Assessing current feeding practices of farmers and energy requirements of working farm dogs in New Zealand

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Ishwani Singh

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ABSTRACT

Working farm dogs in New Zealand (NZ) where studied in this thesis, and were found to usually be fed once a day on a diet consisting of 50% TUX Energy biscuits and 50% homekill (50:50). Diet composition does not change between peak and off-peak work periods. Instead the amount fed changes, with dogs fed more during peak periods. The digestibility of the average diet of the working dog is high and working farm dogs fed 50:50 or 100% homekill meets all energy and minimum nutrient requirements, including essential amino acids, calcium and phosphorus as set by the Association of American Feed Control Officials (AAFCO). The calcium: phosphorus ratios were high in both diets (1.85:1 in 100% homekill and 1.93:1 in 50:50). However, these minimum requirements are defined for the household pet dog and may not fulfil the requirements of working farm dogs.

Actical® activity monitors were calibrated with doubly labelled water to estimate activity associated energy expenditure in the dog. A constraint of this study of the weight range and number of dogs used and may only be useful for dogs weighing between 18 and 26 kg. However, when using activity monitors, the basal metabolic rate (BMR) has to be estimated.

The mean energy requirements for Heading dogs and Huntaways were different between peak and off-peak periods, with dogs requiring more energy from their diets during peak periods. Global positioning systems were used to measure the distances covered by farm dogs in this study (10 ± 0.7 km/d during off-peak periods and 20 ± 1.3 km/d during peak periods), with these results similar to distances that sled dogs cover while training (Grandjean and Paragon, 1993a), and they are also similar to data obtained from Australian cattle dogs.

Currently there are no nutritional guidelines which state the requirements of a working dog, and the findings from this work show that the farm dogs in NZ may not be receiving the energy required for work from their current diet.

ABBREVIATIONS

AAFCO	Association of American Feed Control Officials
Ach	Acetylcholine
ADP	Adenosine diphosphate
AEE	Activity associated energy expenditure
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
BCS	Body condition score
BMR	Basal metabolic rate
BW	Bodyweight
C	Carbon
Ca^{2+}	Calcium ion
cFQ	Corrected food quotient
CO_2	Carbon dioxide
d	Day(s)
DE	Digestible Energy
dGPS	Differential Geographic Positioning System
DLW	Doubly-labelled water
DM	Dry matter
DNA	Deoxyribonucleic acid
EE	Energy expenditure
EGNOS	European Geostationary Navigation Overlay System
FMCP	Fragmentation of the medial coronoid process
FFA	Free fatty acids
FQ	Food quotient
G	Generalisability
g	Gram(s)
g	Gravity force
GPS	Geographic Positioning Systems
^1H	Hydrogen
^2H	Deuterium
^3H	Tritium
h	Hour(s)
H_2O	Water

ha	Hectare
HAD	3-hydroxyacyl CoA Dehydrogenase
HB	Hawke’s Bay
Hz	Hertz
IQR	Inter-quartile range
IRMS	Isotope-Ratio Mass Spectrometry
IU	International Unit
Kcal	Kilocalorie(s)
k_d	Flux rate of deuterium
Kg	Kilogram(s)
KJ	Kilojoule(s)
k_o	Flux rate of oxygen
l	Litre(s)
LNI	Lower North Island
LQ	Lower quartile
m	Metre(s)
ME	Metabolisable Energy
min	Minute(s)
MJ	Mega joule(s)
ml	Millilitre(s)
mm	Millimetre(s)
N	Dilution space
n	Number
N_d	Dilution space of deuterium
NMR	Nuclear Magnetic Resonance
N_o	Dilution space of oxygen
NRC	National Research Council
NZ	New Zealand
NZSDTA	New Zealand Sheep Dog Trialists Association
O_2	Oxygen
^{18}O	Heavy oxygen
PTT	Platform Transmitter Terminals
rCO_2	Rate of CO_2 produced
RQ	Respiratory quotient

$R_{dilspace}$	Average dilution space ratio
s	Second(s)
SEE	Standard error of the estimate
SEM	Standard error of the mean
SIRIS	Stable Isotope Ration Infrared Spectrometry
sx	Surgical treatment
T4	Thyroid hormone
TEE	Total energy expenditure
TCA	Tricarboxylic acid cycle
UQ	Upper quartile
Vet	Veterinarian
VO_2	Oxygen consumption
WAAS	Wide Angle Augmentation System

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CHAPTER ONE:

A review of the literature: Working dog exercise physiology and nutrition

1.1 Introduction

New Zealand (NZ) farmers rely heavily on both the Heading and the Huntaway breeds of dog to help maintain livestock on their farms. MacGregor-Redwood (1980) summed up the importance of sheep dogs to NZ stating “Without the dog’s able assistance the shepherd would be unable to control the flock, but the sheep dog is unaware of the fact that the economy of NZ rests on it four paws”. Although technology has improved, such as the advent and popularity of the quad bike, the working dog is still vitally important in helping the farmer control stock. Given the obvious reliance of the farmer on these working dogs, it is therefore imperative that these animals receive proper nutrition to ensure optimal performance and longevity. Working/performance dogs have different nutritional needs to those of companion animals, expending, and therefore requiring, more energy and nutrients than companion animals. Working or performance dogs include not only farm dogs, but hunting, racing and assistance dogs (e.g. guide dogs). Optimal nutrition enables dogs to work to their full genetic potential, efficiently repair wounds and resist disease and even delay the effects of aging. There is a lack of research on working dogs on NZ farms, which means that working farm dogs in NZ may not be getting optimal nutrition to perform the workload expected of them. Nutritionists are currently unaware of the exact energy requirements of working dogs and, therefore, how much energy their diet should supply (Kronfeld *et al.,* 1994).

A working muscle needs energy in order to remain functional, and this energy can originate from either carbohydrates, fat or less commonly protein, which are all used to generate adenosine-triphosphate (ATP). These nutrients/fuel sources are obtained from the diet of the animal. Nutritionists need to assess the nutritional requirements of the working dog, and understand how the muscle works, because a working muscle needs more fuel than an inactive muscle. The type of work can determine what sort of fuel the muscle will require. Short sprints rely heavily on glycogen as a muscle energy source, whereas heavy long runs require free fatty acids to maintain muscle activity.

An important measure in nutritional studies is digestibility, which is the amount of nutrients that the animal is digesting from its diet, and is calculated from the difference in the amount of nutrients in the diet, and the amount remaining in the faeces or digesta (Maskell and Johnson, 1993). Digestibility trials help determine how digestible the diet is. The digestibility of a diet can be measured by a variety of methods, such as the total faecal collection method, the ileal collection method, (including cannulation methods), and euthanasia protocols. The most common and least invasive method is the total faecal collection method. The limitation to this method is that apparent digestibility is measured and not true digestibility. Apparent digestibility does not take into account endogenous losses and nutrient manipulation/fermentation by microbes in the colon. Endogenous losses include protein loss from digestive enzymes and cells sloughed off from the gut lining. Endogenous proteins are lost in the faeces, and this leads to an underestimation of protein digestibility.

To be able to work out the dietary concentrations needed in a working dog diet, researchers need to work out how much energy the dog is using, or the energy expenditure of the dog. Energy expenditure can be broken down into resting or basal metabolic rate (BMR), which is the amount of energy an organism needs to maintain vital functions at rest, including breathing, maintaining body heat and heart rate etc., and total energy expenditure, which includes BMR, as well as extra functions, such as, digestion of food, walking, running and other normal movements that require energy. The amount of energy an animal will use in a day can be measured by a variety of methods; the two main ways of measuring energy expenditure are direct calorimetry (using heat chambers) and indirect calorimetry (using respiratory chambers, food intake-mass balance, heart rate monitors, pedometers, accelerometers, global positioning systems and isotopic washout methods). Once the energy requirements of the dogs are met, then other macro-nutrients requirements can be determined, these include, fat, protein and carbohydrate requirements.

1.2 The NZ working farm dog

Dogs appear to have been associated with humans from as early as the Middle Pleistocene period (Clutton-Brock, 1995). This association spans a period longer than human domestication of cows, horses or goats, and during this time dogs have adapted to their role as companion animals (Pennisi, 2002). Hunters occasionally killed wolves and used the fur for clothing, and every so often submissive wolf pups may have been adopted into a human family. The adopted wolves matured and mated with other submissive wolves and became the precursors to the domestic dog. In time, these domesticated dogs would assist in hunting by tracking down prey, and bringing down wounded animals (Clutton-Brock, 1995). There are five main theories regarding why the dog may have been domesticated: domestication for food, as guards, for hunting, via commensalism and as pets.

Regardless of why wild canids were domesticated, the domesticated dog provides unconditional acceptance, no matter the success or appearance of the owner (Hart, 1995). Owning a dog has been shown to enhance the psychological and physiological well-being of people (Beck and Meyers, 1996). Dogs not only provide companionship, but the working dog eases some of the daily burdens of human life, for example, guide dogs for the blind, police dogs, rescue dogs and farm dogs.

The bond between a farmer and their working dog is important. The working dog performs the tasks given to it, and is a reflection of its devotion to the farmer rather than anything else (Greig, 1953). Due to the pack mentality of dogs, the farmer is the leader of the pack, and therefore the dog wants to please its leader. This relationship is crucial in establishing a working bond (Dalton, 1996). Working dogs have been specifically bred to have stock handling skills, loyalty, hardness and courage (Oliver and Shield, 2004).

The Border collie is a breed as old as the sheep industry in Great Britain, and arrived in NZ during the late 1840s. The historic characteristic ‘strong eye’ is an objective term, referencing the fact that these dogs work by crawling along while stalking and staring down livestock. This feature seems to be one that has been selected for in NZ. The Heading dog in NZ is a descendant of the Border collie. There is little documentation regarding the history of the Heading dog, although it has been established that the strong eye was a characteristic of Collies from about the 1790s (MacGregor-Redwood, 1980). Heading dogs are long legged and fast; they work in close quarters to the sheep and need to have quick reactions, in case a sheep breaks out from the flock. Heading dogs are usually black and white, but there are other strains which are black and tan, red/amber with or without white (Dalton, 2010).

The Huntaway is a breed unique to NZ, and is specially bred to suit the conditions of NZ farms, that are usually covered with bush and scrub (Knight, 1984). They are strongly built dogs and can vary widely in size and shape, the coat colour is usually black and tan (Dalton, 2010). Early shepherds saw the advantage of dogs that barked and chased sheep, and they deliberately mated their best barking sires and bitches and developed the Huntaway breed (MacGregor-Redwood, 1980). The exact lineage of the Huntaway is unknown, but has origins in Settler, bloodhound and Labrador breeds selected for their barking ability (Dalton, 1996). The Huntaway is an all-rounder working farm dog, in that they chase and hunt stock away (hence the name Huntaway), and force sheep into pens.

Farm dogs in NZ start training at an early age; many are instinctively interested in sheep as early as three months (Knight, 1984). Dogs are taught commands via whistles (e.g. short then long whistles may mean move to the left, whereas long then short whistles may mean move to the right). The functions of a Heading dog are to caste around the sheep, and bring them back to the farmer (i.e. to head the sheep). The aim is to get the sheep in between the farmer and the dog. The Heading dog does the bulk of gathering and quick-reaction, and close quarter work (Dalton, 1996). The way a Huntaway works is different, most of the Huntaways work is done while facing and moving away from the farmer. The function of the Huntaway is the use of noise, through their bark, to move stock.

There is little to no published data on the working behaviour of the farm dogs in NZ, and no literature on the types or periods of work, and if this work changes during the course of the year. The type of work conducted appears to be seasonal, with livestock animals generally only being born and requiring attention at certain times of the year. The type of work that farm dogs may be required to do can vary from herding in paddocks, to yard work, which involves maintaining a regular through put of animals for shearing etc. Although no research has been conducted in this area, the information exists in educational material for farmers by authors such as Dalton (1996) and MacGregor-Redwood (1980).

1.3 Basic digestion in the Dog

The term digestion describes mechanical and chemical processes that break food down to smaller components, which can be absorbed from the gastro-intestinal tract for use in the body. Digestion starts in the mouth, food particles are initially ground by teeth, and the enzyme lingual lipase initiates the breakdown of triglycerides (Totora and Grabowski, 2000). Food particles are mixed with saliva and pass through the oesophagus into the stomach. Food is mixed and broken down further in the stomach and when food particles are small enough they pass into the intestinal tract. The portion of the intestinal tract distal to the stomach is divided into two sections, the small intestine and the large intestine. The small intestine is sub divided into three sections, the duodenum, the jejunum and the ileum. The first section is the duodenum and this is the shortest section, followed by the longest section, the jejunum followed by the ileum (Maskell and Johnson, 1993). The primary function of the small intestine is to absorb nutrients. To achieve this, there are numerous structures, such as mucosal folds, villi and microvilli, which increase the surface area of the gut lining and facilitate the absorption of nutrients.

The large intestine can be sub-divided into four parts: the caecum, colon, rectum and the anal canal. The ileocolic junction/sphincter separates the ileum from the colon and regulates the movement of digesta from the ileum to the large intestine. The main function of the large intestine is absorption of water. The caecum is a blind sac which branches off from the colon and is located immediately after the ileocolic junction/sphincter. The caecum contains a multitude of organisms, such as bacteria and yeasts, which ferment carbohydrates that have not been hydrolysed in the small intestine. In carnivorous species, such as cats, the caecum is functional but when compared with the dog, the caecum does not contain a large microbial population and it has been well established that the caecum of the dog contains a microbial population capable of fermenting any nutrients that reach the large intestine (Balish *et al.,* 1977: Davis *et al.,* 1977; Flickinger *et al*., 2000). This suggests that the caecum of the dog is different to the cat, which seems reasonable, as the dog is omnivorous and not a strict or obligate carnivore.

1.3.1 Digestibility trials

Nutrient digestibility is an important measure in nutritional studies; it tells us the amount of nutrients that the animal is digesting from its diet, and is calculated from the difference in the amount of nutrients in the diet, and the amount remaining in the faeces or digesta. Digestibility studies using animals can be used to determine the apparent or true digestibility of a feed, or feed ingredient. The difference between the two methods is that apparent digestibility does not take into account endogenous nutrient and nitrogen losses, whereas true digestibility takes into account these losses. True digestibility also takes into account nutrient manipulation (i.e. fermentation of mostly fibres and proteins) by the organisms in the colon of the dog, whereas apparent digestibility does not. Apparent digestibility is measured through the total collection method, whereas true digestibility is measured through the ileal collection method (Sauer & Ozimek, 1986). The two methods are similar; and involve feeding an animal a diet and collecting all faeces produced over a given period, or collecting digesta from the ileum at a specific time over a given period. The ileal collection method can be carried out using euthanasia or ileal cannulation protocols.

The total collection method, although only allowing apparent digestibility values to be determined, is straight forward and the most common method of establishing the digestibility of a feed or feed ingredient. The total collection protocol starts with an adjustment period during which the animal adapts to the diet. A measured amount of the diet is fed and all faeces are collected over the 'collection period'. There are a number of protocols with different lengths of adaptation and collection periods. For example, Nott *et al.* (1994) studied three different collection periods in dogs. Beagles were fed a diet for 21 days and faeces collected over days four - seven, days eight - 14 and 15 - 21. The authors found there were no significant differences between different collection periods in any of the variables measured in dogs and suggested that a four day collection period, following a three day adaption period is sufficient to measure apparent digestibility in dogs.

The main problem with the total collection method is that it is time consuming and labour intensive. The animals need to be kept separate and in an environment that ensures total recovery of faeces. However, when compared with other available methods, it is the least invasive and generally the cheapest to run.

The feeding regime for the ileal collection protocol is the same as the total collection protocol, however instead of faecal collections, the animal is euthanased and the intestinal digesta is collected. This method requires the use of an indigestible marker, which relates the undigested nutrient content of the digesta sample to the nutrient intake of the animal. This method may be unsuitable, primarily because of the ethical cost of euthanising animals for science, but also the monetary cost of animals, especially if the animals are expensive, difficult to replace, or if large numbers are needed.

The principle behind the cannulation protocol is similar to the ileal collection protocol, except digesta is collected from a permanent tube like structure called a cannula that is inserted into the ileum of the animal. Multiple samples of digesta can be collected via the cannula; this eliminates the need to euthanise the animal. The cannulation method is the most accurate approach to determine small intestinal digestion (Harmon, 2007), but this method requires invasive surgery (Walker *et al.*, 1994), which has its own complications as surgery requires lengthy recovery and adjustment periods for the animals to become accustomed to the cannula. There is also the potential problem of animals chewing the plastic cannula, which can be replaced with metal, but then the weight of the cannula must also be taken into consideration (Harmon, 2007).

1.4 Nutrient requirements

Adequate nutrition is essential for optimal performance in performance or working dogs. To achieve the optimal performance from a working dog, the dog needs to consume a balanced diet that not only replaces the energy used that day, but also allows triacylglycerides and glycogen to be stored for use later. If storage consistently exceeds expenditure, it will lead to obesity. The consumed nutrients can also be used to repair any tissue damage that may have occurred. For a dog, energy requirements are provided by three main dietary sources: fat, protein and carbohydrates. Although it should be noted that protein are only used for energy during period of starvation.

1.4.1 Fat

Fats are palatable and highly digestible and are the preferred source of energy in racing dogs (Grandjean, 1996). Dogs require fat for three main reasons; to provide energy, to supply essential fatty acids and act as a carrier for fat soluble vitamins (Debraekeleer *et al.,* 1998). A diet that is rich in fats is often formulated for animals with higher energy requirements (Kienzle, 2002) and can increase the stamina of dogs (Kronfeld *et al.,* 1979). Training in conjunction with diets, where the majority of the energy comes from fat and an increase in the carbohydrate threshold, increases the proportion of energy supplied by FFA oxidation during high intensity work (Toll and Reynolds, 1998). The carbohydrate threshold is the point at which dogs switch from aerobic FFA metabolism to aerobic carbohydrate metabolism. During moderately intense work, both FFA and carbohydrates are metabolised for energy. Feeding a diet, where the majority of the energy comes from fat, during training causes a shift in metabolism, which increases the carbohydrate threshold, which causes a switch from FFA metabolism to carbohydrate metabolism. The advantage to this change is twofold; firstly fats have more energy per gram so each gram oxidised nets more fuel for exercise than carbohydrates. Carbohydrates are available in very limited supply in the body therefore sparing them is beneficial. Also, by feeding a higher fat diet during regular exercise, the amount of circulating FFA increases, providing a readily available energy source. Working dogs consuming high fat diets respond to an exercise bout by releasing more FFA than dogs fed an isocaloric diet of low fat content (Kronfeld *et al.,* 1977). Finally, increased fat in a balanced diet has been shown to increase the maximal rate of fat oxidation by 20-30 % in dogs exercised at a moderate intensity (less than 75% VO_2 max), which leads to an increased oxidative capacity (Reynolds *et al.,* 1995).

However, a diet excessive in fat can cause diarrhoea, simply because the gastro-intestinal tract cannot effectively absorb large amounts of fat (Booth *et al.,* 1961).

1.4.2 Protein

Proteins have various functions in the body, and protein reserves play a critical role in the well-being of the dog and cat. Skin and skeletal muscle are the primary protein reserves in the body. Amino acids are essential for both structural and metabolic functions; they are the building blocks for enzymes, hormones and are major structural components of hair, skin, nails and connective tissue (Bounous et al., 1983). Proteins are also found in the blood as carrier substances and contribute to the acid-base balance by forming intracellular buffers. The immune and musculoskeletal system both rely on proteins for normal functioning. Many important structural and functional components of the immune system are dependent on a readily available supply of protein and specific amino acids i.e. immune cells and antibodies. Further, lymphoid tissues (involved in tissue repair) have a high cell proliferation rate and rapid protein turnover, making them vulnerable to nutritional deficiencies (Chandra, 1993). Amino acids are also essential for the synthesis of antibodies and other specialised blood proteins that are critical for optimal immune function and general health of the animal and for the synthesis of enzymes, which are the catalysts of all metabolic functions. These metabolic functions include energy production, neurological function, and maintenance and health of the entire body (Allison *et al.*, 1946:1947:1954; Arnold and Schad, 1954; Kade *et al*., 1948; Melnick *et al.,* 1937; Rose & Rice, 1939).

Skeletal muscle, the primary protein reserve in the body, is essential for both structural and metabolic functions. Maintenance of skeletal muscle or lean body mass is dependent on optimal dietary protein intake. Optimal dietary protein intake provides the source of amino acids and is the building blocks of protein for turnover of skeletal muscle. Protein turnover is a dynamic process of breakdown and synthesis of endogenous proteins that occurs on a continuous basis in almost all cells of the body. The rate of protein turnover is reduced when protein intake is deficient and maximised at optimal protein intake. Protein turnover is the continuous redistribution of amino acids to other tissues to support metabolic functions. At an optimal dietary protein intake, amino acids lost from the skeletal muscle for protein turnover are replaced with dietary amino acids.

Dietary proteins provide essential amino acids for protein synthesis and also supply nitrogen to synthesise non-essential amino acids. Dogs require 10 of the 22 main amino acids used for protein synthesis to be provided in their diet, these essential amino acids are; arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, tryptophan, threonine and valine.

Protein requirements are affected by growth, pregnancy and work, and these states require a higher concentration of protein to maintain and build muscle. Protein quality in feed is important, with the quality significantly influencing the amount of protein that must be fed to a dog. The quality of the protein affects the digestibility of protein i.e. higher quality is more digestible than lower quality protein. This means that if a dog consumes a diet containing high quality protein, it will be able to digest more of the protein; therefore, there will be more amino acids available for metabolic and biological processes, than if it consumed a diet containing low quality protein. Generally animal protein sources provide a higher quality source of protein for cats and dogs than plant protein sources; not only because they are more digestible, but also because they are more likely to provide all of the essential amino acids. Beef and poultry by-products are good sources of protein for dogs, but the digestibility of these products is variable due to fluctuations in the quality of meat (Murray *et al.,* 1997). For example, if there is a drought, this will affect growth of livestock and could result in less protein and fat on a carcass. Ultimately this could result in dogs fed drought affected homekill receiving a diet lower in protein than those fed a non-drought affected homekill. Individually vegetables and grains may not provide a balance of essential amino acids required by the cat or dog, for example, corn flour has significantly lower levels of tryptophan than wheat flour

(50 mg vs 0.32 g: Souci *et al.,* 1989). In addition many vegetable proteins are less digestible and provide limited amounts of some amino acids (e.g. lysine deficient; Newberne, 1974). In a commercially prepared diet, there are usually a variety of different vegetable proteins used (i.e. corn, wheat, soybean), these contribute different proportions of amino acids, thus producing a complementary effect and a commercially prepared diet which will contain all essential amino acids required by the dog.

A study by Reynolds *et al.* (1996) used sled dogs and compared the difference in injury rates and some haematological variables between dogs fed different diets. Dogs were fed diets containing 16, 24, 32, and 40% of their caloric requirement from protein. Fat concentrations were kept constant and the source of protein did not differ between diets. The dogs that were fed higher concentrations of protein maintained a larger plasma volume and red blood cell mass during a subsequent race. Dogs on the lowest protein diet (16%) sustained at least one injury during the racing season. Two dogs on the medium protein diet (24%) sustained injuries, and no dogs from the higher protein diets sustained any injuries. Further studies by Reynolds *et al.* (1999) showed that sled dogs had more soft tissue injuries when fed diets containing 17.8% protein, than dogs fed 22.8, 28.6 or 34.5% protein (% energy basis). This suggests that in order to prevent injuries, working dogs may require a diet containing minimum protein concentrations of between 22.8 and 24% of caloric intake (ME), as protein is essential for muscle repair after exercise. This is higher than the AAFCO recommendation for the protein requirements for maintenance of pet dogs of 18% of caloric intake (ME). Severe protein deficiency in dogs can result in poor food intake, weight loss, and subnormal concentrations of blood proteins, muscle wasting, emaciation and death. Less severe deficiency may cause a rough, dull coat and compromised function of the immune system (Allison et al, 1946; 1947; 1954). Chronic, marginal deficiency of protein may result in decreased protein reserves, and those animals with inadequate protein reserves may appear healthy but are more susceptible to infection (Allison *et al*, 1954).

1.4.3 Carbohydrate

Carbohydrate is not essential to the dog for maintenance, if sufficient amounts of fat and protein are contained in the diet (Hammel and Kronfeld, 1977). However, carbohydrates are essential in other life stages such as pregnancy and lactation (Romsos *et al*., 1981). The main role of carbohydrate is to supply the body with energy and replenish glycogen stores in muscles. This is important for dogs such Greyhounds that use muscle glycogen in short fast sprints (Hill *et al.,* 2005). The digestibility of carbohydrates is important to the racing dog, although it has been shown that some carbohydrates can also alter the digestion of other nutrients in food, with poor starch digestibility reported to hinder the digestibility of proteins (Kienzle *et al.,* 1991a: Earle *et al.,* 1998). Stamina of the dog is highly influenced not only by the energy density of the diet, but also the digestibility of the food (Orr, 1966: Kronfeld, 1973: McNamara, 1972: Downey *et al.,* 1980). Therefore, working dogs require a diet that contains a highly digestible carbohydrate source.

