) Gastrointestinal				1. Anal gland 2. Constipation 3. Other		
(F) Reproductive	1. Mammary 2. Testes 3. Uterus/vagina/vulva 4. Prostate		1. Single 2. Multiple	1. Mammary tumour 2. Mammary hyperplasia 3. Cryptorchid 4. Unequal size 5. Thickened epididymis 6. In heat 7. Other 8. Pregnant 9. Lactating 10. Enlarged		
(G) Urinary						
(H) Musculoskeletal	1. Front Limb 2. Hind Limb 3. Spine 4. Tail 5. Head	0. Skull 1. Shoulder 2. Elbow 3. Carpus 4. Hip 5. Stifle 6. Tarsus 7. Digits 8. Metatarsals/-carpals 9. Spine 10. Tail 11. Ribs	1. Unilateral 2. Bilateral 3. General	0. Other 1. Crepitus 2. Range of motion 3. Swelling - Hard 4. Swelling - Soft 5. Dew Claw - Bony 6. Dew Claw - Soft tissue 7. Amputated 8. Painful 9. Angular deformity 10. Muscle wastage/damage	0. Unknown 1. Dog bite 2. Trauma 3. Congenital 4. Other	In analysis: Merge Location1-Tail with Location1-Spine Indicators for dew claws not used
(I) Lameness	1. Front limb 2. Hind limb 3. Both front and back		1. Left 2. Right 3. Bilateral			
(J) Skin	1. Legs 2. Trunk 3. Face 4. Ear 5. Pad 6. Nail 7. Tail 8. Neck		1. Unilateral 2. Bilateral 3. General 4. Abdomen	1. Callous / hygroma 2. Alopecia 3. Mass 4. Infection 5. Scar 6. Laceration 7. Inflammation 8. Missing 9. Itchy 10. Poor coat	0. Unknown 1. Dog bite 2. Trauma 3. Other	
(K) Lymph nodes	1. Mandibular 2. Prescapular 3. Popliteal 4. Inguinal		1. Unilateral 2. Bilateral			
(L) Nervous						
(M) Endocrine						
(N) Miscellaneous						
(O) Hernia	1. Umbilical 2. Inguinal 3. Other					

Appendix 4: Principal component analysis

Background and methods

Each principal component has a set of coefficients, which correspond to the input variables (Joliffe and Morgan, 1992). The coefficients can be used in two ways. First, they are used to interpret which aspects of the data each principal component is associated with and secondly, they are used to calculate principal component scores. Coefficients can be any number between -1 and 1 and their value represent how each input variable contributes to the principal component score. A score of zero indicates no contribution and a score of one indicates 100% contribution. The signs of the coefficients indicate the direction of the contribution. Principal component scores for individuals are calculated by multiplying the coefficients of the component with the centred, standardised input values of each individual and summing the products.

In the current study the aim of carrying out PCA was to generate scores that represent overall skeletal size rather than to explore all aspects of the data. Previous studies that used PCA to explore morphometric measurements in dogs have found that the first principal component represented skeletal size. As mentioned above, skeletal size scores were calculated by taking the first principal component (after transformation to ensure that the smallest dogs had the lowest scores) and adding a value of six. Six was added to ensure that skeletal size scores could be used with the equation developed by Leung et al. (Leung et al., 2018) to calculate predicted lean body mass. Summary statistics of skeletal size scores in Heading dogs and Huntaways are presented.