1.4.4 Water

Water is the most essential of nutrients to all living things. Every cell in the body contains water and approximately two thirds of the body's weight is water (Houpt, 2004). Water provides a substrate for metabolic processes and chemical reactions, acts as a biological solvent, transports nutrients, waste and heat, helps lubricate surfaces of the body and helps with physical shock absorption (Anderson, 1982: Toll and Reynolds, 1998).

Dogs, as with other mammals, primarily lose water through respiration and urination (Toll and Reynolds, 1998), and these losses must be replaced to keep the body in metabolic equilibrium, or homeostasis. There is debate regarding the best technique to maintain fluid and electrolyte balance in the working dog (Toll and Reynolds, 1998). During work, the dog loses more water than electrolytes, and this causes an osmotic imbalance. Therefore, in order for the body to return to its normal state, dogs need to be rehydrated with water (Toll and Reynolds, 1998). Young *et al.* (1959) found that Beagles were able to expend 842 more calories when they had access to water, compared to carbohydrate supplemented water, while running to exhaustion on a treadmill.

Therefore, water replenishment during work maintains the normal state of hydration, improves temperature regulation, and because the blood flow is not diverted to regulate body temperature, this is beneficial to carbohydrate metabolism, because the body can again supply glucose to working muscles by mobilising glucose (Young *et al,* 1959). Clean water (i.e. bacteria free) should be made available to the working dog whenever possible (Dalton, 1996; Toll and Reynolds, 1998). It may not be practical for the farmer to stop work and let the dog go for a drink, however if the dog has the opportunity to have a drink (i.e. if close to a stream or water trough), they should take the opportunity to have a drink and cool down.

1.5 Exercise physiology

Exercise involves many systems in the body working together to make the body move in ways that does not harm the body. As muscles start to move and work, muscle fibres contract and relax a process which requires energy in the form of adenosine triphosphate (ATP). Adenosine triphosphate is the sole source of energy for muscle contraction, where ATP is cleaved to ADP (adenosine diphosphate). Adenosine triphosphate is formed when glucose is broken down, which occurs in response to the stimulating effect of movement or exercise. Adenosine triphosphate is generated through a series of metabolic processes in the body. Glucose is broken down into pyruvate via the production of glucose-6-phosphate through cellular respiration. Further metabolism depends on the type of exercise and will be discussed in section 1.5.2.1. The fuel sources (carbohydrate, fat or protein) utilised to supply energy may change due to a change in exercise intensity or as primary fuel sources are used up. Nutrients provide the prerequisites that ensure that muscle tissue receives sufficient ATP to keep up with demand (Toll and Reynolds, 1998).

1.5.1 Basic muscle structure

Skeletal muscle is made up of many layers (see figure 1.1). The first outer layer, covering the entire muscle, is called the epimysium, which holds together small bundles of fibres called fascicules. Each fascicule is surrounded in turn by a connective sheath called the perimysium (Wilmore and Costill, 2004). Within each fascicule are bundles of muscle fibres that contain individual muscle cells (see figure 1.2). These muscle cells are covered by a connective tissue called the endomysium and each muscle cell is surrounded by a plasma membrane called the sarcolemma, which fuses with a tendon at the end of each muscle fibre. The tendon (fibrous connective tissue) inserts into the bone and helps create motion by transmitting the force generated by muscle fibres. Within the sarcolemma is the sarcoplasm, the cytoplasm of each muscle fibre, which contains substantial amounts of glycogen, which is broken down into glucose and is used to produce energy (Wilmore and Costill, 2004). The sarcoplasm also contains myoglobin, which is only found in muscle tissue, and binds the oxygen (O_2) needed for aerobic cellular respiration (explained in section 1.5.4) within the mitochondria (Erikson and Poole, 2004) via oxidative phosphorylation (Hoppler and Lindstedt, 1985). Mitochondria are found in rows throughout the muscle fibre in close proximity to the muscle proteins that use ATP during muscle action (Tortora and Grabowski, 2000).

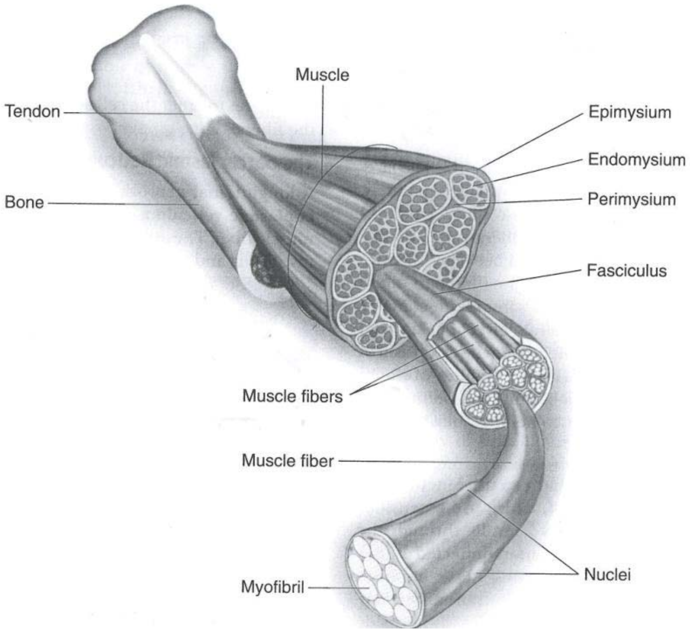

Figure 1.1: The basic structure of muscle (from Wilmore and Costill, 2004).

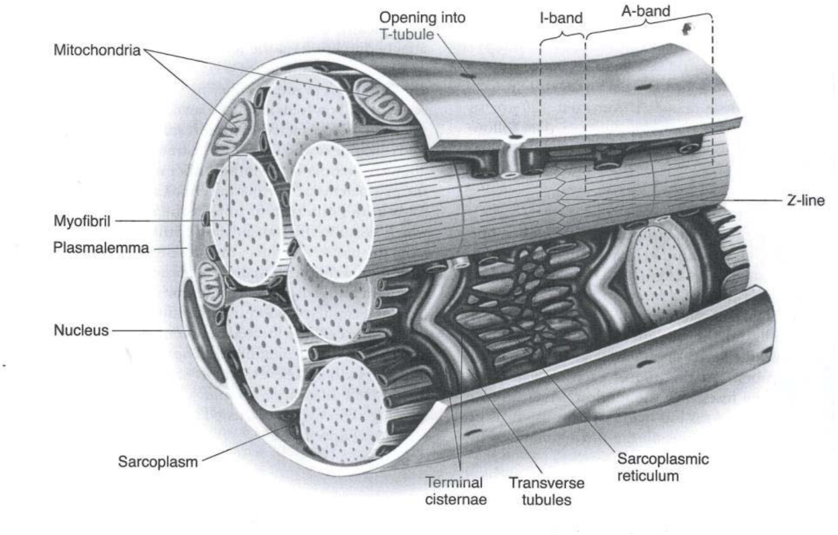

Figure 1.2: Structure of a single muscle fibre (from Wilmore and Costill, 2004).

1.5.2 Muscle contraction

A muscle fibre is excited when the neurotransmitter acetylcholine (Ach) binds to receptors on the sarcolemma. If enough Ach binds to the receptors it causes the muscle cell membrane to allow sodium to enter the muscle cell, in a process called depolarisation. This creates an electrical impulse, called an action potential, which travels through the fibre's network of tubules and into the interior of the cell. This charge causes the sarcoplasmic reticulum to release its store of calcium ions (Ca^{2+}) into the sarcoplasm. The released Ca^{2+} binds to troponin, causing tropomyosin to lift away from the myosin binding site on the actin filament (Wilmore and Costill, 2004). The myosin heads bind to the actin filaments by hydrolysing ATP, which is converted to ADP. The release of the phosphate group from ATP during hydrolysis triggers the power stroke of contraction where the myosin heads rotate and release ADP (Toll and Reynolds, 1998). As the myosin heads rotate, it causes the thin filament to slide past the thick filament towards the M line (see figure 1.3 below).

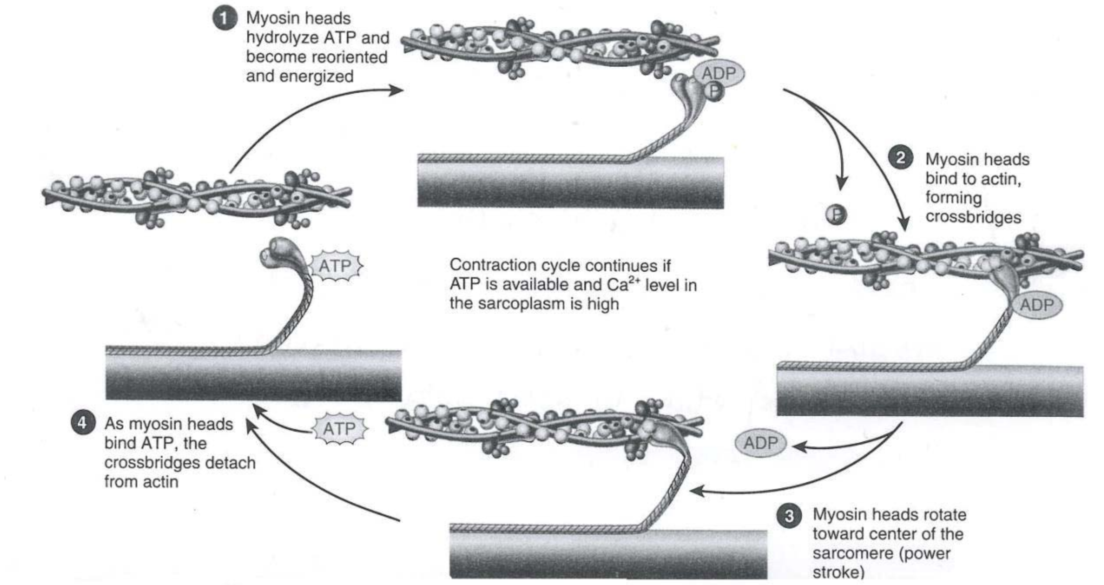

Figure 1.3: Movement of myosin heads during the power stroke of contraction (from Tortora and Grabowski, 2000).

1.5.3 Muscle energetics

Adenosine-triphosphate production can be estimated by measuring O_2 consumption. A measurement of O_2 consumption at rest gives an estimate of the body's basal metabolic rate. At rest, the body's energy requirements are low, but as soon as any movement occurs (e.g. as walking, running etc) the muscles increase their rate of ATP production. The fuel sources that help replenish ATP are either stored in the muscle (endogenous), or at other body sites (exogenous). Energy generating pathways begin by breaking down glucose molecules into pyruvate, and then further metabolism of fuel sources can occur by using oxygen (aerobic), or without oxygen (anaerobic). The anaerobic pathways (creatine phosphate shuttle and glycolysis) occur in the cytoplasm, whereas the aerobic pathways (complete oxidation of metabolic fuels) occur in the mitochondria of the muscle cell. The intensity of exercise determines the proportion of each pathway used.

During rest, muscle cells have only enough ATP to fuel a few seconds of muscle contraction. If energy is required beyond this point, ATP has to be generated from other metabolic fuels (Nadel, 1985; Rusko *et al.*, 1986). While at rest, muscle cells produce more ATP than the cell requires for resting metabolism. Some of the excess ATP is used to synthesise creatine phosphate. When muscle contractions start, the phosphate from creatine phosphate is transferred to ADP to form ATP. However, this pathway can only supply enough energy for short periods of time. The metabolism of glucose to pyruvate also produces two molecules of lactic acid. Lactic acid can be used to regenerate glucose through the Cori cycle (Reichard *et al.,* 1963). During anaerobic pathways, glucose is converted to pyruvate in muscle cells; the resulting lactate is transported to hepatic cells in the liver and converted back to glucose. However, this process results in the net consumption of 4 ATP molecules per lactate molecule, and therefore cannot be sustained for long periods of time.

During exercise, oxygen consumption increases until it reaches a steady state, where the body's ATP requirements are met by the aerobic pathways. Before the steady state is reached, ATP is supplied via anaerobic pathways. The period where there is a lag in O_2 uptake and consumption at the beginning of exercise is termed the O_2 deficit, and is shorter in trained subjects compared to untrained subjects (Powers and Howely, 2007). The fate of glucose in producing ATP is referred to as cellular respiration and involves 4 sets of reactions: glycolysis, the formation of acetyl coenzyme A, the tricarboxylic acid cycle (TCA cycle) and the electron transport chain (Rolfe & Brown, 1997). Glycolysis can occur aerobically, or anaerobically and involves the conversion of one glucose molecule to two pyruvate molecules, this results in the formation of two ATP molecules and two nicotinamide adenine dinucleotide molecules ($NADH + H^+$). This step occurs in the cytosol of the cell. Pyruvate is then transported in the mitochondria, which is where the next three steps occur. The next step is the conversion of pyruvate to acetyl coenzyme A to enter the TCA cycle; this step also produces $NADH + H^+$ (Rolfe & Brown, 1997). The TCA cycle is a series of reactions which produces two ATP molecules, 6 NADH + 6 H^+ molecules and two molecules of flavin-adenine dinucleotide ($FADH_2$). The TCA cycle, in addition to producing the reducing equivalents is also anapleurotic. Anapleorsis is the description of metabolic pathways which replenish metabolic cycles; it serves to counteract the loss of intermediates during metabolic reactions (Gibala *et al*., 2000). The NADH and $FADH_2$ produced from the previous three reactions are then used in the electron transport chain to form 32 or 34 ATP molecules. When energy is not required, glucose is stored endogenously as muscle glycogen, or exogenously as glycogen in the liver through a process called glycogenesis (Rolfe & Brown, 1997). Glucose is used as a metabolic fuel source and metabolised to supply energy for muscle contractions either through anaerobic or aerobic pathways. Anaerobic pathways can rapidly produce ATP, but can only produce two molecules of ATP per molecule of glucose metabolised. Aerobic pathways use glucose more efficiently, by completely oxidising the glucose, and producing 36 ATP molecules per glucose molecule. However aerobic pathways regenerate ATP slower than anaerobic pathways. Glucose stores are limited in the body, so during prolonged exercise, where a sustained source of energy is required, the body uses fatty acids as the next source of metabolic fuel (Toll *et al.,* 1998). Figure 1.4 outlines the major energy-generating pathways used during exercise.

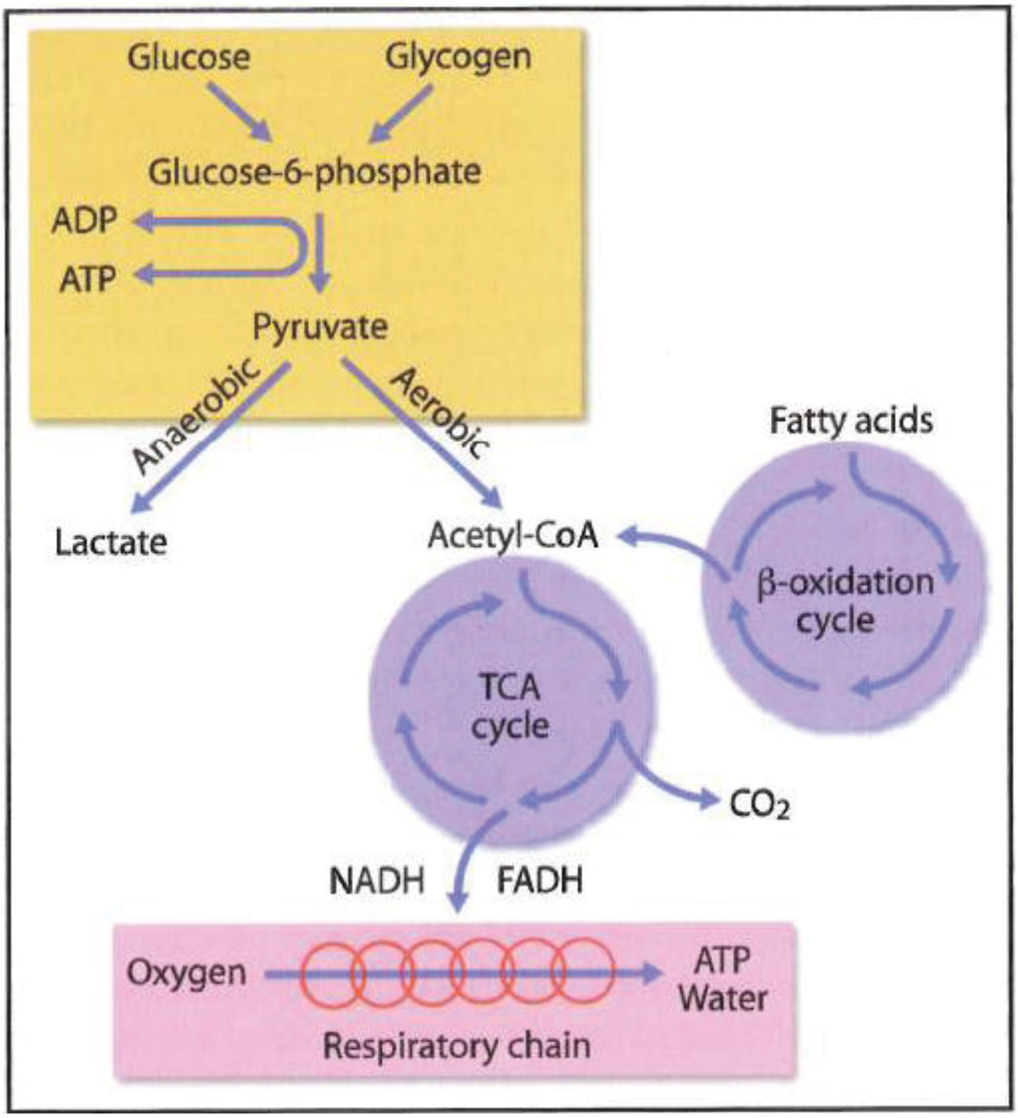

Figure 1.4: Summary of major energy-generating pathways used during exercise. Key: ADP = adenosine diphosphate, ATP = adenosine triphosphate, TCA = tricarboxylic acid, NADH = reduced form of nicotinamide dinucleotide, FADH = reduced form of flavin-adenine dinucleotide (from Toll *et al.,* 1998*)*
Fatty acids are aerobically metabolised through the β-oxidation cycle to produce acetyl-CoA (which is also produced from the metabolism of glucose to pyruvate, the pyruvate is then metabolised into Acetyl-CoA). Acetyl-CoA then enters the TCA cycle to form a reduced nicotinamide dinucleotide (NADH) and produces CO_2. The NADH then enters the electron transport chain to produce more ATP and water.

1.5.4 Muscle fibre types

Within the muscle fibre there are two types of fibres, slow-twitch (ST) and fast-twitch (FT) fibres. The fibres are named depending on how fast the ATPase enzyme in the myosin head can hydrolyse ATP. There is only one type of ST fibre, whereas the FT can be categorised into two major types: fast-twitch type a (FT_a) and fast-twitch type b (FT_b). Slow-twitch fibres have a slow form of myosin ATPase, whereas FT have a faster form, therefore ATP is produced faster in FT fibres. Fast-twitch fibres in the dog are highly oxidative and different breeds of dogs have different muscle compositions. Therefore this may relate to performance characteristics for that particular breed (Armstrong et al., 1982). Greyhounds have a higher proportion of fast-twitch than slow twitch fibre types compared to Foxhounds and crossbreed dogs (Guy and Snow, 1981), and therefore have lower oxidative capacity and favour anaerobic metabolism. Section 1.5.6.1 to 1.5.6.4 expands on different types of work, muscle fibre and therefore nutritional requirements of the Greyhound, Sled dog and other working dogs. Table 1.1 outlines fibre classifications and characteristics of fibre types.

Table 1.1: Classification of muscle fibre types (modified from Wilmore & Costill, 2004).

	Fibre Classification		
System 1	Slow-Twitch (ST)	Fast-Twitch a (FT_a)	Fast-Twitch b (FT_b)
	Characteristics of fibre types		
Oxidative capacity	High	Moderately high	Low
Glycolytic capacity	Low	High	Highest
Contractile speed	Slow	Fast	Fast
Fatigue resistance	High	Moderate	Low
Motor unit strength	Low	High	High

For endurance exercise highly oxidative fibres are required and need fat reserves. Therefore the higher oxidative potential of ST and FT_a make them more suitable for prolonged activity, where fuel reserves can be used for greatest advantage. FT_b fibres are best suited for short, intense activity where production and tolerance of lactate is required (Erikson & Poole, 2004). This is because the sarcoplasmic reticulum of FT fibres are more highly developed than ST fibres, this means that FT fibres are better adapted for delivering Ca^{2+} ions when stimulated and leads to faster muscle contractions.

Slow twitch fibres are recruited during low intensity endurance events (Wilmore & Costill, 2004). On the other hand, FT fibres have low aerobic endurance and are more suited to anaerobic pathways (in the absence of or during the inadequate supply of oxygen, ATP is formed through anaerobic pathways). FT_a fibres generate more force than ST fibres, fatigue easily, and therefore are mainly used during shorter, higher intensity events. Dogs do not appear to have the classic FT_b fibres; instead they have two other types of fibres that are more oxidative (FT_{Dog} and FT_C: Toll *et al.,* 1998). These fibres may contribute to the general observation that dogs show great fatigue during running (Snow *et al*, 1982; Latorre *et al.,* 1993; Rivero *et al.,* 1994).

The activity level and the breed of the dog also dictates which fuel source is used, as there is a difference between fuels supplied to working muscles in inactive, and active dogs (Issekutz *et al.,* 1965). As mentioned previously, dogs that are normally active use energy stores of adipose tissue as the metabolic fuel, while dogs that are normally inactive only have limited access to these energy deposits, and therefore utilise anaerobic metabolism more than aerobic metabolism. Greyhound muscle types favour anaerobic metabolism and rely heavily on muscle and liver glycogen content during races, with this glycogen a product of glucose metabolism. Greyhound muscle mass comprises a larger proportion of their total body weight (57 vs. 43%) compared to other dogs (Gun, 1978). Greyhounds, in comparison with other dogs, have a lower proportion of oxidative fibres (Armstrong *et al.,* 1982; Gunn 1978a; Snow, 1987), which favour anaerobic cellular respiration. To run at speed, the muscle fibres must be able to contract quickly and to ensure this is possible, delivery of energy should not be the limiting factor. Therefore high glycolytic capacity would be advantageous to the Greyhound (Guy & Snow, 1981).

A few studies have been published which examine the differences in fibre types and breeds of dogs. Guy and Snow (1981) reported that Foxhounds, when compared with crossbreed dogs, had a lower proportion of FT fibre and concluded that this is a reflection of the athletic work which Foxhounds have been bred for. Foxhounds have to be able to maintain moderate speeds for many hours, but still be able to run at relatively fast speeds when in pursuit of a fox. Parsons *et al.* (1985) also reported that Foxhounds have a greater proportion of FT fibres *versus* ST muscle fibres. Agurea *et al.* (1990) measured the proportion of FT and ST muscle fibre types in German Shepherds, Spanish Greyhounds, Spanish Mastiff and the Iberian Hound and found no significant differences in the fibre types within or between breeds.

Rosenblatt *et al.* (1988) and Kuzon *et al.* (1989) found that the fibre-type percentages of mixed breed, hound-type dogs and Beagles were the same and could be attributed to these dogs having similar exercise histories. Another observation was that the heavier hound-type dogs (> 15 kg) had larger muscle fibres that the lighter Beagles and the hound-type dogs had significantly larger ST fibres than the mixed breeds (> 15 kg) (Rosenblatt *et al.,* 1988). Newsholme *et al.* (1988) also found that Beagles had similar proportions of FT fibres to ST muscle fibres in both male and female dogs, however the FT fibres were larger and cross sectional area of FT fibres were always greater than ST. This may suggest that fibre type and cross sectional area of fibre is important for athletic ability. Gerth *et al.* (2009) found that during summer there was muscle atrophy of fibres in Inuit sled dogs compared with winter. During winter the dogs were well fed and exercised regularly, compared with summer when dogs were chained with no exercise, fed intermittently and often fasted for several days.

Anaerobic glycogenolysis and glycolysis, rather than fat oxidation, would provide most of the energy required for a 500m race which lasts only around 30 seconds, therefore this type of exercise may favour high carbohydrate diets (Guy & Snow, 1981). Endurance-adapted dogs, such as sled dogs, transport higher circulatory free fatty acids (FFA) than species such as goats and humans (Kronfeld *et al.,* 1994; McClelland *et al.*, 1994). When dogs are fed a high fat diet, it stimulates an increase in the number of mitochondria, and thereby increases the maximum rate of fat oxidation (Reynolds *et al.,* 1995b). Aerobic cellular respiration occurs in the mitochondria, and with an increase in the number of mitochondria, more glucose can be converted into ATP for energy. As consumption of fuels is higher, this allows the body to release FFA into circulation for use. This in turn favours utilisation of fats rather than carbohydrates.

It may be that Heading dogs are similar to Greyhounds, and favour anaerobic cellular respiration for energy, as the Heading dog needs to react quickly if a sheep breaks from the rest of the flock. The Heading dog may therefore have a higher proportion of fast twitch fibres than the Huntaway. The Huntaway works differently to move sheep by barking and scaring them therefore the Huntaway may not need as high a proportion of fast twitch fibres as the Heading dog; however this hypothesis needs to be tested, as currently there is no published work on the muscle types of either Heading or Huntaway dogs. Muscle types may be easily established in Huntaway and Heading dogs by taking multiple muscle biopsies from various regions of the body i.e. the semitendinosus, gastrocnemius and triceps muscles. These samples can be taken when working dogs are either taken to the veterinarian for surgery or if they are euthanised.

1.5.5 By-products of muscular work

The main by-product of exercise is heat, which must be released from the body into the environment. If exercise is performed in a high temperature environment then there are limiting demands between evaporative cooling and energy output, which may limit performance and in some instances lead to heat stroke. The heat generated during exercise requires a large amount of water for evaporative cooling (Taylor, 1974), so if there is a reduction in evaporation, this could lead to high body temperatures. As body temperatures rise, there is an increase in the rate of peripheral blood flow to transfer the heat from the working muscles, to the environment. Baker (1984) showed that during mild exercise, dehydrated dogs regulate body temperature by changing the body temperature-evaporation and body temperature-carotid blood flow relationships, where both evaporation and thermoregulatory blood flow are lower in dehydrated animals versus hydrated animals during exercise. Whereas in hydrated dogs, blood flow is primarily to the nose, tongue and mouth (Baker et al., 1982), thus increasing panting, in dehydrated animals, energy and water need to be conserved and therefore blood flow remains within the core of the body (Baker *et al.*, 1982).

Another by-product of exercise is the extra production of carbon dioxide (CO_2) and accumulation of lactate (which is the end-product of anaerobic metabolism) in the blood system. The respiratory system increases ventilation to eliminate CO_2 build-up from exercise. Working muscles can convert lactate into energy and the liver can convert lactate into glucose via gluconeogenesis and the Cori cycle. This process provides new glucose molecules for another few seconds of maximal muscle activity; however, glycogen must be restored for continued physical activity (Rusko *et al.,* 1986).

1.5.6 Nutritional aspects of exercise

As mentioned previously, the body needs fuel to maintain work. Fuel for the body is provided in the form of food. Consumed food is ultimately broken down into smaller molecules to produce energy in the form of ATP. During exercise stored carbohydrates and fats are broken down to form ATP. Proteins are the body's building blocks and, in relation to exercise, are mainly used for muscle construction and production of enzymes.

Carbohydrates are broken down into glucose which is transported through the blood system to cells in the body. At rest, ingested carbohydrates are stored by the liver and muscles as glycogen. Glycogen is stored in the cytoplasm of cells until it is needed to form ATP. These stores are limited and need to be continually replenished from the diet. If stores become depleted, another source of energy must be used. The glycogen stores in human muscle are considerably higher than those in dog muscle, possibly due to the high protein and relatively lower carbohydrate diets of dogs (Snow, 1985). Fats contain concentrated amounts of energy, and the fat reserves in the body are considerably larger than those of carbohydrate. More energy is derived from fats than for the same weight of carbohydrates. Kronfeld (1973) 'carbohydrate-loaded' sled dogs by feeding a diet composed of 39% carbohydrate, 32% fat and 29% protein (% energy basis), the dogs were fed once a day in the evening. During a two to eight mile training session, the dogs started exhibiting signs of exertional rhabdomyolysis (breakdown of muscle fibers that leads to the release of myoglobin into the blood stream); however, the condition was eliminated when the dogs were changed to a diet containing 22% carbohydrate, 33% protein and 45% fat. Running performance was further improved when dogs were fed a diet containing 0% carbohydrate. The authors concluded that 'carbohydrate-loading' is not suitable for sled dogs. Downey *et al.* (1980) found that there was a negative relationship between stamina and a high carbohydrate diet fed to Beagles. They recommend a balanced diet with a high fat content for dogs competing in trialling events. This may be because dogs have the ability to utilise fat stores more efficiently than humans. This is indicated by their high 3-hydroxyacyl CoA dehydrogenase (HAD) activity; an enzyme essential in fatty acid metabolism. Even breeds such as Greyhounds, with very low body fat composition, have a higher HAD activity than humans (Snow, 1985).

Although carbohydrates may not be essential in the sled dogs diet, studies have also found that carbohydrate supplementation after exercise helps dogs recover faster after exercise. Carbohydrate supplementation in the form of a glucose polymer mixed with water immediately after exercise has been advocated to replenish glycogen stores (Reynolds *et al.,* 1997). A group of sled dogs receiving carbohydrate supplementation immediately after a 30 km run had significantly higher muscle glycogen concentrations 4 h later than dogs just given water after exercise. The increased muscle glycogen concentration promoted rapid and complete recovery between bouts of exercise, which is important for dogs running multiple races on a single day or several consecutive days (Reynolds *et al.,* 1997). When muscle glycogen is depleted during heavy work, the muscle relies predominantly on lipids during exercise (Therriault *et al.,* 1973: Hammel *et al.,* 1977; Reynolds *et al.,* 1995a: Downey *et al.,* 1980). The depletion of muscle glycogen levels appears to be linked to the inability and the lack of desire of the working dog to restart exercise after a rest period (Reynolds *et al.,* 1997).

Greyhounds, in contrast, mostly rely on anaerobic metabolism of carbohydrates during a 30 second race. During vigorous (short and high intensity) exercise, such as short distance sprinting, the main source of energy is carbohydrates in the form of muscle glycogen and blood glucose (Hill *et al.,* 2005). A slower process involving fat metabolism for fuel is used to perform low to moderate intensity (endurance) exercise over a long period of time. A farm dog may need to use both vigorous (carbohydrate metabolism i.e. glucose metabolism) and endurance (fat metabolism) exercise to muster sheep.

Dietary protein is used for tissue protein synthesis and is unable to be stored like carbohydrates and fats. During starvation or severe energy depletion, protein can be converted to glucose through a process called gluconeogenesis, and the proteins are converted into fatty acids through lipogenesis. In the study by Reynolds *et al.* (1996) when dogs were fed 16, 24, 32 and 40% of their calories from protein, the animals fed 40% protein maintained a higher plasma volume and red blood cell mass during strenuous exercise. Proteins also provided 5 – 15% of the energy generated during training and this value increased as glycogen stores diminished and gluconeogenesis became the primary system for maintaining blood glucose levels during exercise (Reynolds *et al.*, 1996). This suggests that protein is used to maintain energy requirements during exercise in the dog.

The ratio of CO_2 produced by an animal, to the volume of O_2 consumed, is referred to as the respiratory exchange ratio, or the respiratory quotient (RQ). The RQ is used to estimate the percentage contribution of carbohydrates or fat to energy metabolism and can be estimated using indirect calorimetry (see section 1.6.1 below). The oxidation of fats and carbohydrates produces differing amounts of O_2 consumption and CO_2 production. The worked example below shows this:

Fat (palmitic acid) $C_{16}H_{32}O_2$

Equation 1.1: Oxidation: $C_{16}H_{32}O_2 + 23\ O_2 \longrightarrow 16\ CO_2 + 16\ H_2O$

Therefore, the RQ $= CO_2$ output / O_2 consumed

$= 16\ CO_2 / 23\ O_2$

= 0.70

Carbohydrate (glucose) $C_6H_{12}O_6$

Equation 1.2: Oxidation: $C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6H_2O$

Therefore, the RQ = CO_2 output / O_2 consumed

= $6\ CO_2 / 6\ O_2$

= 1

These reactions are referred to as oxidation reactions; they all use O_2 and produce CO_2. The amount of O_2 used and CO_2 produced will always be at fixed proportions to each other, with this proportion referred to as the respiratory quotient (RQ). The RQ is the ratio of CO_2 produced to O_2 used during oxidation of carbohydrates, fats or proteins. The RQ for the breakdown of carbohydrates is 1.0; therefore, the same amount of O_2 is consumed as CO_2 produced, while the RQ of fats and proteins are 0.7 and 0.8 respectively. Table 1.2 lists a range of RQ values and the percentage of fat or carbohydrate metabolism. Under normal circumstances, protein is not normally used for energy synthesis, and therefore is excluded from the Table 1.2.

Table 1.2: Respiratory quotient determined by different percentages of metabolised fat and carbohydrate.

RQ	% fat	% carbohydrate
0.70	100	0
0.75	83	17
0.80	67	33
0.85	50	50
0.90	33	67
0.95	17	83
1.00	0	100

In humans, fats are the primary fuel for muscles during low-intensity exercise, and as intensity increases, muscles tend to favour fuel from carbohydrate sources. In dogs doing short, high intensity work, 20-30% of the fuel for energy expenditure is supplied by free fatty acids (FFA), while 70-95% of energy is supplied from FFA for low intensity work (Paul and Issekutz, 1967). This shift is caused by the intensity of exercise, and the metabolic fuel source available to the muscle cell. High intensity exercise involves recruitment of fast twitch fibres, and this increases the levels of epinephrine in the blood. Fast twitch fibres are better equipped to metabolise carbohydrates because they have an abundance of glycolytic enzymes and few mitochondrial and lipolytic enzymes. Epinephrine regulates carbohydrate metabolism during exercise. The blood level of epinephrine rises as exercise intensity increases, which causes muscle glycogen breakdown, carbohydrate metabolism and lactate production. Lactate production also reduces fat metabolism by reducing the availability of fat as a source of fuel (Powers and Howely, 2007), thus lactate is used preferentially to fat as a fuel source. In slow twitch muscle fibres, lactate from the blood can be converted into pyruvate (which can be converted to acetyl-coA through aerobic metabolism, and enter the TCA cycle, or to glycogen and be stored), which contributes to oxidative metabolism. This is referred to as the lactate shuttle (Powers and Howely, 2007). After prolonged exercise, glycogen stores in muscle become diminished and blood glucose declines. This stimulates liver glycogenolysis and glucose is released into the blood. If the liver also depletes its store of glycogen, it will lead to muscle fatigue. Endurance-adapted dogs transport higher circulatory fatty acids than species such as goats, loading more fatty acids on plasma albumin, and can also use strategies such as increasing plasma flow, or increasing albumin concentration, to enhance fatty acid supply to their working muscles (McClelland *et al.*, 1994).

There are different types of canine athletes, and these different athletes require different levels of nutrients in their diets. Table 1.3 estimates the nutritional requirements of different canine athletes. The conversion factor for changing kcal/day to kj/day is 4.184.

Table 1.3: Current nutritional recommendations for different canine athletes (from Toll and Reynolds, 1998).

Dietary Factors	**Sprint athletes (e.g. Racing Greyhounds)**	**Intermediate athletes[1] (e.g. Agility dogs)**	**Intermediate athletes[2] (e.g. Hunting dogs)**	**Endurance athletes (e.g. Racing sled dogs)**
Energy density (kcal ME/g DM)	3.5 to 4.0	4.0 to 5.0	4.5 to 5.5	>6.0 kcal
Fat (DM)	8 to 10 %	15 to 30 %	25 to 40 %	>50 %
(calories)	20 to 24 %	30 to 55 %	45 to 65 %	>75 %
Soluble carbohydrate (nitrogen-free extract) (DM)	55 to 65 %	30 to 55 %	30 to 35 %	<15 %
(calories)	50 to 60 %	20 to 50 %	15 to 30 %	<10 %
Protein (DM)	22 to 28 %	22 to 32 %	22 to 30 %	28 to 34 %
(calories)	20 to 25 %	20 to 25 %	18 to 25 %	18 to 22 %
Digestibility (DM)	>80 %	>80 %	>80 %	>80 %
Water	Unlimited except just before a race	Unlimited	Unlimited	Unlimited

[1] low/moderate duration and frequency

[2] High duration and frequency

The majority of published research conducted on working dogs has been conducted on Greyhounds or sled dogs. It would be interesting to see which of these two different canine athletes the energy requirement of the working NZ farm dog is closest to, or if the work conducted by farm dogs in NZ is somewhere in between.

1.5.6.1 Greyhounds: Short distance sprint athletes

Greyhounds are an ancient breed of dog, purpose-bred for extreme sprinting performance. Explosive activity over short distances, as expected, requires a certain level and type of nutrition. Nutrition of Greyhounds has progressed significantly since 1969, when Griffiths conducted a survey of 22 Greyhound kennels that found that trainers all fed home prepared feed. This diet consisted of a variety of protein sources such as horse meat, tripe or sheep's head, bread, vegetables (when available), milk (as required, or when available), with no vitamin supplementation. Griffiths concluded that because of the large variation in diet, and the inconsistency of diets, the results showed "unsatisfactory and disturbing aspects of Greyhound nutrition". However, since 1969 scientific research has been conducted into the nutritional requirements of the Greyhound. A series of studies carried out by Hill *et al.* (1996; 1998; 2000a; 2001) have investigated the best combination of nutrients for optimal performance of the Greyhound (see Table 1.4).

Table 1.4: The effect of varying concentrations of fat, protein and carbohydrate on race speeds for Greyhounds.

	Nutrient concentration (% ME)			**Speed**
Reference	**Fat**	**Protein**	**Carbohydrate**	**(m/s)**
Hill *et al.* (1996)	38.2	23.0	38.8	15.20
	27.6	20.4	51.2	15.11
Hill *et al.* (1998)	34.0	36.0	30.0	15.34
	33.0	24.0	42.0	15.43
Hill *et al.* (2000)	32.5	24.6	42.6	15.25
	24.9	20.9	54.3	15.13
Hill *et al.* (2001)	33.0	37.0	30.0	15.34
	33.0	24.0	43.0	15.42

In this series of studies it was reported how long it took the dogs to finish a sprint of a given distance. Table 1.4 reports calculated m/s to try and standardise the speed of the Greyhound to be able to compare between studies. Trials conducted by Hill *et al.* (1996, 1998, 2000 and 2001) fed protein ranging from 20.4 – 37% on an ME basis, which showed that a Greyhound fed 20 – 23% protein, will run a 500 m race slower than a Greyhound fed 36 – 37% protein. These trials also used a range of carbohydrate concentrations, ranging from 30 – 54.3 %, and showed that when fat concentrations are reduced and carbohydrate concentrations increased, the dogs run faster. Hill *et al.* (1996) showed that dogs ran slower when the diet contained 38.2% fat and 38.8% carbohydrate *versus* Hill *et al*., (1998) where Greyhounds were fed 33.0% fat and 42% carbohydrate (on a ME basis). Therefore, these studies suggest that a high protein diet, when compared with a medium protein diet, in the racing Greyhound actually slows racing times. The high protein diet may have slowed Greyhounds because the protein replaced fat and carbohydrates, which are the preferred fuels of choice during exercise. This series of trials show that racing Greyhounds generally perform better on a high carbohydrate diet; the best results, were observed with a diet of 51.2% carbohydrate, 20.4% protein and 27.6% fat on a ME basis (Hill *et al*., 1998), although other combinations may have had much greater effects on the performance of racing Greyhounds. Even though the speed of the Greyhound increased with a high carbohydrate diet, there was a nutritional limit to how much carbohydrate and fat the diet could contain.

Similar results were found by authors Toll *et al.* (1992) who fed Greyhounds a high carbohydrate (52%), low fat diet (16%) and compared race performance in dogs fed a high fat (56%), low carbohydrate (8% diet). The authors found that after five weeks, the Greyhounds on the high carbohydrate, low fat diet ran 2.6 seconds faster (over 500 m) than dogs on the high fat, low carbohydrate diet. Although optimal for the Greyhound, the high carbohydrate combination may not be suitable for dogs serving a different function, i.e. carrying out a different type of exercise/work. Grandjean (1996) suggested the optimum nutritional distribution of nutrients (on an energy basis) is 40 - 45% carbohydrate, 35%

protein and 20 - 25% fat. This ratio of nutrients was not tested in the series of trials conducted by Hill *et al.* But comparisons show that the suggested concentration of protein by Grandjean (1996) may be too high and the concentration of fat may be too low. Greyhounds use a tremendous amount of energy during the initial acceleration, Staaden (1984) found that racing Greyhounds use 3 $\text{kcal}\cdot\text{kgBW}^{-1}\text{km}^{-1}$ during the initial acceleration and 1 $\text{kcal}\cdot\text{kgBW}^{-1}\text{km}^{-1}$ for the remainder of the 60 second run. Hill *et al.* (2000a) proposed that racing Greyhounds require 155 ± 9 $\text{kcal}\cdot\text{kg}^{-0.75}\cdot\text{d}^{-1}$ for maintenance requirements. This value is towards the low end of the range proposed by Grandjean and Paragon (1993a), who suggest a range of 150 – 190 $\text{kcal}\cdot\text{kg}^{0.75}\cdot\text{d}^{-1}$ was a sufficient estimate for the maintenance energy requirements of the Greyhound, depending on the number of races run in a day.

Fat reserves are not important for sprint racing, because little fat is burned during a race. Therefore in a sprinting dog, fat mass may represent dead weight. The main fuel source used during exercise in the Greyhound muscle appears to be endogenous glycogen, and the preferred metabolic pathway to produce glycogen is anaerobic glyconeogenesis (Dobson *et al.,* 1988). Studies have shown that racing Greyhounds use significant amounts of muscle glycogen (Dobson *et al.,* 1988; Richter and Gakbo, 1986). The series of trials conducted by Hill *et al.* (1996, 1998, 2000 and 2001) suggests that racing Greyhounds are highly reliant on carbohydrates. Carbohydrates are stored in the muscle as glycogen, these sources of energy are quickly mobilised during exercise as they do not need to be transported from different parts of the body, as they are already stored in larger amounts in the muscle that fat.

Anaerobic metabolism can produce large quantities of lactate (Nold *et al*., 1991). The Greyhound largely relies on anaerobic metabolism for energy and produces high plasma lactate concentrations from a short sprint (Snow *et al.,* 1988; Ilkiw *et al.,* 1989; Nold *et al*., 1991). This increase in lactic acid concentration indicates that anaerobic metabolism contributes greatly to energy production in the racing Greyhound (Ilkiw *et al.,* 1989). Greyhounds run short fast sprints, and therefore, their muscle fibres are adapted to produce, and tolerate high lactate concentrations (Rose and Bloomberg, 1989). Greyhounds have a higher proportion of fast twitch muscle fibres than slow twitch fibres (Guy and Snow, 1981), and therefore have lower oxidative capacity and favour anaerobic metabolism.

If lactic acid builds up, it can cause serious imbalances to the acid-base balance in the body. Greyhounds, like all mammals, increase their respiratory rate to compensate for CO_2 build up and hyperventilate to help with thermoregulation after a race (Ilkiw *et al.,* 1989; Staaden, 1984). Buffers are substances that help maintain or restore natural balance in the body. Sodium bicarbonate is considered a buffer to restore intracellular acid-base balance after strenuous exercise. Therefore, ingestion of a buffer before a race may lower intracellular acid-base disturbance in the racing Greyhound, and improve performance time. However, trials have shown that consumption of sodium bicarbonate does not reduce the acid-base imbalance associated with exercise, or significantly affect performance times (Holloway and Sundstrom, 1996; Kesl and Engen, 1998).

Further studies have been conducted to determine if the effects of thyroid hormones (Hill *et al.,* 2001a), vitamin C (Marshall *et al.,* 2002) and vitamin E (Hill *et al.,* 2001b) on the running time of racing Greyhounds. Thyroid hormones regulate and are regulated by metabolic rate and since exercise alters metabolic rate, it was therefore thought that hormone concentrations may affect racing times. Hill *et al*. (2001a) found that serum thyroid concentrations (T4) remained unchanged (when adjusted for the increased albumin concentrations) and concluded that although racing Greyhounds have a lower resting T4 concentration than other breeds of dogs, it may be due to interbreed variation. Vitamin C and E both act as antioxidants, and may defend against the radical damage caused by exercise, therefore, supplementation of vitamin C and E may influence performance and race times in Greyhounds. Marshall e*t al.* (2002) found that vitamin C supplementation at high doses actually slows down the racing speed of the Greyhound. When Greyhounds were given a dose of 1 g of vitamin C per day, it slowed the dog by 0.2 s over 500 m. The authors indicated that even though the time difference is small, it equates to 3 m over a 500 m race, and therefore, may represent the difference between losing and winning. Similar results were found when the effect of vitamin E was tested.

Greyhounds supplemented with high doses (1000 IU per day) ran slower than the dogs supplemented with medium doses (100 IU per day) of vitamin E (Hill *et al.,* 2001b). However, Scott *et al.* (2001) showed that the vitamin E plasma concentrations were lower in Greyhounds that did not receive supplementary vitamin E. It is thought that high doses of antioxidants may have harmful effects. Podmore *et al.* (1998) found that vitamin C may exhibit prooxidant properties at high doses and induce oxidative stress, which may cause the slower race times. Although high doses of vitamin E slows down the running speed of Greyhounds, Vitamin E is still essential for the well-being of the dog (Anonymous, 2006) and should be included in the diet of racing Greyhounds. Vitamin E is a lipid-soluble antioxidant and prevents free-radical or oxidative damage to nucleic acids and cell membranes containing polyunsaturated fatty acids (Anonymous, 2006). Clinical signs of vitamin E deficiency in dogs include muscle weakness, reproductive failure and retinal degeneration (Anonymous, 2006).

A practice commonly employed by many racing Greyhound trainers, is food restriction, which is believed to make the dogs run faster. The theory behind the practice is that a lighter object will accelerate faster than a heavier object. Hill *et al.* (2005) conducted trials on feed restricted (85% of maintenance energy requirements) or free choice (up to 100 %) fed animals. They concluded that the feed-restricted animals ran 0.7 km/h faster over a short sprint race (500m) and weighed 6% less than animals that were fed free choice. This supported the theory that a slight reduction in weight will result in a slight (0.7 km/h) improvement in performance. It could be argued that there are long-term effects to restricting feed intake, which could result in negative ramifications for the future health of the dog. However, a long term study, using dogs from eight weeks of age to death, showed that dogs that were fed 25% less food had an increased median lifespan, compared with its pair-mate, which received 100% of estimated ME for large breed dogs (Kealy *et al*., 2002). The timing of feeding for the racing Greyhound should also be considered. Feeding a small amount (< 1% of bodyweight) before a race can provide a ready source of energy for the race, but Kohnke (1997) also recommended feeding the Greyhound its pre-race meal at least 6 - 8 hours before exercise to allow enough time for the food to be digested.

1.5.6.2 Sled Dogs: Long distance endurance athletes

During the mid-18th century, European explorers first encountered the Inuit, their dogs, and their unusual mode of transportation, which was a team of dogs pulling a sled. This led to teams of dogs being the accepted mode of transport for gold prospectors and their families. While the gold fields were still being mined in Alaska in the beginning of the 19th century, other adventurers saw the value of using sled dogs. Over the next 90 years sled dogs have served research stations in Antarctica and guided U.S. army rescues (Reinhart and Bolser, 1996). Sled dog nutritional research was initiated in 1959 when significant complaints were made that dog pemmican (a concentrated form of dog food) was nutritionally inadequate. Dogs that were fed pemmican for more than six weeks showed signs of weight loss, diarrhoea, coprophagy and some dogs developed sore gums or palatal ulcers (Taylor *et al.,* 1959). Research showed that pemmican had an abnormal ratio of protein (g) to fat (g) (1:0.43) and a new pemmican diet proposed by Taylor *et al.* (1959) with a protein to fat ratio of 1:1.84 appeared to be better when trialled on dogs at their research facility in England. However, the new pemmican diet still resulted in weight loss in sled dogs. Further trials by Wyatt (1963) and Orr (1966) also tried to perfect a sled dog diet. Since then many trials have been conducted to understand what nutritional factors are important for optimal performance of the racing sled dog.