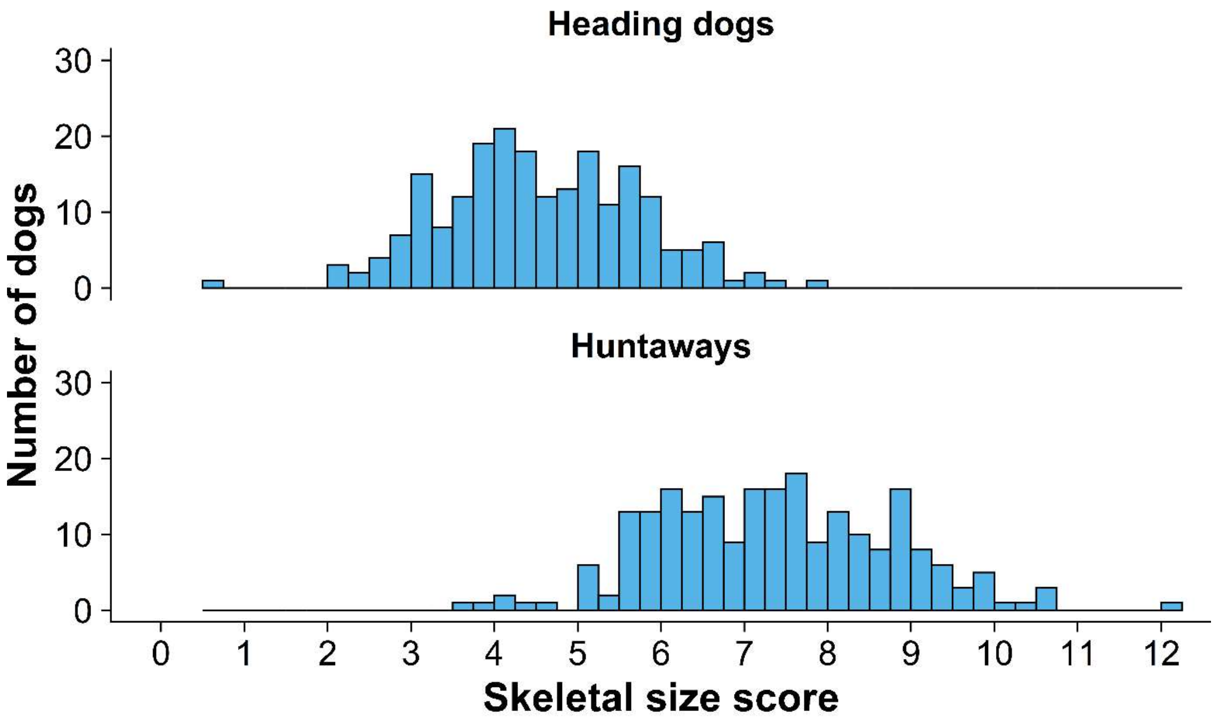
Results and interpretation

Four hundred fifty-six Heading dogs and Huntaways had plausible observations for all morphometric measurements. Supplementary table 2 lists the percentage of explained variance and the coefficients of the first four principal components (PC1 to PC4). The four principal components account for 91.6% of the variance in the morphometric data. The PC1 coefficients are all positively correlated and relatively similar in value, indicating intercorrelation between all of the measurements and suggesting that this component represents an overall measure of skeletal size. PC2 appears to differentiate front leg and body length from head length and to some degree head circumference and thoracic girth. In PC3 head length contributes the most strongly, and in the opposite direction to thoracic girth and head circumference, suggesting the component differentiates between head length and overall skeletal width. In PC4 hind leg length and body length contribute most strongly and the component seems to differentiate between leg length and body length and to some degree thoracic girth. These results are similar to those found in previous studies which used PCA to analyse skeletal morphometrics in dogs (Chase et al., 2002; Leung et al., 2018; Sutter et al., 2008). All these studies found that PC1 represented overall skeletal size, while the remaining principal components represented different aspects of skeletal shape. Based on this agreement between our results and previous studies, we are satisfied that using PC1 as the basis for a skeletal size score is appropriate.

Supplementary table 2: Coefficients of the first and second components generated from a principal components analysis of morphological measurements in working farm dogs. The first component is interpreted to represent the overall skeletal size of the dog. The second component could be interpreted to represent a length (vs width) variable of skeletal shape.

	Principal components			
	First	Second	Third	Fourth
Variance explained (%)	61.0	14.5	8.5	7.7
Measurement				
Head length	-0.36	0.48	0.79	-0.02
Head circumference	-0.45	0.29	-0.32	0.13
Front leg	-0.39	-0.55	0.06	-0.39
Hind leg	-0.44	0.00	-0.14	-0.61
Body length	-0.37	-0.56	0.24	0.59
Thoracic girth	-0.44	0.26	-0.44	0.33

Skeletal size scores were calculated for 456 dogs. The mean skeletal size was 6.0 (SD = 4.1 – 7.9, range = 0.6 – 12.0). Heading dogs (n = 213) had a mean skeletal size of 4.6 (SD = 3.4 – 5.8, range = 0.6 – 7.8) and Huntaways (n = 227) had a mean of 7.4 (SD = 6.0 – 8.8, range = 3.7 – 12.0). The distribution of skeletal sizes in the population is illustrated in Error! Reference source not found.. One dog had a skeletal size of lower than one (skeletal size = 0.6). This dog was excluded from further analysis that included the skeletal size.


Heading dogs
Huntaways
Number of dogs
0
10
20
30
0
10
20
30
0
1
2
3
4
5
6
7
8
9
10
11
12
Skeletal size score