The major source of fuel used for muscular work by sled dogs comes from the metabolism of FFA (Hammel *et al.,* 1977; Paul and Issekutz, 1967; Kronfeld, 1973). Hammel *et al.* (1977) investigated the need for carbohydrates in the diets of racing sled dogs. They concluded that as far as glucose homeostasis was concerned, racing sled dogs had no dietary need for carbohydrate. A high fat, low carbohydrate diet enhanced the sled dog's ability to mobilise body fat during a bout of exercise, which coupled with their haematopoietic response (the ability to sustain the circulating blood volume) to training, suggested that an ideal diet for racing sled dogs was formulated using fat rather than carbohydrate as the main energy source. Hammel *et al.* (1977) also suggested that a high fat, low carbohydrate diet may be suitable for other dogs that are subjected to sustained (endurance) strenuous work, such as foxhounds, gun dogs and military scout dogs. A diet with high fat and protein content and virtually no carbohydrates appeared to have no adverse effects on sled dogs. Kronfeld (1973) suggested that the maximum amount of carbohydrate in a sled dog's diet (when fed 1.3 times maintenance energy) should not exceed 39%. Feeding a high fat diet has a glycogen sparing effect on sled dogs which is beneficial for endurance activities (Reynolds *et al.*, 1995a:1996). A high fat diet enhanced performance by increasing the availability of lipids at the mitochondria (which is the site of lipid combustion for energy). An enhanced VO_{2max} (maximum O_2 consumption) also increases the rate at which fat combustion occurs. VO_{2max} is determined in part by the genetics (Maxwell *et al.,* 1977), level of aerobic training (Banse *et al.,* 2007), age (Haidet, 1989) and gender (Ogawa *et al.,* 1992). When dogs were exercised at 40% of their VO_{2max}, it caused a significant and steady increase in circulatory FFA in dogs, and their FFA concentration remained significantly higher than resting states for 30 min after exercise ceased. Exercise at 60% VO_{2max} also caused an increase in circulatory FFA. These factors contribute to the glycogen sparing effect in the sled dog (Reynolds *et al.*, 1996). Dogs that are fed a high fat diet have a greater ability to mobilise and use FFA than dogs that are fed a high carbohydrate diet (Reynolds *et al.*, 1994). This diet prepares the dog for endurance work by supporting efficient mobilisation and metabolism of FFA as an aerobic fuel (Reynolds *et al.*, 1995b).

Consumption of a carbohydrate-free diet does not influence post-prandial concentrations of circulating glucose or insulin (Raabs *et al.*, 1976). This combined with the fact that dogs do not develop ketosis (Young, 1959), suggests that dogs have certain metabolic advantages over humans such as; a higher O_2 carrying capacity due to larger red blood cell numbers, more haemoglobin, and an ability to mobilise higher concentrations of FFAs, which are the major fuel for aerobic metabolism in muscle during prolonged exercise (Kronfeld *et al.,* 1977). However, the influence of genetic selection in the sled dog must be taken into account. Management and local food availability have both contributed to their adaption to a high fat diet over many years and may account for sled dogs ability to compensate for a carbohydrate-free diet.

Sled dogs race in extremely cold climates and dogs that work in cold climates require more energy to perform to the same level as dogs in warmer climates (Blaza, 1982). A number of studies have investigated the nutritional and energy requirements of working dogs in cold climates, more specifically, working sled dogs.

Sled dogs have high energy requirements. Doubly-labelled water has been used to estimate the energy expenditure of sled dogs running long distances (Hinchcliff *et al.*, 1996: 1997a). These studies used the doubly-labelled water technique, to estimate that sled dogs expended 11,200 kcal/d over a distance of 460 km, running at average of 7 km/h and averaging 160 km/d. This figure is significantly higher than the 3500-4600 kcal/d that was previously estimated by Wyatt (1963). Estimates on the work output of sled dogs have also been conducted by Taylor (1957), who found that a team of nine sled dogs weighing an average of 39 kg each, trotting and pulling a 55 kg weight, had the same work out-put as the same team of nine sled dogs walking and pulling 95 kg (1100 kcal/hr). Table 1.5 estimates the energy requirement of a 20 kg Husky in a harness during various workloads.

Table 1.5: Changes in energy requirements for a 20-kilogram Husky in harness during various workloads.

Type of exercise	Energy requirements (kcal of ME)
Maintenance	100-1,200
Training (5-8 km/day)	1,300-1,400
Training (10-20 km/day)	1,700-1,800
Training (30 km/day)	2,000-2,400
Speed racing	1,400-1,800
Long-distance (Alpirod)	2,500-3,000
Iditarod	7,000-8,000

ME = metabolisable energy

(From GrandJean and Paragon, 1993).

Another study has shown that Alaskan sled dogs participating in sprint races (consisting of either 12 km for a team of six dogs, 9 km for a team of four, and 2 km for a team of two) use 572 kJ/kg $BW^{0.75}$ per day. Therefore a 20 kg dog would use 5,410 kJ/day or 1,293 Kcal/day (Brown *et al.*, 2009), which according to Table 1.5 equates to training 5 – 8 km per day.

Intense exercise results in oxidative stress and therefore oxidative damage which can cause injuries and result in reduced performance of the dog. Intense exercise can also lead to a combination of immunosuppression and increased protein catabolism (McKenzie *et al.,* 2007). Injuries can be minimised by adequate nutrition and supplementation. Hinchcliff *et al.* (2000) concluded that minimally trained sled dogs did not have the mechanisms to cope with oxidative damage caused during repetitive endurance exercise. Antioxidant supplementation benefits the racing sled dog by increasing plasma concentrations of antioxidants and decreasing DNA damage caused by oxidation (Baskin *et al.,* 2000: Chew *et al.,* 2000; Hinchcliff *et al.*, 2000, 2000a, 2004: Piercy, *et al.,* 2000; Dunlap *et al.,* 2006). The antioxidants tested in these studies included vitamin E, blueberries and a mixture of β-carotene, α-tocopherol and lutein. However, Piercy *et al.* (2001) found no association between low plasma vitamin E concentration and reduced performance with respect to either endurance or team speed in sled dogs, suggesting that vitamin E decreases DNA damage, but may not enhance the athletic ability of the dog. Grandjean *et al.* (1998) used two groups of search and rescue dogs at sea level and high altitudes to search for and discover victims hidden by debris in a defined area. Group 1 were fed 500 mg of Vitamin E and fish oil in a special diet formulated to combat stress, while group two were fed a standard diet. Group one performed better at higher altitudes (4,800 m and 5,980 m above sea level) when compared with group two, however the special diet fed to group one had higher concentrations of nutrients and was less moist than the standard diet which may have confounded results. The authors found higher plasma concentrations of vitamin E in group one even at higher altitudes, but they attributed the better performance of group one to the fish oil supplementation. The (n-3) fatty acid induced endothelial vaso-relaxation and enhanced red cell deformability, which both improved O_2 uptake by muscle cells.

Antioxidants may help the immune system; however, currently a comprehensive set of recommendations for nutrient support on the immune system does not exist for large or small animals. Extrapolation from human or other animal studies is not recommended since over-feeding a specific nutrient can cause toxicity, and also different species have different metabolic pathways and different enzymes that hinder aspects of the immune system (Saker, 2006).

1.5.6.3 Other working dogs

There are many other types of canine work including, search and rescue, hunting and farm dogs. Although some research has been carried out into the nutritional requirements of these dogs, the requirements have not been well defined (Jones *et al.,* 2004). One of the problems with estimating the requirements of dogs such as search and rescue dogs is that there is a large variation in breed, age, and type of work performed (Jones *et al.,* 2004). This is also true of working farms dogs in NZ. While there are only two main breeds of working dogs in NZ; the Heading dog and the Huntaway, there are large variations in age, weight and also body size in both these breeds (Cave *et al.,* 2009).

A study conducted in NZ using Harrier hounds running on treadmills found that a high protein (49%), low carbohydrate (13%) dry kibble seemed to benefit working dogs when compared to a low protein (22%), high carbohydrate (45%) dry biscuit (Hill *et al.,* 2009). These benefits included higher apparent digestibility of dry matter, protein, fat and energy, lower glycaemic index and reduced large intestinal fermentation of carbohydrates. This study reproduced results from previous studies and suggested that show working dogs perform better on a low carbohydrate diet (Kronfeld, 1973; Hammel *et al.,* 1977).

Studies conducted on hunting English pointers also found that there was an influence of diet on working performance (Davenport *et al.,* 2001). Dogs were fed two commercially available diets differing in the amounts of nutrients and quality of ingredients used. Dogs were initially fed to NRC recommendations for very active dogs, but the handlers were told to adjust the feeding, if required, to maintain ideal body condition. Diet A had higher amounts of fat, protein and ME, and lower amounts of carbohydrates than Diet B. The dogs performed better (judged on total finds per hunt) on Diet A and were able to maintain an ideal body score (on a 5 point scale) pre and post hunting season better than dogs on Diet B.

1.5.6.4 Implications for the Heading dog and Huntaway in NZ

To date, there is no published literature to establish the energy expenditure of farm dogs in NZ. It is not currently known whether the data obtained from the studies of Greyhounds and sled dogs are useful in determining the nutritional requirements of a NZ farm dog.

Generally from the types of work the Heading dog and the Huntaway conduct, it may be hypothesised that these breeds may have different proportions of muscle fibres, with the Heading dog closer to the Greyhound, with a higher proportion of fast twitch fibres compared to the Huntaway. However this still needs to be investigated. If there are differences in muscle fibre types, this could have further implications on the nutritional requirements of the two breeds. Section 1.5.6.1 showed Greyhounds have faster race times with specific macronutrient proportions (i.e. higher carbohydrate diets), while sled dogs race better with a higher proportion of their calories coming from fat. Although there is no evidence to indicate that sled dogs have a higher proportion of slow-twitch fibres, which require aerobic metabolism for energy synthesis, it could be predicted that this may be the case, and could have implications for the Huntaway. The appearance of Heading dogs and Huntaways are distinctly different, with Huntaways having a strong large build, whereas the Heading dog is slender and long legged (Dalton, 2010). These physical differences may indicate metabolic differences (as mentioned above) and further studies need to be conducted to establish any differences.

The type of work farm dogs carry out varies from season to season, with the highest workload period occurring during spring and early summer, however there are slight differences between the North Island and South Island. The heaviest workload usually occurs when lambs are docked (a process where the tail is removed), weaned, or for shearing stock. Typically this occurs in November and December in the North Island and January to March in the South Island. This difference in peak periods occurs because of the difference in climate; generally the North Island exhibits warmer weather earlier on in spring than the South Island. This means that lambs are born earlier in the North Island when compared to the South Island. To the authors knowledge, there is no literature available on the general scheme of the working dog, however, from personal observation, during heavy workload periods, a typical day can start at 5am in the morning. Farmers will start mustering sheep to the stock yards early in the morning. The time taken to muster varies depending on the size of the farm and number of workers and dogs. Generally all stock is in yards before mid-day (when the sun is at its hottest in NZ). At this time shearing, docking or other yard duties (drenching, veterinary checks etc) occur. The stock is then led back to the paddock, usually in the early to late afternoon. During times when mustering and yard work is not required (i.e. off-peak periods of work), farmers usually take this down time to fix fences and finish odd jobs around the farm.

1.5.7 Injuries associated with work

Working dogs sustain injuries, and surveys have been conducted in NZ looking at injuries in farm dogs. Worth and Bruce (2008) conducted a survey between December 1991 and January 2005 investigating working dog injuries in NZ, where 96 working dogs were identified with carpal disease. More recently, 66 veterinary practices participated in a survey of diseases in working farm dogs conducted by Cave *et al.* (2009). The majority of dogs surveyed were Huntaway (51%) and Heading dogs (39%), as these are the dominant breeds used as working dogs on NZ farms. Gastro-intestinal diseases accounted for 9% (n = 200 of 1,024 dogs) of the cases presented, of which 25% presented with constipation (n = 51). Injuries associated with work, were non-traumatic musculoskeletal disease, of which arthritis was the most common (13% of non-traumatic cases n = 129). Huntaway’s appeared more susceptible to hip dysplasia (70%: n = 16 of 23) than Heading dogs in the study (n = 5 of 23). A large number of dogs were brought in for foot trauma (31%: n = 260 of 848), and injuries to the stifle ligaments were slightly more common (54%; n = 35 of 65) in Heading dogs than other breeds. The majority (68%: n = 44 of 65) of the stifle ligament injuries appeared to occur while the dog was going through a fence (crawling under barbed-wire strand, jumping between strands or jumping over a fence). All fence-related injuries were evenly distributed between Heading and Huntaway's. Heading dogs (compared to Huntaway's) tended to have more injuries to the Achilles mechanism (73%; n = 16 of 22) or tarsal joints, fractures and fracture-luxation's of the tarsus (72%: n = 23 of 32), and hip luxation's (63% n = 17 of 27). This suggests that these injuries might be related to the working behaviour of the dog, as Heading dogs need to run faster while herding livestock. Marcellin-Little *et al.* (2005) reviewed literature on typical injuries and trauma induced by activity in sporting dogs. Table 1.6 shows the common orthopaedic injuries and problems linked to sporting activities in dog and the injuries Marcellin-Little *et al.* (2005) linked with Heading dogs (stifle, hip and tendon injuries) which generally agree with results from Cave *et al.* (2009).

Table 1.6: Common orthopaedic injuries and problems linked to sporting activities in dogs (from Marcellin-Little *et al.* 2005)

Structure	Injury	Dog affected	Treatment
Bone	Tarsal and carpal fracture	Racing Greyhound	sx, bone screws
	Acetabular fractures	Racing Greyhound	sx, bone plate
Joint	Interphalangeal luxations	Racing Greyhound	sx (when severe)
Carpus	Accessory carpal bone structure	Racing Greyhound	sx, bone screws
Elbow	Traumatic FMCP	Racing Greyhound	sx, excision
Shoulder	Medial glenohumeral ligament axulsions	Agility, Hunting dogs	no sx
Hock	Distal tibial fracture	Racing Greyhound	sx, bone plate
	Central tarsal bone fracture	Racing Greyhound	sx bone screw(s)
Stifle	Traumatic cruciate ligament axulsions	All sporting dogs	sx, stabilisation
Hip	Craniodorsal luxations	All sporting dogs	sx, stabilisation
Ligaments	cranial cruciate ligament injuries	Flyball dogs, Disk dogs	sx, stabilisation
Muscle	Tear: gracilliss mm., tensor fascia lata mm	Racing Greyhound	no sx
	Contracture: infraspinatus mm	Hunting dogs	sx release
	(Partial) common calanean	Hunting dogs	sx (when severe)
Tendon	Tendon tear, Superficial digital flexor tendon	Agility, Heading dogs	sx, stabilisation

FMCP: fragmentation of the medial coronoid process; mm: muscle; sx: surgical treatment

A questionnaire developed by Houlton (2008) found that there were no statistically significant associations between the type of injury and breed, or the number of days worked in the 2005 and 2006 seasons for Gun dogs in Great Britain. Geographic location was also not a significant factor in 2005, but in 2006 dogs working in the Midlands, the South West, the North and Wales had a higher incidence of wounds, although the authors had no obvious explanation for their findings. Cut pads on the feet of dogs made up 58% of all foot injuries. Table 1.7 shows the number and percentage of lame/injured gun dogs per season, and the number requiring veterinary treatment in Great Britain during the 2005 and 2006 seasons. From these studies, it can be seen that working dogs, including heading and gun dogs tend to have a large proportion of foot injuries.

Table 1.7: Number and percentage of lame/injured gun dogs per hunting season, and the number requiring veterinary treatment in Great Britain during the 2005 and 2006 seasons (from Houlton 2008).

Season	Number of dogs	Number of lame /injured dogs	Number of lame /injured dogs per season	Number of dogs treated by Vet	Number of days worked
2005	690	192	28%	89	46%
2006	668	145	22%	60	48%
Total	1358	337	25%	158	47%

1.6 Energy requirements

Different breeds and different sizes of dogs have different maintenance energy requirements, which is evident in any food section of the pet store or veterinary clinic. Dogs with different activity levels also require different energy requirements, for example, inactive dogs require less energy than active dogs (Table 1.8). There are numerous research studies into the energy requirements of dogs, table 1.8 summarises this work.

Table 1.8: Various research conducted to establish energy requirements of dogs.

Reference	energy requirement	type of dog
Kienzle and Rainbird (1991)	$BW^{0.75} \times 0.550$ MJ of DE	Most breeds
Manner (1991)	$BW^{0.75} \times 0.432$ MJ of DE	Inactive dogs
	$BW^{0.75} \times 0.5$ MJ of DE	active dogs
Burger (1994)	$125 \times BW^{0.75}$ ME Kcal/d	
AAFCO	132 × BW0.75 ME Kcal/d	active dogs
NRC	$132 \times BW^{0.75}$ ME Kcal/d	active dogs

Activity associated energy expenditure (AEE) can also be calculated using various equations (Burger and Johnson, 1991).

Equation 1.3: The energy used per meter jumped by a dog can be calculated as

$$= \frac{9.81\ BW\ \text{(acceleration due to gravity)}}{18.8\ BW^{1.25}\ \text{(energy efficiency of a vertical jump) KJ/d}}\ \text{KJ/M}$$

Equation 1.4: Energy cost of running =

$$\frac{18.8\ BW^{0.612}\ \text{KJ/KM}}{18.8\ BW^{1.25}\ \text{KJ/KM}}$$

And the total cost for standing is 5.9 W KJ/d (Burger and Johnson, 1991).

One hour of work causes approximately a 10% increase in maintenance energy requirements, so one day of sport or work may cause a 40 – 50% increase in energy intake (Grandjean. 1996).

1.6.1 Measuring Energy Expenditure

There are two main ways of measuring energy expenditure; direct calorimetry and indirect calorimetry. Direct calorimetry measures the total heat lost from the body (in the form of radiant, convective, conductive, and evaporative heat), and is achieved by placing the subject in a thermally isolated chamber and measuring heat dissipated by the body. Indirect calorimetry measures the total amount of energy produced by the body, and is achieved through a combination of measurement of CO_2 produced and O_2 consumed by the body (Ainslie *et al.,* 2003). Only indirect calorimetry methods will be considered in this literature review as direct calorimetry has little practical use for measuring energy expenditure in free-living animals.

There are many methods for establishing the energy requirements of a subject indirectly, these including the use of respiration chambers, ventilation hoods, or masks. Energy requirements can also be measured using food intake-mass balance (Boisen and Verstegen, 2000; Burger, 1994), by measuring heart rate (Brage *et al.,* 2003), using accelerometers (Berlin *et al.,* 2006), pedometers (Chan *et al.,* 2005), global positioning systems (GPS; Ahlstrom *et al.,* 2006) or by isotopic washout methods (Ballevre *et al.,* 1994). Some of these methods, such as the use of heart rate monitors, activity monitors and GPS require estimation of basal metabolic rate (BMR) to be made.

1.6.2 Respiratory chamber

Indirect calorimetry remains the 'gold standard' method for measuring energy expenditure (Hill, 2006; Maddison *et al.,* 2007). It relies on the fact that as nutrients are oxidised and energy is released, O_2 is consumed and CO_2 is produced. Measurements of either (or both) O_2 intake and CO_2 output are made from the air within the chamber at specific intervals. There are open circuit and closed circuit systems. In closed circuit systems the respirator contains pure O_2 and as the subject breathes, CO_2 is removed and passes over gas analysers. The rate of gas volume decrease is measured, which is a direct measure of O_2 consumption. This method is suitable for resting or BMR but not exercise metabolism. In open circuit systems there is a constant, uniform, pre-set temperature. Fresh atmospheric air is continuously drawn through the chamber and mixed air leaves through ducts where gas analysers and ventilation modules measure gas proportions and flow rates respectively. The gas analysers measure the changes in O_2 and CO_2 concentrations by measuring O_2 and CO_2 entering and leaving the chamber, and can then be used to calculate the RQ (Ainslie *et al.,* 2003).

Respiratory chambers can measure energy expenditure of dogs at rest and during exercise such as running on treadmills in standardised conditions. However, the equipment is costly; Ravussain *et al.* (1986) spent $90,000 in 1984 for materials for the chamber alone. The respiration chamber requires subjects to spend 24 hours in a sealed chamber, and is not suitable for measuring the energy expenditure of free-living subjects such as working farm dogs. Dogs would also have to be acclimatised to the environment, which aside from the timeline involved, may cause stress and therefore influence results.

Another method to assess energy expenditure is by use of a ventilated hood, canopy, mask or the Douglas bag technique. These work in a similar way to a respiration chamber but do not require the subject to spend 24 hours in a chamber and are mostly used to measure resting metabolic rate (Webb, 1991). Using masks or a mouth piece with a nose clip are effective ways to measure O_2 intake and CO_2 output during exercise. Furthermore, using a mask and a nose clip allows breath by breath analysis. The expired breath is collected either with the Douglas bag, or through online equipment that sends the information to a computer. This does limit the study to laboratory conditions, although this equipment has been used by the NRC to estimate the nutrient requirements of pet dogs (Anonymous, 2006). The equipment is again expensive, the dogs need to be trained to run on treadmills, and again they have to be acclimatised to the procedures used for collecting expired gas.

1.6.3 Food intake-mass balance

Food intake-mass balance involves weighing the food consumed by the animal, analysing its faeces and calculating if any body mass changes occur. This method measures the nutritional requirement of an animal by measuring if the animal loses or gains weight. If the animal loses or gains weight over the testing period, then the animal is either not receiving enough or receiving too much energy from the diet respectively. This technique is based on the following relationship:

Equation 1.5: Energy expenditure = metabolisable energy intake – energy retained in the body (Haggarty and McGaw, 1988).

The food intake balance technique can also be used in conjunction with the serial-euthanasia technique, which requires animals to be euthanised at the start and the end of a trial and analysed for protein, fat and energy (Boisen and Verstegen, 2000; van Milgen and Noblet, 2003). This method is accurate when there is a large difference in bodyweight between the start and the end of the trial and therefore is suitable for studies involving growth of an animal. A large disadvantage with this method, other than it involves euthanising animals is that to be accurate a large sample is required to combat the inter-animal variation (Boisen and Verstegen, 2000). This technique is not suitable for use in companion animals due to the large numbers of animals that would need to be euthanised, and there are other less invasive methods available.

1.6.4 Heart rate monitors

Measuring heart rate using heart rate monitors is another method used to indirectly measure energy expenditure. This method uses the assumption that heart rate is related to O_2 consumption during exercise and varies with age, fitness and excitement (Brage *et al.,* 2003). There are two main types of heart rate monitors, the holter and the surgically implanted monitors. Both models function in a similar way, with the main difference being how the monitor is attached to the animal. The basic heart rate monitor setup is comprised of a monitor, lead wires, electrodes and a battery.

Holter type monitors are strapped onto the subject with leads placed on shaved areas of the animal on the lateral chest wall. The leads are then bandaged into place to prevent their displacement (described by Petrie, 2005). The monitor itself is usually placed on the back of the animal. Hill (2006) used holter monitors to record electrocardiograms of the heart of racing Greyhounds before and after a race. However some dogs did not run well due to the weight of the apparatus, and the motion of running also caused artefacts that made some of the traces unreadable.

The implantable monitors are surgically implanted into the animal at the start of the experiment and removed at the end. The main advantage of using implantable heart rate monitors to measure energy expenditure is their ability to gather data over long periods of time (Butler *et al.,* 2004). The heart rate monitors can be recovered when it is convenient for the researcher, which is an advantage for free-living animal research. Also, depending on the particular model of monitor, researchers are able to measure other variables such as body temperature, acceleration and altitude (Butler *et al.*, 2004). A major disadvantage is the need for surgical implantation, and another disadvantage is that the weight of the monitor apparatus may restrict the species that can be studied. More specifically the weight of the battery is a major limitation on the size of the transmitter, which, in turn limits the minimum size of the animal that can be studied. A transmitter that weighs 1g cannot be placed in an animal that weighs less than 40g (Butler *et al.,* 2004).

The heart rate method requires the use of equations that use heart rate and O_2 consumption. Therefore, a new calibration equation is required for every new species that is studied, and this can be costly to establish. Another potential source of error using this technology is the increase in the dogs' heart rate due to excitement, especially, in the case of Greyhounds, just before the race when the dogs are standing still in their boxes. Heart rates may also continue to remain high for many minutes during recovery; therefore heart rate monitors may not produce reliable estimates of energy expenditure in dogs (Hill, 2006). Gerth *et al.* (2010) also found that using heart rates was not a good indicator of energy expenditure at rest in Inuit dogs, except when the physiological condition of the dog is known. The authors found that in resting dogs there was an increase in heart rate during digestion and decrease in heart rate during periods of under nutrition.

1.6.5 Pedometers, accelerometers and global positioning systems

Pedometers, accelerometers or GPS can also be used to indirectly measure activity associated energy expenditure (AEE). These devices still require an estimation of BMR to be made. Pedometers count the number of steps taken by responding to the vertical acceleration of the subject, using a horizontal spring suspended lever arm. Vertical acceleration of the hip causes the arm to move up and down, which in turn opens and closes an electrical circuit and accumulates the number of steps taken into a digital display unit (Berlin *et al.,* 2006). Pedometers are relatively small and cheap, but they generally lack the sensitivity to enable the researcher to predict accurate energy expenditure of the subject (Ainslie *et al.,* 2003). Pedometers are also unable to predict when the subject is stationary or sedentary (Melanson Jr *et al.*, 1996). Chan *et al.* (2005) found that pedometers over-estimated the actual number of steps taken by large and medium dogs which were walking by approximately 17 %, and steps were underestimated by > 5% by large dogs which were running. When dogs run, both front feet are extended and touch the ground close together in time and the hind limbs are flexed at the hips, so there may not be enough movement in the thoracic girdle to cause the pendulum in the pedometer to register a step when pedometers were attached to the collar.

The first descriptions of electrical motion counting devices to measure acceleration in humans date back to the early 1970's (Kupfer *et al.,* 1972: Morris, 1973). Essentially there are two types (Meijer *et al.,* 1991). The first type is a large scale integrated motor activity monitor, with a sensor consisting of a cylinder containing a mercury ball. Movement of the sensor causes the mercury ball to close a switch thereby registering a count (LaPorte *et al.,* 1979: McPartland *et al.,* 1976: Schulman *et al.,* 1977). These large scale integrated monitors are comparable to pedometers as the function and accuracy are similar (Meijer *et al.,* 1991). The second type of electrical motion counting device is considered a real accelerometer (Meijer *et al.,* 1991) and this type will be discussed in this review. There are many different brands of pedometers and accelerometers used by researchers (Tyron, 2008). Accelerometers can be categorised into uniaxial, triaxial and omnidirectional. These categories are a measure of the sensitivity of the units: uniaxial detect movement in one axis, triaxial measure in three and omnidirectional are sensitive to movement in all directions. Uniaxial accelerometers are useful for assessing activity levels between two groups, whereas the triaxial accelerometer is more sensitive and better suited for predicting energy expenditure in conjunction with GPS (Ainslie *et al.*, 2003).

Different brands of accelerometers consist of different functional parts. There are a few articles that discuss best practices and make recommendations as to what a researcher needs to think about when conducting trials using accelerometers (Ward *et al.,* 2005: Trost *et al.,* 2005: Tyron, 2008). The Actical® accelerometer is the smallest accelerometer available to date, it is omni-directional, and also water resistant; these two features make it appealing for research in free-living subjects (Pfeiffer *et al.,* 2006). There are an increasing number of studies looking at the reliability of accelerometers (Meijer *et al.*, 1991: King *et al.* 2004). One study conducted by McClain *et al.* (2007) using the Actigraph monitor, found that inter-instrument reliability for raw variables, total activity counts and steps were high in free-living subjects.

Trost *et al.* (2005) stated that there was no definitive evidence to indicate that one make or model of accelerometer was more accurate or reliable than another, however an earlier study (Welk *et al.,* 2004) studied the reliability of four different accelerometer types (CSA/MTI, Biotrainer Pro, Tritrac-R3D, and Actical®). The human participants underwent three trials of treadmill walking for 5 min followed by a 1 min rest period. The results showed that the CSA/MTI monitor was the most reliable, and Actical® accelerometers were the least reliable. Actical® monitors had the lowest G value (generalisability: which is an extension of intraclass reliability used to quantitatively separate the total variability associated with the accelerometer data). Actical® monitors also had the highest variability in responses of participants across the individual monitoring units.

The Actical® accelerometer is an omnidirectional device. It contains a piezoelectric bimorph plate and seismic mass which is sensitive to movement in all directions. The device works when there is a change in motion i.e. during acceleration, which causes the piezoelectric sensor to generate a voltage. The voltage is amplified and passed to an analogue-to-digital converter which converts the voltage reading to a digital value. These conversions are repeated at 32 Hz. The digital value is used to set a running baseline value and, filters constant acceleration such as gravity (Hansen *et al.*, 2007: Lascelles *et al.,* 2008). This is achieved by taking the mean value of 32 consecutive readings obtained over a period of one min. The current digital value is compared to the baseline and the difference from the baseline is added to the 1 min accumulated value. The value is divided by four and added to the accumulated activity value to create a raw activity value for the measurement period (epoch). The one min accumulated value is reset to zero. The raw activity value is compressed and converted and reported as an activity count (Hansen *et al.*, 2007). An activity count is derived from the force and intensity of displacement (Berlin *et al.*, 2006), and activity counts can be considered as arbitrary units (Lascelles *et al.*, 2008).

Accelerometers have been validated in humans against whole body calorimetry, and results suggest that it is useful for assessing the total daily physical activity and energy expenditure in free-living subjects (Kumahara *et al.,* 2004). The drawback of using accelerometers is that they cannot measure activity at rest, so estimates of resting energy expenditure still needs to be made. In addition, these devices also do not estimate the increased energy expenditure due to standing, moving up and down hills, pulling loads, running over rough ground and maintaining body temperature at low ambient temperatures, or during stressful periods (Hill, 2006). Therefore, these devices are only capable of giving a rough guide of energy expenditure.

However, other studies in humans using uniaxial accelerometers have found that these devices are capable of detecting changes in speed during walking and therefore acceleration. But acceleration in the vertical plane does not correctly estimate energy expenditure during running because the sensor of the device detects vertical acceleration from body movements up to 1.94*g*. *G* is a measure of acceleration, where 1.00*g* is equal to acceleration at free-fall (Kumahara *et al.,* 2004). The centre of gravity during running can exceed 1.94*g,* therefore, exceeding the upper limit of the accelerometer and resulting in inaccurate measurements (Kumahara *et al.,* 2004).

Human studies varying the placement of Actical® accelerometers found that there were no significant differences between ankle, hip or arm placement for adults and children in assessing physical activity (Heil, 2006). The placement of the accelerometer has also been studied in dogs; Hansen *et al.* (2007) placed Actical® accelerometers in eight locations (top and bottom of a collar, on the axilla, on the lateral portion of the humerus, on the antebrachium, on the lateral portion of the thorax, under the sternum and under the abdomen). Although all eight locations provided similar results (r^2 ranged from 0.71 - 0.93) for movement, the ventral portion of the collar was the most convenient and well tolerated, suggesting this may be the best location for fitting the monitors on dogs. A study conducted on cats wearing both harnesses and collars with activity monitors attached found that there was good correlation (r^2 = 0.95) between the two placements (Lascelles, 2008). These authors also found that the monitors attached to collars were able to produce counts during activities such as eating and grooming.

As the popularity of the activity monitors for use in human activity and energy expenditure trials is increasing, there is a need to validate accelerometers with laboratory standards for assessing energy expenditure. The Actical® accelerometer has been successfully calibrated for energy expenditure in preschool children (Pfeiffer *et al.,* 2006), children aged 6 – 16 years old (Puyau *et al.*, 2002) and monkeys (Sullivan *et al.,* 2006) using indirect calorimetry. Meijer *et al.* (1991) suggest that in order to investigate the accuracy of using accelerometers to estimate energy expenditure, it should be used on subjects conducting normal daily activities in conjunction with DLW (section 1.6.1.5.2). Such studies have now been conducted in women with methods including accelerometery and DLW (Leender *et al*., 2001). Doubly-labelled water (DLW) is becoming the gold standard for validating field methods of measuring physical activity, and therefore energy expenditure (Westerterp, 1999). Researchers have developed regression equations relating counts to energy expenditure in adults (Brage *et al.,* 2003: Heil *et al.,* 2003). However, there are studies that have shown that in order for the equations to correctly convert activity counts to energy expenditure, there needs to be separate equations for the level of activity conducted (Crouter *et al.,* 2006: Heil and Klippel, 2003). Two-regression models have been developed for various accelerometers (Crouter *et al.,* 2006: Crouter and Bassett, 2007).

Currently accelerometers have not been calibrated to measure energy expenditure in dogs. All of the trials to date have used accelerometers to measure physical activity, by the means of activity counts. Accelerometers have been used in various clinical settings, and provide valuable information about daily activity that is unobtainable by other methods. Veterinarians have used accelerometers to distinguish between pruritic and healthy dogs (Nuttall and McEwan, 2006), and have determined that Elizabethian collars do not affect spontaneous activity in dogs (Yamada and Tokuriki, 2000a). Culp *et al.* (2009) used accelerometers to prove that ovariectomy via laparoscopy in small dogs resulted in higher activity and therefore faster recovery than via open surgery technique. Yamada and Tokuriki (2000b) concluded that using accelerometers is a better method to investigate behavioural changes due to toxicity in dogs than videotaping dogs, suggesting that accelerometers can measure activity in the dark and results are not biased due to human contact during the filming period. Accelerometers also provide adequate in-home activity monitoring and therefore quality of life assessment for companion animals with chronic diseases (Hansen *et al.,* 2007), and are suitable to follow changes in activity in individual dogs over time (Dow *et al.,* 2009). Accelerometers are becoming an invaluable tool in veterinary medicine, and there is the opportunity, once calibrated for measuring energy expenditure in dogs, for them to have the potential to be an invaluable tool in nutritional studies.

The 1980's saw the development of satellite systems which used radio collars that had transmitters implanted in them (platform transmitter terminals or PTTs) to pick up signals from satellites and send the information to a service centre. However, the elevation of the PTT had to be estimated before the location was calculated, and this caused errors (Keating, 1995). A more recent development is the insertion of global position systems (GPS) into collars. The GPS uses microelectronics that calculates GPS locations from 24 orbiting satellites (Wells, 1986). There are three different types of GPS collars, 1) collars that store information and need to be retrieved in order to download information, this type of collar does not have a transmitting device that lets the researcher know the whereabouts of the animal and collar for retrieval, 2) collars that store and transmit data to a satellite to be retrieved by a data management centre or 3) collars that store information and provide the researcher with information to the whereabouts of the collar for retrieval (Biggs *et al.,* 2001).

Global positioning systems are used to track and determine the density and distribution of wild animals around the world, and have been used on wild dogs (Mills and Gorman, 1997), and wolves (Merrill *et al.,* 1998; Merrill and Mech, 2003). This interest in using GPS has also encouraged studies into assessing precision and accuracy of using collars with GPS to track wildlife (Adrados *et al.,* 2002; Johnson *et al.,* 2002; Mills *et al., 2*006: Schwager *et al.,* 2007). Studies have suggested that terrain and canopy coverage can reduce the number of satellites visible to the GPS collar, and generally tall, dense vegetation and steep topography degrades reception of satellite signals (Rempel *et al.,* 1995; Moen *et al.,* 1996; Rempel and Rodgers, 1997; Dussault *et al.,* 1999; Bowman *et al.,* 2000; Jay and Garner, 2002). It has been established that the accuracy of GPS collar position is affected by the number of satellites from which the signal is received (Wells, 1986; Rempel *et al.,* 1995; Witte and Wilson, 2005). The best trajectory is when there are four satellites visible, this calculates a three dimensional fix (longitude, latitude and elevation). If only three satellites are visible, the elevation is estimated and a two dimensional location is calculated (Wells, 1986), and this is the single most common factor affecting GPS precision, when collars are placed on free-ranging animals. Moen *et al.* (1997) found that 25% of projections were two dimensional when collars were placed on free ranging Moose in Voyageurs National Park USA, and > 50% of projections were three dimensional.

Recently GPS has been used not only for tracking wildlife, but studies in humans and domesticated species. Witte and Wilson (2004) used cyclists to determine the accuracy of GPS for the determination of speed. They concluded that using GPS was generally accurate for determining speed under all conditions where a satellite position was fixed and determined. Differential GPS (dGPS) was used in this study, which uses a network of ground-station controlled satellites, which emit a low power radio signal which contains atomic clock data. The transit-time delays are used by the receiver to establish a triangulated position. There are also satellite-based differential systems that transmit transit-time data via satellite rather than land-based radio transmissions such as wide angle augmentation system (WAAS) and European geostationary navigation overlay systems (EGNOS) (Witte and Wilson, 2004).

Global positioning systems are being incorporated into studies involving working dogs. Ahlstrom *et al.* (2006) showed, in a pilot study, that GPS can accurately measure running distance in hunting dogs. Global positioning systems have been used in conjunction with heart rate monitors to evaluate the work variables and heart rate responses of the working cattle dog during mustering in Australia (Hampson and McGowan, 2007). In this study, GPS were able to record speed of the dogs (the average speed was 34.6 ± 5 km/h with a maximum speed of 43.7 km/h), and provide reliable data in a real mustering situation. The distance covered by these dogs were 13.3 and 30.2 km in 10 mustering sessions ranging from 2.0 to 4.5 hours long (Hampton and McGowan, 2007).

Continuously measured data is usually required for studies that require animals to be tracked, which leads to a problem with GPS. The receivers use a large amount of power, and therefore battery requirements are often a significant constraint (Witte and Wilson, 2004).

The problem with using methods such as heart rate monitors, activity monitors and GPS is that these devices only measure activity associated energy expenditure and some measurement of BMR needs to be estimated. There is on-going debate regarding the formulation of predictive equations and how they should be constructed.

1.6.6 Isotopic washout methods

1.6.6.1 Isotopic carbon washout method

Isotopic washout of stable or radioactive isotopes of carbon (^{13}C and ^{14}C respectively) or hydrogen (^{2}H and ^{3}H respectively) and a radioactive isotope of oxygen (^{18}O) can be used to estimate the rate of CO_2 production, and therefore energy expenditure. Methods developed in dogs have used bicarbonate

(HCO_3^-), or water (H_2O) enriched with one or more of these isotopes (Hill, 2006). The isotopes were administered to the subject via an injection, ingestion or inhalation. The most efficient mode of ^{13}C administration is intravenous (IV) infusion over a period of a few hours. When comparing the recovery of $^{13}CO_2$ (from ingestion) in exhaled breath and ^2H (from an injection) in the saliva of dogs after administering labelled octanic acid, the recovery of ^2H was 1.59 hours earlier than ^{13}C due to post-gastric processes (Wyse *et al.*, 2003). This suggests that the method of administration of the isotopes is very important as it will establish when to take initial and final samples. However, infusion and breath collection may not be possible in free-living subjects since animals need to be restrained to stay still and not accidently remove the IV line and must be acclimatised to wearing a face mask for breath collection.

Little work has been conducted on the use of ^{13}C in dogs. Pouteau *et al.* (2002) compared ^{13}C enrichment in conjunction with a respiratory chamber, and found there was incomplete recovery of ^{13}C by breath analysis. This may be because of the slow turnover rate of CO_2 in the less permeable body pools of the dog. There may also be a degree of fixation of the isotope into other compounds such as amino acids and glycogen. These compounds may have a slower turnover rate or are not oxidised. Other compounds such as urea, which may also incorporate the isotope, are not expelled through the respiratory system, and therefore will not be measured in breath.

One of the disadvantages of using carbon isotopes is the cost associated with its analysis. Analysis of samples containing carbon isotopes requires the use of a mass spectrometer which can be costly.

1.6.6.2 Doubly-labelled Water (DLW)

The doubly-labelled water technique was developed by Lifson *et al.* (1949) and published in a paper describing the theoretical outline of the technique (Lifson *et al.* 1955). Lifson *et al.* (1955) conducted the first validation of DLW involving 12 mice and produced an estimate of CO_2 production with an accuracy of 4% and a precision of 10%. Using this method, only two measurements were required and it allowed mice to live normally between sampling. Subsequent studies were carried out to measure the energy expenditure of free-living, uncaged animals using the technique (Lifson *et al*., 1955). The authors made six assumptions which need to be accounted for when using the technique, but they concluded that these assumptions did not produce serious errors as they either cancel each other out or could be minimised. These assumptions are as follows:

1) Rates of CO_2 production and water losses/gains are constant.
This assumption seems flawed as the amount of CO_2 produced during the day (e.g. during exercise and rest) will vary. However, this assumption has been validated. Alaskan sled dogs lost 0.31 l of water during a 70 hour race, however, this loss did not significantly affect the calculated rCO_2 (rate of CO_2 produced) and energy expenditure (Hinchcliff *et al.,* 1997a). Even though CO_2 and H_2O concentrations change during a given period, these changes do not appear to be significant enough to affect calculations.

2) Isotopic species leaving the body of the animal do so at the same abundance as that of water leaving the body at the same time.
The physical properties of lighter isotopes are slightly different from those of heavier isotopes and leads to an isotopic fractionation (lighter isotopes require a lower heat to change from liquid to gas states which may affect mixing with labelled water). However, equations have been formulated and modified to account for this fractionation (Speakman and Racey, 1988).

3) N (dilution space) is constant throughout the measurement.
Hinchcliff *et al.* (1997a) showed that during an Alaskan sled dog race, dogs lost 1.1 kg of bodyweight which represented a 0.31 kg decrease in total body water. However, this did not produce a significant effect on the average relative total body water or calculations for rCO_2 production and therefore energy expenditure. Nagy (1980) measured CO_2 production in 9 species of mammals and found that DLW provided a good estimate of body water space.

4) The isotopes turn over in the same pool, which is equal to the body water pool.

Coleman *et al.* (1972) divided tissues into two categories; one with poorly permeable, large-volume tissues and the other with highly permeable, low volume tissue. This categorisation is the same as that of Speakman's (1997) two pool method (described in section 1.6.1.5.2.3). This problem of a poorly permeable tissue can be minimised by leaving enough time between samples to let the isotopes perfuse into the poorly permeable tissues. Speakman (1997) suggested using a 6 h equilibration time for dogs. The use of equations can also help correct any errors that this assumption may cause.

5) All substances entering the animal are labelled at the background level and there is no entry of unlabelled CO_2 or water via the skin.
There may be recycling of isotopes in small confined pools and re-breathing of isotopes may occur because expired gas builds up in the environment, and therefore causes the isotopes to re-enter the body (Haggarty and McGaw, 1988). This has been reported to occur in burrowing animals, where labelled water lost from the animal rapidly exchanges with unlabelled soil water, even in dry soil (Nagy and Costa, 1980). This is not a problem unless the labelled animal leaves the burrow and re-enters at a later time when the animal has a lower concentration of labelled water than when it left (Girard, 2001). This would mean that the animal would breathe in isotopes at a higher concentration, thereby under-estimating the flux rate (explained further on in section 1.2.1.5.2.2). This can be avoided by separating individual animals during experimental periods.

6) Background levels of isotopes are constant.
Work in European Robins showed that there were seasonal variations in ^{18}O and ^{2}H abundance; with high summer and low winter values (Tatner, 1990). A study using Alaskan sled dogs showed that during a 70 h race, background levels of ^{2}H decreased significantly, while levels of ^{18}O increased significantly, and had a significant effect on calculation of total energy expenditure (Hinchcliff *et al.,* 1997a). However, this error can be minimised by measuring background levels of ^{2}H and ^{18}O at the beginning and end of the experimental period.

Doubly-labelled water can be used to measure water turnover (Hinchcliff *et al.,* 1997b), body composition (Ballevre *et al.,* 1994) and energy expenditure. It has been validated in seals (Sparling *et al.,* 2008), humans (Maddison *et al.,* 2007), birds (Tatner, 1990), mice (Lifson *et al.,* 1955), skinks (Brown *et al.,* 1992) and dogs (Speakman *et al.,* 2001). Measuring energy expenditure in free-living animals is a difficult process but the alternative of capturing an animal from the wild and bringing it back to the laboratory to measure its energy expenditure is also very difficult. Captivity alters the animal's normal behaviour and therefore the measurements originally sought are not easily measured, in some cases the process would prove ethically unacceptable. For example, measuring the energy that a fox uses to capture prey would be hard, if not impossible, to measure in a laboratory setting. The DLW technique is regarded as an accurate method for measuring daily energy expenditure (Norgan, 1996; Ainslie *et al.,* 2003), and gives an estimate of energy expenditure with an accuracy of approximately 5% (Speakman and Racey, 1988).

Doubly-labelled water provides an estimate of CO_2 production using the isotopes, heavy oxygen (^{18}O) and deuterium (^{2}H) or tritium (^{3}H) as labels. Normally these isotopes do not occur naturally in the body and O_2 is present as ^{16}O.

The basis of the DLW method is the measurement of the decline of the two isotopes in body water, after initial labelling of the body water pool. Heavy oxygen (^{18}O) is lost from the body as CO_2 and in water, whereas deuterium (^{2}H) is only lost as water (H_2O). The difference in disappearance of the two isotopes is used to measure CO_2 production during the study period. The technique assumes that the O_2 in CO_2 is in complete isotopic exchange equilibrium with O_2 in body water (Speakman, 2005). To understand how the DLW technique works, an understanding of the fate of O_2 during aerobic metabolism is important. Oxygen is associated with substrate oxidation and receives protons and forms 'metabolic water' during oxidation reactions (Speakman, 1997). The example below shows the oxidation of glucose:

Equation 1.7 $C_6H_{12}O_6 + 6H_2O + 6O_2 \longrightarrow 6CO_2 + 12H_2O$

The inspired O_2 on the left side of the equation reappears as body water (H_2O) in the right hand side of the equation. The body water then enters the tricarboxylic acid (TCA) cycle which produces CO_2. Figure 1.5 shows the TCA cycle.

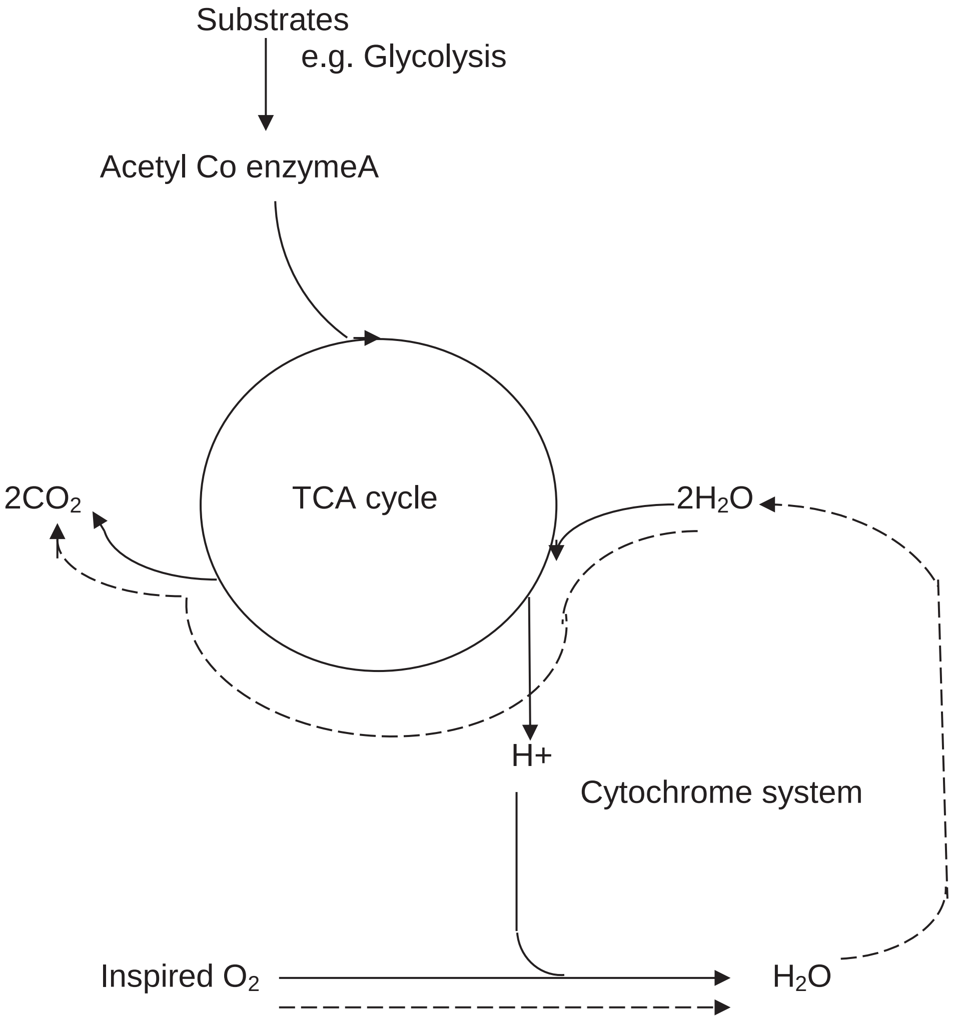

Figure 1.5: Tricarboxylic acid cycle and Cytochrome system showing fate of O_2 and H_2O. The CO_2 receives half of its O_2 from the route ---- and half from the route —— (Modified from Speakman, 1997).

Products of glycolysis enter the TCA cycle as acetyl coenzyme A. Body water also enters the cycle and becomes incorporated into the compounds. Hydrogen molecules leave the TCA cycle, enter the cytochrome system and combine with inspired O_2 to form water. Another product of the TCA cycle is CO_2, with one molecule of CO_2 produced for each molecule of water that enters the TCA cycle. The CO_2 and body water are in complete isotopic equilibrium, which is the key to the DLW technique for evaluating CO_2 production (Speakman, 1997).

1.6.6.2.1 Dilution principle

The body has a pool of water within it termed body water. This pool has a series of inputs and outputs, such as water ingested and eliminated, which is referred to as the flux rate. If a marker such as a labelled isotope is ingested, then the volume of body water can be estimated from the dilution factor of that marker provided the concentration of the marker was known before being added to the body water. This method provides an estimate of the body water pool rather than a direct measurement and is referred to as the ‘dilution space’ or ‘dilution volume’ method. This is one of the fundamental principles of the DLW technique (Speakman, 1997).

By injecting or ingesting isotopes of hydrogen (for example deuterium ^{2}H) and O_2 (^{18}O) in the form of heavy water ($^{2}H_2{}^{18}O$), the dilution space (N) can be estimated by taking a sample from the body some time later and measuring the dilution of deuterium with normal hydrogen from the body. By taking successive samples, the exponential decline (k_d) of deuterium or O_2 (k_o) from the body can be tracked. However, while the cells of the body are impermeable to certain compounds, they are permeable to solvents such as water through osmosis (Speakman, 1997). Isotopes are chemically and physically indistinguishable from the primary compounds (water), and the body should not discriminate between them within the more complex body pools (Speakman, 1997).

1.6.6.2.2 Flux rate

As mentioned previously, the flux rate is the amount of water entering and leaving the body pool. If the body water pool has a marker added to it, the constant influx and efflux of water would reduce the concentration of the marker until no marker remained. If this relationship is plotted on a graph it would follow a curve (see Figure 1.6a), and if it was converted to a logarithmic scale the relationship would be linear (see Figure 1.6b).

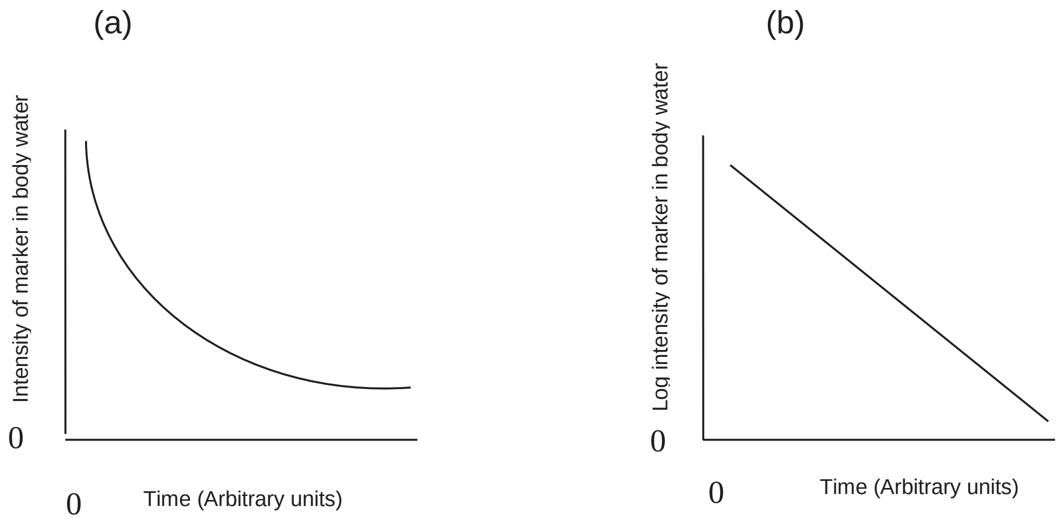

Figure 1.6: Relationship of the concentration of marker in the body over time (a) and the log relationship of the concentration of marker in the body (b) (From Speakman, 1997).

The gradient of the decline of the marker ('turnover rate') depends on the rate of the influx and efflux of water ('flux rate') in the system (Speakman, 1997). If the flux rate increases, then the rate of marker disappearance also increases and the gradient of the log converted line shows a steeper decline. For example, a turnover of 0.10 per hour means that in an hour, approximately 10 % of the marker in the system is washed out (Speakman, 1997). However, the model assumes that influxed water equilibrates with the body pool and that the water leaving the body pool contains the same concentration of marker as that remaining in the body pool. If the influxed water did not mix with the pool and instead left the body, then the dilution space would be overestimated.

Another factor that influences flux rate is the amount of water in the body pool. If there is a small body pool volume, then the rate of marker disappearance is faster. If the influx and efflux of water in the system is rapid then the disappearance of the marker would again be faster. The flux rate can be worked out from the gradient of the log converted graph (k_d or k_o), and the volume of the system (from the dilution space, N), i.e.

Equation 1.8: $N \times k_d = rH_2O$ (where r is the rate) for deuterium and

Equation 1.9: $N \times k_o = rH_2O + r(CO_2)$ for oxygen

This takes into account dissolved respiratory CO_2, where each molecule of CO_2 flushed from the body contains two atoms of O_2 compared with one in each molecule of water.

1.6.6.2.3. Body pool

The body contains impermeable membranes that certain substances (except water and other small molecules) cannot penetrate. Since $H_2{}^{18}O$ has the same properties as body water, it can easily penetrate through these membranes. However, penetration of water into cells takes longer in cells from smaller more isolated body water pools compared to larger pools closer to the blood system. This is referred to as the two pool system, where the large body water pool is one pool and the smaller pool the other. No matter what the method of administration of DLW, the labelled isotopes end up in the blood system. Speakman (1997) recommends using this system when studying larger animals and to use the group average dilution space ratio. The combination of the two equations given above results in an equation to estimate the rate of CO_2 production:

Equation 1.10: $rCO_2 = (N/2.078)(k_o - k_d) - 0.0062k_d.N.R_{dilspace}$ for deuterium

Equation 1.11: $rCO_2 = (N/2.078)(k_o - k_t) - 0.0084k_t.N.R_{dilspace}$ for tritium.

Where rCO_2 is the rate of carbon dioxide production

N is the dilution space

k_o is the flux rate of oxygen

k_d is the flux rate of deuterium

k_t is the flux rate of tritium

$R_{dilspace}$ is the average dilution space ratio across all the group members

$R_{dilspace} = N_d/N_o$

$N = (N_o + (N_d/R_{dilspace}))/2$

Where N_d is the dilution space of deuterium and N_o is the dilution space of oxygen.

1.6.6.2.4 Estimating RQ from DLW

Energy is produced in the body by breaking down, or oxidising substrates into smaller molecules. As previously mentioned in section 1.5.3, this process produces chemical energy in the form of ATP. For example: when an animal ingests carbohydrates in the form of glucose the net break down reaction is:

Equation 1.12: $C_6H_{12}O_6 + 6O_2 \longrightarrow 6H_2O + 6CO_2$

For fatty acids (such as palmitic acid) the net reaction is:

Equation 1.12: $CH_3(CH_2)_{14}COOH + 23O_2 \longrightarrow 16CO_2 + 16H_2O$

The RQ values can then be converted into energy equivalence using empirically derived equations. The RQ value is essential and needs to be calculated so it can be incorporated into an empirical formula to convert rCO_2 into energy expenditure. Young and Price (1961) found that a suitable RQ for working dogs fed carbohydrate and protein as major fuel sources should be 0.9 ± 0.09.

When using the DLW technique, there are three ways of measuring RQ. The first is to measure food composition, which is achieved using a food quotient (FQ). The food is combusted and the ratio of CO_2 to O_2 produced can be assumed to be the same as in the same reaction occurring naturally in the body (Ainslie *et al.,* 2003). The second method involves using a value that is published by researchers working with the same species. Speakman (1997) suggested using a RQ value equivalent to 0.8 in free-living animals. This RQ is thought to produce small errors when estimating daily energy expenditures, however, Gorman *et al.* (1998) used an RQ of 0.9 when estimating energy expenditure of African wild dogs whereas Speakman *et al* (2003) use a RQ of 0.8 for domestic dogs. The last method involves measuring RQ directly from background isotopes.

Speakman *et al* (2001) validated the DLW technique with indirect calorimetry and food intake-mass balance in eight Labrador Retrievers, and concluded that the DLW method was as good as the indirect calorimetry and food intake-mass balance methods. In another study, the DLW method produced similar results when compared to energy expenditure calculated from dietary analysis in racing Alaskan sled dogs (Hinchcliff *et al.,* 1997a). Similar studies using DLW and intake-balance have been conducted in humans with results from both methods within 3% of each other and with 95% confidence interval limits of 4 - 10% (Schoeller *et al.,* 1986). The DLW method involves administering a known concentration of the isotopes and an equilibrium time of 6 h to allow isotopes to mix into body water (Speakman *et al.* 2001: Wyse *et al.,* 2003), allowing the isotopes to penetrate both large and small water pools of the animal. After equilibration, an initial sample can be taken, and a final sample can be taken at a later appointed time. After isotopic analysis Speakman *et al.* (2001) recommended using the two-pool model equation for dogs based on observed dilution space data. Table 1.8 shows the variation of energy expenditure in the experiment conducted by Ballevre *et al.* (1994) by using the different equations suggested by different authors. Equation three (Table 1.9) was validated for smaller species (< two kg) whereas equation four (Table 1.9) is more appropriate for humans and larger species and takes into account the smaller and harder to reach body water pools.

Table 1.9: Calculations of CO_2 production and energy expenditure in dogs from DLW experiments using different equations[1]

CO_2 production ($mmol.kg^{-1}.d^{-1}$)	Mean
Equation 3	576
Equation 4	515
Energy expenditure ($kJ.kg^{-1}.d^{-1}$)	
Equation 3 with cFQ	294 (1.3)
Equation 3 with FQ	291 (1.2)
Equation 4 with cFQ	263 (1.1)
Equation 4 with FQ	260 (1.1)
ME intake ($kJ.kg^{-1}.d^{-1}$)	236

[1] Equation 3 corresponds to equation 3 ($rCO_2 = (N_o/2.08)-(k_o-k_d)-0.015(k_dN)$) proposed by Lifson and McClintock (1966)) and equation 4 corresponds to equation 7 ($rCO2 = 1/2.08)(N_ok_o-N_dk_d)-0.0258(N_ok_o-N_dk_d)$) proposed by Schoeller and Coward (1990: c.f. Ballevre *et al.,* 1994). Food quotient (FQ) was derived from macronutrient content of the diet and corrected food quotient (cFQ) was calculated from macronutrient intake corrected for bodyweight changes (Black *et al*., 1986 c.f. Ballevre *et al.,* 1994). Corrected food quotient is used when a state of energy balance does not exist and some corrections for fat and protein

loss need to be included. Values in parenthesis correspond to the ratio of expenditure to ME intake one calorie = 4.184 joules (From Ballevre *et al.,* 1994).

1.6.6.2.5. Difficulties with using DLW

The difficulty in using the DLW technique is deciding which of the many equations to use to estimate the rate of CO_2 production. Speakman (1987) used equation:

Equation 1.14: $rCO_2 = 0.5(k_o-k_d)$

from Lifson and McClintock (1966) and

Equation 1.15: $rCO_2 = 0.5[(N_o.k_o)-(N_d.k_d)]$

from Coward *et al.* (1985) and found results differed between the two equations as Table 1.8 also illustrates. There are also technical difficulties associated with sample analysis, but this can be minimised by analysing samples in a specialised laboratory (Westerterp, 1998). Another difficulty is that activity by dogs is episodic and varies minute to minute and also varies in the amount of activity performed. The turnover of labelled carbon is much faster, minutes to hours, compared to days, and therefore can be used to measure energy expenditure at rest and during short bursts of exercise (Hill, 2006). Doubly-labelled water may not be able to accurately measure energy expenditure of dogs participating in short duration activity, but can measure energy requirements that vary from dog to dog (Hill, 2006). No ill-effects have resulted from the use of low concentrations of deuterium oxide (D_2O)in any mammalian species. However, deer mice showed a 6% (Suter and Rawson, 1968) and 7% (Burgess Dowse and Palmer, 1972) lengthening of the circadian rhythm period when 30% concentration of D_2O was introduced to their drinking water. This returned to normal once D_2O was removed from the drinking water.

Doubly-labelled water is expensive and analysis of isotopes requires a mass spectrometer. Pouteau *et al.* (2002) also compared nuclear magnetic resonance (NMR) and mass spectrometry methods for analysis of DLW. There are two advantages to using NMR; it is applicable and reliable over a range of possible ^2H concentrations, therefore samples do not have to be diluted, and secondly it only requires minimal sample preparation and single use filtrationcentrifugation steps. It was found that a variation of 10-15% was produced by technical errors during mass spectrometry, which were avoided by using NMR (Pouteau *et al.*, 2002). Despite this, mass spectrometry is more commonly used to analyse DLW, with analysis methods for mass spectrometry fully described by Sparling *et al.* (2008).

Another method of isotope analysis is stable isotope ratio infrared spectrometry (SIRIS). Measurements are made on the absorption due to rotational vibrations of molecules and not their masses. Speakman (2005) suggests that SIRIS may be a more reliable method when compared with isotope-ratio mass spectrometry (IRMS) because of the increase of precision of individual measurements. Kerstel *et al*. (2006) compared IRMS and laser spectrometry for the analysis of triply-labelled water and found no significant differences between the two methods.

1.6.7. Estimating basal metabolic rate (BMR) in the dog

Historically there has been much debate over whether basal metabolic rate (BMR) is related to the surface area or metabolic body size of the animal. The metabolic body size of an animal is the mass of the animal times a power function and the BMR can be predicted by multiplying the metabolic body size by a given factor. According to surface law, the BMR is proportional to surface area (Kleiber and Rogers, 1961). The body surface area law is based on the theory that in animals of different body size, the BMR is proportional to their respective surface areas or the 0.67 power of their bodyweights. The major problem with the surface area law is that the surface area of an animal is not well defined, for example should the ears of a rabbit count?

In 1932, Max Kleiber pioneered basal metabolic rate research and had a profound influence on promoting use of allometric equations to express empirical metabolic data (Schmidt Nielsen, 1984). Kleiber and Rogers (1961) stated that the linear correlation between the logarithm of the basal metabolic rate and the logarithm of bodyweight showed that the BMR is proportional to a given power function of bodyweight. When the logarithm of the BMR and the logarithm of bodyweight is a linear function, then BMR is proportional to a given power of bodyweight. Recent research into predicting metabolic rate of animals relies on the assumption that basal metabolic rate is proportional to its metabolic bodyweight or, that the surface area is a function of 0.67 power of bodyweight.

Allometric relationships between biological variables and body mass are generally fitted to models of the form $y = aM^b$ where, a is the allometric coefficient, b is the scaling exponent (or for the purposes of this work, the mass exponent), y is the biological trait of interest and M is the bodyweight of the animal (Burger and Johnson, 1991). In the allometric form of the equation, both sides are converted to a log scale:

Equation 1.6: $\mathrm{Log}_e(y) = \log_e(a) + b \times \log_e(BW)$

Linear form a = intercept on y axis and b is the gradient of the relationship.

Many authors have suggested that the mass exponent should be 0.67 and basal metabolic rate is proportional to the surface area of the mammal. White and Seymour (2003) suggest the mammals tested by Kleiber in 1932 are derived from domestic species and have been under artificial constraints for generations. These authors later concluded that earlier trials did not measure true BMR and found that the interspecific mass coefficient should be 0.69 (White and Seymour, 2005). Heusner (1981) suggests that Kleibers equation is a statistical artefact and if ANOVA was used, rather than regression analysis, then the mass exponent would have been 0.67, which correlates to the surface area of the animal. Schmidt-Nielsen (1984) wrote a book discrediting the surface area law, as did Kleiber (1961). There are numerous articles and reviews arguing the advantages and disadvantages of metabolic weight *vs.* the surface area law. This review will concentrate on the mass coefficient and predictive equations as it relates to the dog.

Only a few studies have investigated the BMR of dogs (Kunde and Steinhaus, 1926; Kitchen, 1924; DeBeer and Hjort, 1938; Galvao, 1947; Hammel *et al.,* 1958), and of these, only the studies by Kunde and Steinhaus (1926) and Galvao (1947) studied dogs with a large range of bodyweights. Kunde and Steinhaus (1926) reported a mass exponent of 0.67, whereas Galvao reported a mass exponent of 0.88. Anonymous (2006) reviewed literature on the basal metabolic rate of dogs and found the equation to be BMR = 76 ± 23 $BW^{-0.75}$ kcal.d. As with the debate regarding interspecies mass exponent, there is similar debate about which exponent should be used when estimating the energy requirement of the dog. Sunvold *et al* (2004) found that in home owned, or pet dogs, the regression of total intake and bodyweight resulted in a mass exponent of 0.64 in dogs that did not gain or lose weight during the trial. Kienzle and Rainbaird (1991) found a mass exponent of 0.68, however, when young and old dogs, as well as breeds with special requirements were excluded from the data set, a mass exponent of 0.72 was calculated. Manner (1991) found that the regression between the logarithms of fasting heat production and bodyweight produced an intraspecific mass exponent of 0.67, however, still presented the mean minimal heat production (which includes the thermic effect of food and is an average minimal expenditure) across breeds of dogs tested as 0.55 MJ per $kg^{0.75}$. This suggests that BMR should use the exponent 0.67, but for maintenance the exponent 0.75 should be used. Burger and Johnson (1991) also suggested that for active house pets the mass exponent changes from their calculated value of 0.64 to 0.73. Further, Hill and Scott (2004) suggest that the relationship between BMR and bodyweight is greater than $BW^{0.67}$. There seems to be a greater variation in which mass exponent is more appropriate for use in dogs, than between mammalian species. Burger (1994) summarised this dilemma perfectly and suggested that even though a mass exponent of 0.67 is more appropriate, a practical solution is to use the mass exponent 0.75. The justification was that the fractional equivalent to 0.75 is easy to calculate and is not as daunting as 0.67. By fixing the exponent, it forces all of the variation between groups into the coefficient that simplifies comparison and interpretation between and within species.

These days, computer programmes such as Microsoft Excel make using exponents such as 0.67 easier and less daunting. If 0.67 is more appropriate as Burger (1994) suggested, then this exponent should be used. However the exponent 0.75 seems to have stood the test of time, and both Kleiber (1961) and Schmidt-Nielsen (1984) make compelling arguments against the surface law and for using $BW^{0.75}$.

1.7 Conclusion

There are many methods of measuring energy expenditure, and although indirect calorimetry remains the ‘gold standard’ there are many new methods that may be more suitable for measuring the energy requirements of an exercising dog. The preferred method of assessing energy expenditure varies with different studies, and can depend on a myriad of factors such as the number of subjects, how long the trial will run for and of course financial constraints. Although there are some promising techniques (such as the heart rate method or accelerometers) further studies need to be conducted to increase accuracy. It seems it would be beneficial to use techniques such as the DLW method in conjunction with accelerometers and as Anslie *et al.* (2003) suggests, using accelerometers and GPS to increase accuracy when predicting energy expenditure of free-living subjects.

Accelerometers are small, light-weight and cause minimal disturbance to subjects and for this reason they are becoming increasingly popular for physical activity trials in free-living subjects. There are an increasing number of studies validating different monitors for a number of different subjects and it seems likely that there will be many more trials using accelerometers to measure energy expenditure of subjects. The biggest disadvantage with this method is the need to estimate BMR in subjects, and as shown, there are discrepancies in the literature as to which predictive equations, or more accurately, which mass exponent, is suitable. Even though there are conflicting data about reliability and validity, using accelerometers to measure energy expenditure of free-living subjects is a promising alternative to historical methods that measure subjects in a laboratory setting.

Doubly-labelled water provides an estimate of carbon dioxide (CO_2) production with the use of labelled isotopes ^2H, ^3H or ^{18}O. With the assumptions of Lifson *et al.* (1955) in mind, DLW has proved to be an accurate method for estimating energy expenditure. Doubly-labelled water has been compared to a variety of other methods (e.g. indirect calorimetry) and most, if not all researchers found no difference in results between the methods. It is a valuable tool for both measuring energy expenditure of free-living animals, and for validating new methods. Although DLW is a relatively simple and non-invasive method, the disadvantages of the technique include the difficult sample analysis, as well as the costs involved in the analysis and purchasing of isotopes. Even though the DLW technique was first used to measure rate of CO_2 production in 1955, experiments are still being conducted to establish a more time efficient and cheaper method of analysis. As the DLW method becomes more popular, the costs will likely be reduced as more companies produce isotopes due to higher demand (Speakman, 2007). The DLW method is still a valuable tool in science to establish the energy expenditure of free-living animals, while the animal is exhibiting normal, everyday behaviour.

Until recently, scientists have not been interested in working farm dogs in NZ, and therefore, little scientific literature exists. To date, there is no scientific literature published on the population, feeding practices or work load information for working farm dogs in NZ. Once we ascertain these most basic of information, we can try and establish the energy requirements and the nutritional needs of these unique working dogs. Currently, the majority of work conducted into the energy expenditure and nutritional requirements of canine athletes has concentrated on racing Greyhounds or sled dogs. These two groups of performance dogs have a completely different energy requirement which suggests that different breeds of dog, with different workloads and exposure to different environmental conditions, will have different energy requirements. Extrapolation of data from either Greyhounds or sled dogs to calculate the nutritional requirements of working farm dogs is unlikely to be reliable. This leaves a large gap in the literature concerning the energy requirements of working farm dogs both in NZ and worldwide that urgently needs to be filled. Farm dogs are invaluable to farmers. Without the eager assistance of the farm dog, the farmer would have a difficult time ensuring efficient handling of stock. Therefore it is essential that these unique dogs receive sufficient energy from their diet to ensure optimal performance. In order to do this, researchers need to establish the energy expenditure of farm dogs in NZ. There are various techniques mentioned in this literature review to assess the energy requirements of a free living subject; the best method is through DLW. However, due to the expensive and laborious nature of this method, is seems prudent to use DLW to calibrate less expensive, and less time consuming methods, such as activity monitors and GPS. This will enhance the feasibility of other studies and enable more work to be done faster and cheaper.

The aim of this thesis is to establish feeding regimes, workload information and to quantify the energy requirements of working farm dogs in NZ. This thesis will also aim to establish if the current feeding practices of farmers meet the requirements of the NZ farm dog.

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CHAPTER TWO:

Age, breed, gender distribution and nutrition of a working farm dog population in New Zealand: Results of a cross-sectional study

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2.1 Introduction

Working farm dogs are a vital component of New Zealand's (NZ) agricultural industry. However, even basic information does not exist on working farm dog populations in NZ, with very little information on their workload, nutrition, or health. In 1996, the estimated number of working dogs in NZ was 200,000 (Dalton, 1996), located on 16,820 sheep and beef farms in NZ (Anonymous 1998), which was equivalent to 12 dogs per farm. However, no current data has been published since then. Working dog populations in other countries have also received very little attention, and limited data exist on both management and feeding practices (Greig 1953; Downs *et al.* 1997; Fox 1964). In contrast, companion dog owner populations in NZ and around the world have received regular attention, with surveys monitoring changes of ownership, investigating market activities (Blackshaw and Day 1994; Griffiths and Brenner 1977; Laflamme *et al.,* 2008; Patronek *et al*. 1997; Robinson 1967), providing general background information on dog demographics (Masters and McGreevy (2008), information for the study of disease (Bonnett *et al.*1999; Hilbink *et al.* 1993; Sallander *et al.* 2001), diet (Donoghue *et al.*, 1991; Roudebush & Cowell, 1992) and diet and exercise (Robertson, 2003; Slater *et al.,* 1992).

Given the importance of working farm dogs to NZ's agricultural industry, it is timely to establish background information on a population of these dogs, and to identify current feeding practices. This information is important in identifying any areas of working farm dog husbandry that may need to be improved in order to enhance their health, productivity and welfare. Therefore, the primary objectives of this study were to describe the composition of a working farm dog population in NZ, with respect to age, breed and gender. The secondary objectives were to determine if this working farm dog population varies across NZ, and identify what diets and feeding regimes are currently used by their owners. Tertiary objectives were to determine basic workload data from estimated level of daily exercise, tiredness after a day of work and number of days rested or spelled in the month. The survey involved a questionnaire which was sent out to the members of the NZ Sheep Dog Trial Association (NZSDTA). This is a 'special interest' group of farmers that are involved in show and yarding dog trials and have an added interest in keeping their dogs in optimum condition due to their trialling interests. Therefore the information collected represents an elite population of animals, and may not be comparable to the general working dog population.

2.2 Aim:

The aim of this study was to establish information, on the age, breed, weight, gender, average diets fed, feeding regimes and workload of a population of working dogs from the New Zealand Sheep Dog Trial Association (NZSDTA), who constitute a ‘special interest’ group of farmers.

2.2.1: Hypothesis

Preliminary information on the age, breed, gender, average diets fed, current feeding practices for a population of working dogs in New Zealand, could be established with the use of a survey.

2.3 Materials and methods

2.3.1 The sample

A questionnaire and covering letter were distributed to working farm dog owners with valid address details on the New Zealand Sheep Dog Trial Association (NZSDTA; 770 members) database in August 2007, which co-incided with the season winter, in NZ. The survey was sent out during winter as respondents may have had more time to respond due to the low work load during this time of the year, if the survey was sent in summer, there may have been fewer responses. Only one recipient per farm was asked to complete the questionnaire. Only one dog owner per farm, who returned a complete valid set of responses to the questionnaire within 4 months of the questionnaire being sent out, were included in the study population.

2.3.2 The questionnaire

The questionnaire was compiled with the help of co-authors and consisted of 18 questions (appendix 2.6), the first five concerning the geographic location and physical characteristics (size, type and terrain) of the farms the dogs worked on. Each owner was also asked for information on the number of working dogs, age, breed, gender and the weight (to the nearest kg) of each of the dogs they owned. Dogs under one year of age were considered puppies and were removed from the dataset before subsequent analysis, and the ages of the remaining animals were adjusted to the nearest full year of age (Table 2.1a). The breeds or types of dogs used as working farm dogs were grouped into the following five categories, *viz* Heading dog, Huntaway, Labrador, Cattle dog or Mongrel.

Three questions concerned the workload of each dog. Owners were asked to estimate the current daily level of exercise each of their dogs was worked at on a 5-point scale, where 1=kennelled all day and 5=mustering in hill country. Owners were also asked to rate the level of tiredness of each dog after a typical day's work on a 5-point scale, where 1=not tired at all and 5=exhausted, and estimate the number of days each dog had been spelled (rested) and not used for work in the previous month. Farmers were also asked how many dogs had been euthanased in the last year. The next five questions related to the diet and feeding regimes used by the owner. The final three questions (questions 16 – 18) ascertained farmers' opinion on TUX dog food (Table 2.1b).

Table 2.1a: Organisation of the questionnaire, key points: Description of farm and dogs.

Questions	**Possible answers**	**Type of Question**
Description of farm		
Size of farm	Ha	Open
Distance to nearest town	Km	Open
Type of farm	Sheep and beef, sheep, beef, dairy, deer, mixed	Closed
Terrain	Mainly flat, mainly hill-country or mixture of both	Closed
Geographic region	Northland, Auckland, Bay of Plenty, Gisborne, King Country, Taranaki, Central Plateau, Hawke's Bay, Manawatu, Lower North Island/Wairarapa, Tasman, Marlborough, Canterbury, Otago, or Southland	Closed
Working dog information		
Number	Range 1 – 40	Open
Age	Range <1 - 16 years	Open
Breed/type	Huntaway, Heading, Labrador, Cattle dog, or Other	Open
Weight	Kg	Open
Gender	Male or female	Closed
Estimate daily level of exercise	Scale of 1 - 5 (1=none, 5=heavy)	Closed
Rating of tiredness after a day’s work	Scale of 1 - 5 (1=not tired, 5=exhausted)	Closed
Number of days rested (in last month)	Range: 1 – 30	Open
Number of dogs injured or ill in (last year)	Range: 1 – 2	Open
Type of injury or illness	Abscesses, broken bones, lameness, flesh wounds, skin conditions, or sore foot pads	Open
Dogs euthanised (in last year)	yes or no	Closed

Table 2.1b: Organisation of the questionnaire, key points: Nutrition of farm dogs.

Questions	Possible answers	Type of Question
Dog food		
Feeding frequency	Every other day, once a day, twice a day	Closed
Feeding regime during peak and off-peak workloads	Canned food, dry food, dog roll, *homekill, or table scraps	Closed
Importance of nutrition, variety, cost, balanced diet, convenience and dog’s acceptance of food	Scale 1 - 5 (1= not important 5 = very important)	Closed
Evaluation of TUX dog food	Scale of 1 – 5 (1 = poor, 5 = very good)	Closed
Qualities of TUX dog food	Scale 1 – 5 (1 = strongly disagree, 5 = strongly agree)	Closed
Possible improvement options for TUX	Yes or no	Closed

* Homekill is fallen stock that is not suitable for human consumption

2.3.3 Statistical analysis

Continuous data that were non-normally distributed were summarised using medians and inter-quartile ranges (IQR), while normally distributed data were summarised using mean ± SD.

The Kruskal–Wallis test was used to compare categorical variables that were not normally distributed. The numbers of dogs per farm were analysed, to determine if there were regional differences in dog ownership within the sample population. The effect of the terrain in which the farm was situated on the number of dogs owned was also investigated, to determine whether there was an influence of topography. The effect of region and topography on the median age of dogs was also investigated. The diets fed to the dogs were categorised according to the proportion of dry food and/or homekill fed, and analysed to determine if there were regional differences in feeding regime. A regression analysis evaluated the effect of farm size on the number of dogs per farm, in order to establish the strength of correlation between the two sets of data. A two sample t-test was used to examine differences in weight due to sex and breed. Significance was assumed if $p<0.05$.

All analyses were conducted using SAS v9.1 (SAS Institute Inc., Cary NC, USA).

2.4 Results

2.4.1 Dog ownership data

The questionnaire was completed by 542/676 (81%) owners of working farm dogs who could be contacted and were eligible for inclusion. The inclusion criterion was owners of working farm dogs, who lived and worked on farms, who were members of the NZSDTA; 78/770 (10%) of the questionnaires were excluded because they were returned to sender, 9/770 (1%) because the farmer had retired and 7/770 (1%) because the members owned dogs solely for trialling or breeding purposes. The respondents comprised 542/12,900 (4.2%) of the dog owners working on sheep and beef-cattle farms in New Zealand (Anonymous, 2009). Of the farms represented in the study, 125/542 (23%) were <100 ha in size, 173/542 (32%) were between 100 and 500 ha, 98/542

(18%) were between 501 and 1,000 ha and 146/542 (27%) were >1,000 ha. The smallest farm was 1 ha (in the Bay of Plenty), the largest was farm 28,000 ha (in Otago), and the median farm size 440 ha (lower quartile (LQ) 132.3 ha: upper quartile (UQ) 1200 ha). There was a large variation in median farm size within each region (Table 2.2), and a significant difference in the median farm size between regions ($p<0.005$). Most farms were situated in either a mixture of hill country and flat terrain (260/542; 48%), or totally in hill country (184/542; 34%); a minority of farms were on mostly flat terrain (98/542; 18%).

Comparing the number of survey respondents in each region with the number of farms reported on the Meat and Wool database (Anonymous, 2009); the distribution of farms across New Zealand was similar (Table 2.2). Larger farms appeared to be over-represented in the current study, with the median farm size in most regions being larger than those reported on the Meat and Wool New Zealand database (Table 2.2).

Table 2.2: Number (and percentage) and median area by region of 542 farms worked on by members of the New Zealand Sheep Dog Trial Association (NZDTA) throughout New Zealand (NZ) who responded to a questionnaire in August 2007, compared with farms listed on the Meat and Wool New Zealand (Meat & Wool NZ) database.

	NZSDAT		Meat and Wool NZ	
Region	N (%)	Median area (ha)	N (%)	Median area (ha)
Upper North Island[a]	115 (21.2)	214	2,990 (23.4)	240
Central/East Coast[b]	92 (176.0)	641	2,340 (18.3)	385
Lower North Island[c]	91 (16.8)	600	1,430 (11.2)	349
Upper South Island[d]	114 (21.0)	450	3,260 (25.5)	390
Lower South Island[e]	130 (24.0)	486	2,760 (21.6)	312
Total NZ	542		12,780	

[a] Auckland, Bay of Plenty, Northland, King Country and Central Plateau

[b] Gisborne and Hawke's Bay

[c] Taranaki, Manawatu, Lower North Island and Wairarapa

[d] Canterbury, Marlborough and Tasman

[e] Otago and Southland

The median number of dogs kept by each farmer was 6.0 (LQ 5.0: UQ 8.0). There was a significant difference in the median number of dogs between regions (*p*<0.0001), and with terrain of the farm (*p*<0.001*).* Farmers in the region Bay of Plenty owned a significantly (*p*<0.0001) lower number of dogs (median: 3; range: 2 - 7) than farmers in Gisborne (median: 8; range: 2 – 12) dogs (Table 2.3). Farms situated totally on hill country had more dogs (*p*<0.001) than those in either a mixture of hill country and flat terrain or totally on flat terrain. However, regression analysis (R^2=0.03) failed to show any correlation between the number of dogs on a farm and the size of the farm.

It was estimated that, on average, a single dog covered 226 (range: 0.3 – 5,400) ha per farm. Figure 2.1 shows the different regions of NZ.

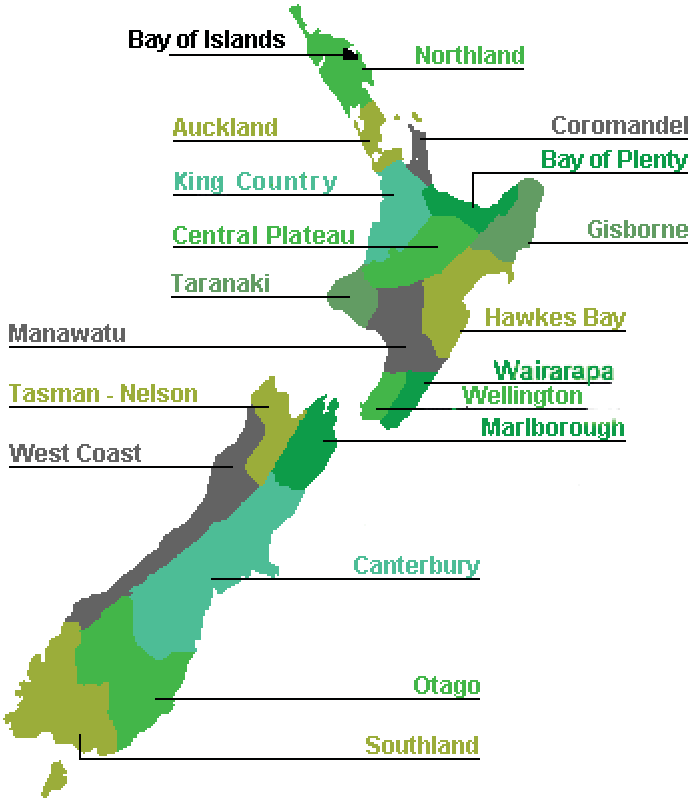

Figure 2.1: Regions of NZ

Table 2.3: Geographic distribution and size of 542 farms worked on by members of the New Zealand Sheep Dog Trial Association, throughout New Zealand (NZ) who responded to a questionnaire in August 2007, with the number of dogs per farm. , compared with farms listed on the Meat and Wool New Zealand (Meat & Wool NZ) database.

		Farm size (ha)			No. Of dogs/farm		
Region	**No. f farms sampled**	**Median (IQR)**	**Min**	**Max**	**Median (IQR)**	**Min**	**Max**
North Island (NI)							
Northland	37	240 (32–430)	2	2,300	5 (4–6)	1	10
Auckland	9	75 (46–480)	3	360	4 (2–4)	2	10
Bay of Plenty	15	45 (18–171)	1	1,550	3 (2–4)	2	7
King Country	43	400 (63–800)	4	7,200	5 (3–7)	1	15
Central Plateau	11	413 (168–1,300)	87	2,000	6 (5–7)	4	20
Gisborne	38	730 (278–1,233)	6	7,000	8 (7–9)	2	12
Hawke's Bay	54	471 (70–1,150)	1	3,800	6 (5–8)	2	24
Taranaki	20	400 (173–759)	16	4,000	7 (5–8)	1	13
Manawatu	54	750 (346–1,290)	3	8,000	8 (6–9)	2	46
LNI/Wairarapa	17	600 (408–1,017)	10	6,000	7 (6–8)	2	14
Total NI	298	425 (101–990)	1	8,000	6 (4–8)	1	46
South Island (SI)							
Tasman	12	400 (175–1,325)	3	3,500	6 (5–7)	1	10
Marlborough	22	727 (52–1,150)	2	2,010	6 (4–9)	2	12
Canterbury	80	440 (210–1,250)	2	27,000	6 (5–8)	2	15
Otago	67	600 (263–2,500)	2	28,000	6 (5–8)	1	15
Southland	63	400 (160–1,175)	1	12,000	6 (5–8)	1	18
Total SI	244	492 (100–1,100)	2	28,000	6 (4–8)	1	18
Total NZ:	**542**	**440 (132–1,200)**	**1**	**28,000**	**6 (5–8)**	**1**	**46**

IQR = inter-quartile; Min = minimum; Max = maximum; LNI = lower North Island

2.4.2 Working farm dogs

The crude estimate for the total number of working dogs on sheep and beef farms (excluding dairy, deer and other livestock farms) in NZ, using farm statistics for the entire country (Anonymous, 2009) was at least 81,000 dogs (calculated using the median number of dogs from the survey and the number of farms from Meat & Wool NZ statistics). When using region-specific data for number of farms, the stratified estimate of the total population was very similar at 82,000 (calculated using the median number of dogs per region from the survey and the number of farms from Meat & Wool NZ statistics).

The median age of the population of working farm dogs surveyed (n = 3,047) was 3.0 (LQ 1.5: UQ 5.0) years. This did include a large number of young dogs in training that had not achieved full working dog status (< 1 year of age: Figure 2.2 below); although when those dogs were removed from the dataset the median age of the 2,861 dogs remaining, was still 3.0 (LQ 2.0: UQ 6.0) years.

The median age (when puppies where excluded from the data set) of females was the same as males (3 years; females n=1,235; males n=1,626). There were no differences between the average age of dogs versus different regions (p>0.05), with different farm sizes (p>0.05) or farm type (p>0.05), or the terrain of the farm (p>0.05).

The distribution of breed of dogs and their weights, age and workload are presented in Table 2.4. Heading dogs were the most common type of dog in the population (1,510/2.861; 52.8%), followed by Huntaways (1,161/2,861: 40.6%). The breeds or types of dogs used as working farm dogs were grouped into the following five categories, Heading, Huntaway, Labrador Retrievers, Cattle dog or mongrel (Table 2.1a). The rest of the working dog population consisted of Labradors (0.3%), Cattle dogs (0.2%) and mongrels (6%). This data suggests that the predominant breeds of working dogs are Heading dogs and Huntaways, therefore, this study and the rest of this thesis focuses on these two breeds.

Table 2.4: Information on a NZ working farm dog population: age, weight, breed and workload.

Variable	Level	Median	Range	IQR
Age (years)	Male	3	1 - 16	4
	Female	3	1 - 15	4
	Median	3	1 - 16	4
Weight (kg)				
Huntaway	Male	31	20 - 65	36
	Female	30	20 - 50	25
	Median	30	20 - 65	38
Heading dog	Male	25	12 - 45	25
	Female	21	12 - 40	22
	Median	23	12 - 45	25
Days off work (d/month)		8	0 - 30	7

Male dogs generally weighed more than females in both breeds. Male Heading dogs were significantly (p<0.0001) heavier than female Heading dogs (25 versus 21 kg respectively). Male Huntaways were heavier (31 kg) than female Huntaways (30kg). There were highly significant (p<0.0001) differences in the weight between breeds, and on average, Huntaway (30 kg; LQ 27: UQ 65 kg) were heavier than Heading dogs (23 kg; LQ 20: UQ 45 kg). There were a large range of weights for dogs, the median weight for Headings dog was 23 kg (range 12 - 45 kg) and the median weight for a Huntaway was 30 kg (range of 20 - 65 kg).

The age distribution of dogs by gender showed a clear bias towards males (57%) versus females (43%). However, in older animals, the proportions of females to males were increased (see Figure 2.2), and at 10 years of age, the proportion of females in the population was slightly higher (53%) than that of males (47%).

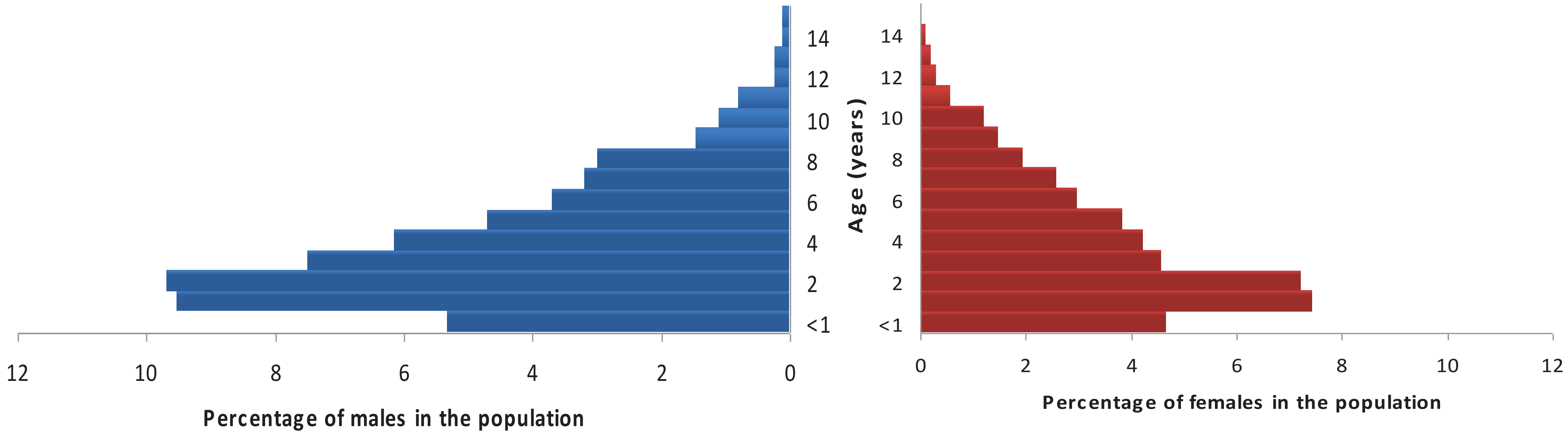

Figure 2.2: Age distribution of dogs by gender (total n = 3,047; female dogs = 1,321; male dogs = 1,726)

The median number of days each working dog was rested (spelled) in the previous month (July 2007) was 8 (IQR 5–12, range 0–30).

The median daily level of exercise for each dog, assessed by the owners, was moderate, e.g. mustering on easy terrain (2; IQR 1– 3). When asked how they rated their dogs for tiredness after a typical day's work, 205/542 (38%) owners rated their dogs as moderately tired (score 3), 79/542 (15%) rated them very tired (score 4) and 7/542 (1%) rated them exhausted. There was a positive association between the number of dogs on a farm and perceived level of tiredness ($p<0.05$); however, there was no association between the perceived level of tiredness and the number of days the dogs were rested ($p<0.05$). In addition, there were also no significant differences in perceived levels of tiredness between farms of different terrain ($p<0.05$). Sick or injured dogs were reported on 205/542 (38%) farms in the previous year. The most common cause of injury reported was trauma (150/205; 73%), with most traumatic incidents caused by livestock, fences or farm vehicles. The illnesses reported included gastrointestinal disease (23/205; 11%) and skin disease (12/205; 6%). On 105/542 (19%) farms, at least one dog (a total of 149 dogs) was subject to euthanasia during the previous year. The most common reason for euthanasia reported was degenerative joint disease associated with old age (60/149; 40%). Other reasons included trauma (22/149; 15%) associated with working with livestock, and dogs that failed to perform satisfactorily (27/149; 18%).

2.4.3 Nutrition and feeding regime

The average diet fed to working dogs established in this survey is presented in Table 2.5. The vast majority of dogs (526/542; 97%) were fed once a day at the end of the working day. Diets were remarkably consistent all year round, i.e. between peak and off-peak work periods, with different combinations of dry food and/or homekill predominating. During peak periods of work 61% (328/542) of owners fed a combination of dry food and/or homekill and 58% (313/542) of owners fed a combination diet during off-peak work periods. Few farmers fed large quantities of wet food (canned or dog roll) or table scraps during the two work periods [116/542 (21%) peak and 132/542 (24%) off peak], with the majority of the wet food and/or table scraps fed in conjunction with either dry food and/or homekill [114/116 (98%) peak and 129/132 (98%) off peak].

The relative amounts of dry food and homekill fed did fluctuate slightly between peak and off-peak work, while other dietary constituents (wet - food and table scraps) were kept constant. Homekill is fallen stock that is not suitable for human consumption.

Table 2.5: Diets fed to working dogs during off-peak and peak periods of work in New Zealand; the number of farmers surveyed that fed each diet (n=542) and the number of dogs receiving each diet type (n=2,861).

Diet Type	No. of farmers	%	No. of working farm dogs	%
Off-peak work				
100% Dry diet	24	4.4	127	4.4
>50% Dry diet : <50% Homekill	54	10.0	299	10.5
50% Dry diet : 50% Homekill	102	18.8	597	20.9
<50% Dry diet : >50% Homekill	105	20.3	678	23.7
100% Homekill	28	5.2	142	5.0
*Other	132	24.3	618	21.6
Unknown	97	17.9	400	14.0
Peak work				
100% Dry diet	21	3.9	109	3.8
>50% Dry diet : <50% Homekill	43	7.9	226	7.9
50% Dry diet: 50% Homekill	90	16.6	477	16.7
<50% Dry diet: >50% Homekill	139	25.7	716	25.0
100% Homekill	35	6.5	196	6.9
*Other	116	21.4	594	20.8
Unknown	98	18.17	543	19.0

*Other includes, table scraps, canned and dog roll

There were no significant regional variations in feeding regimes employed by the owners in the survey. The percent of dry food and homekill fed to dogs throughout the year was remarkably consistent. There were no correlations (*p*>0.05) between the distance of the farm from the nearest town (km), and the proportion of dry food ($r^2 = 0.09$) or homekill fed ($r^2 = 0.33$).

A high percentage of farmers rated nutrition, a balanced diet and the dog's acceptance of the diet as being very important when choosing dog food (75%, 62% and 68% respectively; Table 2.6). The majority of farmers regarded variety, cost and convenience of the food between three and five on the 5-point scale.

Table 2.6: Farmers rating (%) on the importance of different variables when choosing dog food for their working dogs.

	Scale*				
	1	**2**	**3**	**4**	**5**
Nutrition	0.8	1	4.3	18	75.1
Variety	7.9	9.2	24.5	25.2	33.3
Cost	12.7	9.2	20.3	26.6	31.4
Balanced diet	2.1	2.3	9.9	23.7	62.1
Convenience	10.1	7.7	19.2	32.6	30.4
Dogs' acceptance	3.5	2.4	7.8	18.8	67.7

* Scale: 1 = not important to 5 = very important

The questionnaire also investigated the main brands of dog food bought by the owners, which were: TUX Energy (82%), Pedigree Working Dog Formula (11%), TUX Country (4%), Champ Max (2%), Dog Chow (0.5%) and V8 (0.3%). TUX was the main brand bought by farmers, so the questionnaire also investigated the farmers' opinions on TUX dog food. The majority of farmers (67%) gave TUX dog food a ranking of either good or very good (four or five on a five point scale. Farmers were asked to assess their dogs reaction to specific qualities of TUX such as taste, size and hardness, and if expense or health problems of the dog were factors when purchasing TUX. The majority of farmers had positive responses to the qualities, expense and health benefits of TUX dog food (Table 2.7)

Table 2.7: Farmers opinion on qualities of TUX dog food (values expressed as a percentage value).

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
My dogs don't like the taste of TUX	29.8	43.8	14.6	7.1	4.7
My dogs don't like the size of TUX	34.0	42.6	17.7	4.5	12.0
My dogs don't like the hardness of TUX	33.3	42.4	19.3	3.7	1.2
TUX is too expensive	12.8	24.8	29.1	22.6	10.6
I don't buy TUX for health reasons	42.0	33.9	12.4	7.2	4.5

The last question considered options for improving TUX dog food, such as bigger/smaller biscuits, different flavours, high/low calorie option and specially formulated options. There were varying responses for most of the options, however, the majority of farmers (66%) replied they would like a specially formulated working dog formula, 34% would like a high calorie option and 42% said they wanted life-stage formulations (such as puppy formulations).

2.5 Discussion

This study was the first attempt, to our knowledge, to establish nutritional information about age, breed, sex distribution and feeding practices for a population of working farm dogs in NZ. A questionnaire was sent to the members of the NZSDTA, a 'special interest' group of farmers which may have a greater interest in keeping their dogs in optimum condition for dog trialling. Therefore the information collected regarding nutrition, health and welfare (including age and weight information) may not be representative of the total population of working dogs in NZ. However, respondents that indicated in the questionnaire that they kept dogs for trialling and/or breeding purposes only or had retired from farming were placed in the un-contactable category, as opposed to the no response category, and were not included in subsequent analysis. There may also have been sampling errors associated with the current study due to our requirement for only one dog owner per farm to complete the questionnaire. It is common on large farms that a number of shepherds, farm hands or casual staff each with their own dogs, work under a farm manager. Therefore, this is likely to have under-represented the number of dogs reported on the larger farms. The number of injuries and the number of dogs' euthanised may also be miss-represented in this survey. It is highly possible that the trialling dogs are generally in better health and may not have as many injuries as a typical farm dog. A good trial dog is a valuable tool, not only for the running of the farm, but any offspring that they produce will be highly sought after because of their lineage. Farmers who also participate in dog yarding competitions will have an added interest in survival of the dog due to sales from offspring of an award winning dog. These farmers may have more resources and motivation to treat any injuries, where as a typical farmer may choose to euthanise as opposed to, for example, treating a broken leg.

Larger farms appeared to be over-represented in the current study; with the average farm sizes in each region larger than those reported by Meat & Wool NZ (Anonymous 2009; Table 2.2a). The average farm size obtained in the current questionnaire (1,210 ha), from sampling 3.5 - 6.4% of the total number of farms in each region, was almost twice as large as that described in industry statistics (645 ha; Anonymous 2009). It is possible that the sample size in this study was smaller than Meat & Wool, thereby explaining the difference in farm sizes.

The data presented in this chapter is a snapshot of information from a working farm dog population as of August 2007. Heading dogs were the most common breed of working dogs kept in the survey, followed closely by the Huntaway. At this time, the median age of a working dog was 3.0 years. This suggests that there was a very young population of working dogs within the NZSDTA. The numbers of dogs given away, sold or retired per year were not established by the questionnaire, but where farmers indicated that a dog was retired, and gave full information regarding age, weight and breed of the dog, then these dogs were included in calculations regarding the median age. The mean age of the working farm dog population in this study (4.1 years) was similar to previous international studies of companion dog populations (4.6 years; Robinson, 1967; Griffiths and Brenner, 1977). The average retirement age of the working sheep-dog in UK was 8-9 years old (Greig, 1953; Fox, 1964).

There was a skewed sex ratio, with higher numbers of males compared with females. This sex ratio altered in older animals (≥ 10 years old), so the proportion of females to males in the population increases as the animals aged. Previous studies have also shown that the proportion of females to males in the population increased as the animals aged (Robinson 1967; Teclaw *et al.* 1992), suggesting different life expectancies between the genders. Teclaw *et al.* (1992) found that in pet populations, a higher proportion of the female population were sterilised, whereas owners than owned males were less likely to have them sterilised, and they speculated that owners of sterilised dogs had higher education and income levels than owners of sexually intact animals. This survey did not assess the sterilisation status of the working dogs, farmers tend to breed from their best working dogs, and in incidence of sterilisation in working dogs may be significantly different to pet dogs. In the human population, females generally have a higher life expectancy than males, and the same could be true of the companion dog population (Robinson 1967). Identification of the causes of early mortality and the gender differential in mortality in working dog and companion dog populations requires further investigation. One possible explanation maybe that farmers prefer males, due to females coming onto heat and a) not being able to work and b) distracting male working dogs. Another possibility could be a reflection of the gender proportion of the recent dogs produced and also how they performed.

In common with the findings of the current study, a slight skewed gender ratio was also reported from a number of surveys of companion dog populations (Robinson 1967; Sallander *et al.* 2001; Slater *et al.,* 1992; Thrusfield 1989), with slightly higher numbers of males (53.8 - 50.4%) compared with females (46.2 –

49.6%). Grieg (1953), conducted a survey on the population of sheep-dogs in the UK, which showed male Sheep-dogs outnumbered female Sheep-dogs in identical proportions to that found in this study (57% male: 43% female working farm dogs). These figures suggest that farmers in NZ and the UK marginally prefer male working dogs over females. Although there is no published information for the reason for preference of male over females, as suggested earlier, it is possible that when females go on heat it prevents them from working, and/or distracts other nearby dogs from the work that the farmer wants them to complete. Further studies are required to validate this theory.

An interesting finding from this survey was that owners with fewer dogs perceive their dogs to be less tired than owners with more dogs, however, there are likely to be differences in perception between individual farmers and these figures are farmer's perception of tiredness of dogs with no scientific evidence substantiating the results. When farmers were asked to estimate the daily exercise level of dogs, no farmer determined dog workload as heavy, but this was to be expected because the surveys were sent in winter, which is generally a low workload period. If the survey was conducted during summer or spring, the farmers may have estimated that their dogs had a higher workload. Terrain of the farm had no effect (p > 0.05) on the farmer's perception of tiredness of dogs, however, farmers working on hilly terrains owned significantly more dogs (7.9 dogs) than farmers working on flat (4.6 dogs) or mixed terrains (6.6 dogs). Therefore, a possible reason why terrain had no effect on farmer's perception of tiredness of dogs was because there were more dogs used to work the hilly farms, and the workload was therefore shared between more dogs. The average number of days that a farm dog was rested or spelled in the previous month was 8 (range: 0 – 30). Another interesting result was that there was no effect of the number of days a dog was spelled, and the farmer's perception of tiredness of dogs. This suggests that after a day of work, dogs that had not been spelled in the previous month were perceived to be as tired as dogs that had not worked at all in the previous month. Therefore, no matter how many days a dog is spelled, it has no effect on the perception of tiredness of the dog after a day of work, but as mentioned before, this survey was conducted during low work periods (i.e. winter) where there is minimal work conducted. Therefore days spelled may not have an effect on tiredness, as there was minimal work conducted to begin with. . If the survey was conducted in summer or spring, then farmers may have perceived their dogs to be more tired after a day of work than that reported in this survey.

Dalton (1996) estimated there were 200,000 working farm dogs on 16,820 sheep and beef farms in NZ (Anonymous 1998), which was equivalent to 12 dogs per farm. In August, 2007, the number of working sheep and beef farms (excluding dairy, deer and other types of farms) had dropped to 12,900 (Anonymous 2009), and data from the survey reported here indicated there was an average of seven dogs per farm which suggested a total working dog population of between 81,000 and 82,000. It should be noted that there may be more working farms dogs than the crude estimate suggests, because of the other types of farms (i.e. dairy, deer and other farm types) that are not included in this calculation. However, this estimate of numbers appears similar to data from a NZ Department of Internal Affairs report of registered Huntaway and Border Collies. It has to be noted that although Border Collies are not synonymous with Heading dogs, there were no registered Heading dogs in the report. The report states that on April 2008 there were 45,487 registered Huntaway and 36,876 registered Border Collies, which is similar to the estimations of the working dog population in NZ in this study. The estimated numbers of specific breeds reported here were 43,000 Heading dogs and at least 33,000 Huntaways in NZ, during mid-2007. However, it is crucial to note that the number of registered dogs is not the same as the number of dogs in the working dog population. Many of these reported registered dogs maybe used for recreational trialling, breeding or may have retired from work. There also maybe a large number of working dogs that are not registered, it is impossible to tell because the figures from NZ Department of Internal Affairs give no indication of working Huntaway and Border Collies, or whether these registered dogs were farm or companion dogs, therefore, using these figures to estimate the working dog population would lead to inaccurate dog numbers. It may be possible that the drop in dog numbers compared with Daltons' (1996) estimate may be due to a possible drop in the number of farms since 1996, also technology may have had some impact on working dog population numbers, due to evolving farm technologies. Instead of using horses, more farmers now use quad bikes to check and move stock (Moore, 2008), and dogs are able to ride on the quad bike to the paddock, therefore, dogs do not expend as much energy, and their workload is reduced. Farmers may not need to spell dogs for as long and therefore do not need to own as many dogs as before. However, it is also important to note that many hill-country farms are not able to use quad bikes for mustering stock from all paddocks on the farm, and still rely on horses and dogs to help muster livestock.

Euthanasia was considered as part of the survey to try and help understand the turnover of dogs in the population. Euthanasia (due to injury/illness) reported in the study appeared low when the turnover of dogs in the population was considered. Of the 42% of farms that had sick or injured dogs in the past year, only 22% of the farms claimed to have euthanised one dog during the same period. These figures do not include dogs that may have died naturally, been sold or given away, but the fact that the sample of dogs surveyed was a young population may be a contributing factor. Since this is the first study addressing information of working farm dogs in NZ, it is impossible to compare with similar studies.

The majority of farmers (97%) fed their working dogs once a day, Grieg (1953) found that many farmers (55%) in UK also fed their dogs once a day, and this meal was usually fed in the evening. The timing of when to feed a working dog is important, and it is common practice to avoid feeding large meals immediately before and during physical activity (Ahlstrom *et al.,* 2006). Digestion of a meal causes redistribution of blood to the gastro-intestinal tract to aid absorption, digestion of food also causes an increase of heat production, due to the thermic effect of food. If the dog were to exercise immediately after being fed, the heat produced from digestion and exercise would cause the dog to over-heat and result in impaired performance. However, during exercise, blood is redistributed from the gastro-intestinal tract to working muscles (Toll and Reynolds, 1998). This leads to incomplete absorption of nutrients from the diet and may cause vomiting and diarrhoea (Ahlstrom *et al.,* 2006). Exercise before and after a large meal can also increase the risk of gastric dilatation-volvulus (Glickman *et al*, 2000). Therefore, if working dogs are fed immediately before exercise, it could not only impair performance, but result in the dog not receiving essential nutrients due to diet malabsorption (Kenney *et al.,* 1988).

The survey inferred that the feeding regimes of the working farm dogs remained remarkably similar throughout the year during both peak and off-peak work. The most common diet of a working farm dog was homekill combined with dry food, and the amount fed to the dogs at different times of the year appeared to alter, rather than the composition of the diet. Many farmers reported that dry food was fed as a supplement to homekill, providing an energy dense, nutritionally complete food source. The amount of diet fed to dogs increased in response to peak workload (I Singh, unpublished observation), whereas the composition of the diet remained largely unchanged. Other dietary components, wet food (canned food and dog roll) and table scraps, were used as supplements to the homekill and/or dry food, and were only fed by a minority of owners (21% in peak period of work and 24% in off peak periods of work). There were no significant inter or intra-regional differences in the type and proportional amounts of food fed. There was no correlation between the distance of the farm to the nearest town, and the proportions of dry food (r^2 = 0.09) or homekill fed (r^2 = 0.33), suggesting that farms further away from town did not feed more homekill than a farm closer to town. This seems reasonable as farming households would still need to frequently visit urban areas to buy groceries and farming supplies, thus also providing opportunities for buying dry dog food.

Currently, there are no data concerning the energy requirements of working farm dogs in NZ. Guilford (1997) suggested that the best way to ensure that the working dog receives a complete and balanced diet is to feed a commercial diet that has been feed-tested according to Association of American Feed Control Officials (AAFCO) protocols. Current guidelines suggest that their energy needs are between 1.5 and 2.5 times greater than maintenance requirements for pet dogs (Case 2005a). Work in cold weather can further increase these energy needs by an additional 50% or more. A recent review of the scientific literature recommended a dietary protein and fat allowance for maintenance in pet dogs of 100 g/kg and 55 g/ kg of diet respectively (Anonymous 2006). Working dogs have higher requirements for dietary protein than pet animals due to the increased protein synthesis and protein degradation caused by exercise (Case 2005b; Guilford 1997); however, a minimum requirement has not been established. High-protein diets have been proposed to help reduce the occurrence of musculoskeletal injuries in dogs, so may be beneficial for working dogs (Reynolds et al. 1996). A recent study demonstrated that a low-carbohydrate, high-protein diet was advantageous to working dogs, improving apparent nutrient digestibility, delaying glucose release into the bloodstream and reducing intestinal carbohydrate fermentation (Hill et al. 2009).

The carbohydrate requirements for dogs have not been established, however, the National Research Council (Anonymous 2006) set a maximum carbohydrate concentration in diets for dogs of 52% of the energy in the diet.

There is controversy regarding the risks of feeding homekill or a raw-meat diet to dogs. Proponents of feeding homekill claim that a raw-meat diet contains high amounts of energy, increases lean body mass, may help resolve certain health problems (e.g. dental, skin and joint problems), and increases resistance to internal and external parasites (Billinghurst 1993; Lonsdale 1995). However, these claims of health advantages associated with feeding raw-meat diets have yet to be scientifically validated (Freeman and Michel 2001), and uncooked meat contains more bacteria when compared with cooked meat, which may result in gastric upsets and ill health in dogs (Le Jeune and Hancock 2001; Stromeyer 2006). Guilford (1997) also cautioned that homekill is often deficient or marginal in many vitamins and minerals, including iodine, B-vitamins and vitamins A and E. Feeding homekill also involves feeding bones, and the potential problems arising from the ingestion of bones, include gastrointestinal perforation, gastroenteritis (Laflamme *et al.,* 2008), intestinal obstruction leading to constipation (Cave *et al,* 2009), and fractured teeth in animals consuming a raw-meat diet (Freeman and Michel, 2001).

The questionnaire asked if farmers in NZ were concerned about the importance of nutrition, variety, cost, dietary balance, convenience and acceptability when choosing a diet for their working dogs. It appears that the most important factors when choosing a dog food were nutrition, acceptability and dietary balance. Fewer farmers were concerned about convenience, variety and cost, although these were still considered important. The data from this study showed that farmers generally had positive opinions regarding TUX dog food, but wanted a diet specially formulated for working dogs (62%), with a higher calorie option (34%) and wanted a range of products for different life-stages (42%).

This study established basic information, such as breed, gender, and age of a group of dogs in NZ, as well as the current feeding practices of farmers. Survey data, such as those provided in the current study, establish values for further population-based studies on the nutrition of working dogs. Assessment of current feeding practices is both vital for planning veterinary services, and identifying areas of potential improvement in the management and nutrition of working dogs in NZ. This survey has established that the most common diet fed to dogs is a combination of 50% homekill and 50% TUX dog biscuits. Therefore in the next stage of the research, the digestibility of a combination of homekill and TUX diet needs to be determined in order to establish the amount of nutrients working dogs are receiving from their diet.

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2.7 Appendix 1: Copy of survey

MASSEY UNIVERSITY

SURVEY OF WORKING DOG OWNERS

July 2007

INSTRUCTIONS : Please answer the following questions by ticking the appropriate

box or boxes, or by writing in the space provided.

---

1. **Approximately how big is your farm?**

Size: ____________ Hectares

2. **Approximately how far is it to the nearest town?**

Distance: ___________km

3. **What type of livestock farming do you do?**

PLEASE TICK ALL THAT APPLY

Dairying	1
Sheep	1
Beef	1
Deer	1

4. **How would you describe the terrain of your farm?**

Mainly or all hill-country	1
Mainly or all flat	2
A mixture of hill-country and flat	3

5. **How many *working dogs* do you currently own or care for?**

Number of dogs: _________

6. **For each of these dogs, please provide the following information:**

	Name	**Age**	**Gender**	**Breed**	**Weight (kg)**	**Daily exercise Level***
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

* Daily exercise level:
1. Heavy (eg, mustering in hill-country)
2. Moderate (eg., Mustering on easy terrain)
3. Light (eg., Light farm work)
4. Little or none (eg. Kennelled all day)

7. **Generally, how would you rate the tiredness of your dogs after a typical day's work?**

Not tired at all 1 2 3 4 5 **Extremely tired**

8. **In the last <u>month</u>, roughly how many days on average were *each of* your dogs spelled for?**

No. of days spelled in the last month _____________

9. In the last <u>year</u>, were any of your dogs ill or injured?

Yes	1
No	2→**Go to Q10**

If yes, what was the cause of the illness or injury?

____

____

____

10. In the last <u>year</u>, were any of your dogs euthanased?

Yes	1
No	2→**Go to Q11**

If yes, how many were euthanased?

____

What was the reason or reasons for euthanasia?

____

____

____

11. How often do you feed your dogs?

Once every two days	1
Once a day	2
Twice a day	3

12. When selecting your dogs’ diet, how important are each of the following considerations?

	Not important				**Very important**	**Can’t Choose**
Nutrition	1	2	3	4	5	6
Variety	1	2	3	4	5	6
Cost	1	2	3	4	5	6
Balanced diet	1	2	3	4	5	6
Convenience	1	2	3	4	5	6
Dogs’ acceptance	1	2	3	4	5	6

13. What is your normal daily feeding regime during off-peak and peak workloads?

	Off –peak workload Portion (%)		**Peak workload Portion (%)**
Dry Food		Dry food	
Canned Food		Canned food	
Dog Roll		Dog Roll	
Home kill		Home kill	
Table scraps		Table scraps	
	100%		**100%**

14. If you currently use dry food, what main functions does it serve in your dogs' diet?

PLEASE TICK ALL THAT APPLY

It is the only food I give them	1
As a supplement to home kill	1
As an energy "top up' at certain times of the year	1
For variety	1
I don't use dry food	1

Which of the following brands of dog food do you ever buy?

PLEASE TICK ALL THE BRANDS YOU HAVE EVER BOUGHT IN COLUMN A AND THE BRAND YOU BUY MOST OFTEN IN COLUMN B.

	A Ever bought	B Main brand
Champ MAX	1	1
Country Mile	1	2
Dog Chow	1	3
Pedigree Working Dog	1	4
TUX Country	1	5
TUX Energy	1	6
V8	1	7

16. How would you rate TUX as a brand of dog food?

Very poor 1 2 3 4 5 **Very good**

17. How much do you agree or disagree with each of the following statements about TUX?

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Can’t Choose
My dogs don’t like the taste of TUX	1	2	3	4	5	6
My dogs don’t like the size of TUX	1	2	3	4	5	6
My dogs don’t like the hardness of TUX	1	2	3	4	5	6
TUX is too expensive	1	2	3	4	5	6
I don’t buy TUX for health reasons	1	2	3	4	5	6

Which of the following options for TUX would you be interested in?

PLEASE TICK ALL THAT APPLY

	Would be interested in
Bigger size TUX Biscuits	1
Smaller size TUX biscuits	1
Other flavours/varieties of TUX	1
Low calorie TUX option	1
High calorie TUX option	1
Specially formulated TUX working dog food	1
Life stage TUX formulations (eg., puppy/senior)	1
None of these	1

THANK YOU FOR YOUR HELP

PLEASE RETURN YOUR QUESTIONNAIRE IN THE REPLY PAID ENVELOPE PROVIDED

Appendix 2: Copy of published journal article

Scientific Article

Age, breed, sex distribution and nutrition of a population of working farm dogs in New Zealand: Results of a cross-sectional study of members of the New Zealand Sheep Dog Trial Association

I Singh[*], LA Tucker[*], P Gendall[‡], KJ Rutherfurd-Markwick[*], J Cline[#] and DG Thomas[*§]

Abstract

AIM: To establish baseline information about age, breed, sex distribution and feeding practices for a population of working farm dogs owned by members of the New Zealand Sheep Dog Trial Association (NZSDTA) throughout New Zealand.

METHODS: Questionnaires were sent to members of the NZSDTA in August 2007, requesting information on the size and terrain of the farms where they worked, as well as the breed, weight, age and sex of each working dog they owned, feeding regime employed, diet fed, work levels, and general health of their dogs.

RESULTS: The survey was completed by 542/676 (81%) of the eligible sample population, and provided information on 2,861 dogs, excluding those <1 year old. All of the dog owners surveyed worked on sheep and beef-cattle farms. The median farm size was 440 (IQR 132–1,200) ha and varied with region. The majority of farms were situated on either hill country (184/542; 34%) or a mixture of hilly and flat terrain (260/542; 48%), and had a median of six (IQR 5–8) working dogs per farm. The median age of dogs was 3.0 (IQR 2.0–6.0) years. Heading dogs were the most common type of working dog (1,510/2,861; 52.8%), followed by Huntaways (1,161/2,861; 40.6%). The gender distribution of all dogs was biased towards males (57%), but this decreased with age. There was a positive association between the number of dogs on a farm and perceived level of tiredness of dogs ($p<0.001$), but there were no differences in levels of tiredness between farms of different terrain. Most owners (526/542; 97%) fed their dogs once a day. The most common diet fed was a combination of dry food and homekill,

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[*] Institute of Food, Nutrition and Human Health, College of Science, Massey University, Private Bag 11222, Palmerston North 4442 New Zealand.
[‡] Department of Communication, Journalism & Marketing, College of Business, Massey University, Private Bag 11222, Palmerston North 4442, New Zealand.
[#] Technical Communications, Product Technology Center, Nestlé Purina PetCare, Pine Bluff AR, USA.
[§] Author for correspondence. Email: d.g.thomas@massey.ac.nz

which was fed by 328/542 (61%) owners during peak and 313/542 (58%) during off-peak periods of work.

CONCLUSIONS and CLINICAL RELEVANCE: This study has established baseline information on the age, breed, gender and nutrition of a large population of working farm dogs in New Zealand.. Current feeding practices employed by owners include offering a substantial amount of homekill to their animals. Homekill may be deficient or marginal in vitamins and minerals, therefore opportunities could exist to improve the diets and therefore the longevity and performance of these dogs.

KEY WORDS: *Working farm dog, Heading dog, Huntaway, nutrition survey*

IQR	Inter-quartile range(s)
NZSDTA	New Zealand Sheep Dog Trial Association

Introduction

Working farm dogs are a vital component of New Zealand’s agricultural industry, but only basic information exists on such populations in New Zealand, including very little information on their workload, nutrition or health. A recent study of the diseases of working farm dogs in New Zealand presented data on 2,214 dogs from 30 rural veterinary practices and identified several diseases that appeared to be amenable to nutritional modification (Cave *et al*. 2009). Populations of working dogs in other countries have also received very little attention, and limited data exist on both management and feeding practices (Greig 1953; Fox 1964; Downs *et al.* 1997). In contrast, pet dog populations in New Zealand and around the world have received more attention, with surveys monitoring changes of ownership (Blackshaw and Day 1994; Patronek *et al*. 1997; Sallander *et al.* 2001), investigating market activities involving pets (Troutman 1988), and providing a background for the study of disease (Burbridge *et al.* 1994; Bonnett *et al.*1999; Worth *et al.* 2010).

Given the importance of working farm dogs to the agricultural industry it is timely to establish background information on a population of these dogs, and identify current feeding practices. This information is important in identifying any areas of their husbandry that may be improved to enhance their productivity and welfare. The primary objectives of this study were to describe the composition of a population of working farm dogs in New Zealand, with respect to age, breed and gender. Secondary objectives were to determine if this population varied across New Zealand, and identify the diets and feeding regimes were employed by their owners.

Materials and methods

The sample

A questionnaire (see Supplementary Table 1[1]) and covering letter were distributed to working farm dog owners with valid address details on the NZSDTA database, in August 2007. Only one recipient per farm was asked to complete the questionnaire. Only one dog owner per farm, who returned a complete valid set of responses to the questionnaire within 4 months of the questionnaire being sent out were included in the study population.

The questionnaire

The questionnaire consisted of 15 questions, the first five concerning the geographic location and physical characteristics (size, type and terrain) of the farm each dog lived and worked on. Each owner was also asked how many working dogs they owned, and the age, breed, gender and weight (to the nearest kg) of each. Dogs <1 year old were considered puppies, and were removed from the dataset before subsequent analysis, and the ages of the remaining animals were adjusted to the nearest full year of age. The breeds or types of dogs used as working farm dogs were grouped into the following five categories, *viz* Heading dog, Huntaway, Labrador, Cattledog, or Mongrel.

Three questions concerned the workload of each dog. Owners were asked to estimate the current daily level of exercise each of their dogs was carrying out, on a 5-point scale, where 1 = kennelled all day, and 5 = mustering in hill country. Owners were also asked to rate the level of tiredness of each dog after a typical day’s work, on a 5-point scale, where 1 = not tired, and 5 = exhausted, and estimate the number of days each dog had been spelled (rested) and not used for work in the previous month. The final five questions related to the diet and feeding regimes used by the owner

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Statistical analysis

Continuous data that were non-normally distributed were summarised using medians and inter-quartile ranges (IQR), while normally distributed data were summarised using mean ± SD.

The Kruskal-Wallis test was used to compare categorical variables that were not normally distributed. The numbers of dogs per farm were analysed, to determine if there were regional differences in dog ownership within the sample population. The effect of terrain in which the farm was situated on the number of dogs owned was also investigated, to determine whether there was an influence of topography. The effect of region and topography on the median age of dogs was also investigated. The diets fed to the dogs were categorised according to the proportion of dry food and/or homekill fed, and analysed to determine if there were regional differences in feeding regime. A regression analysis evaluated the effect of farm size on the number of dogs per farm, in order to establish the strength of correlation between the two sets of data. A two-sample *t*-test was used to examine differences in weight due to sex and breed. All analyses were conducted using SAS v8 (SAS Institute Inc, Cary NC, USA).

Results

Dog ownership

The questionnaire was completed by 542/676 (81%) owners of working farm dogs who could be contacted and were eligible for inclusion. The inclusion criterion was owners of working farm dogs, who lived and worked on farms who were members of the NZSDTA; 78/770 (10%) questionnaires were excluded because they were returned to sender, 9/770 (1%) because the farmer had retired, and 7/770 (1%) because members owned dogs solely for trialling or breeding purposes. The respondents comprised 542/12,900 (4.2%) dog owners working on sheep-and-beef-cattle farms in New Zealand (Anonymous 2009). Of the farms represented in the study, 125/542 (23%) were <100 ha in size, 173/542 (32%) were between 100 and 500 ha, 98/542 (18%) were between 501 and 1,000 ha, and 146/542 (27%) were >1,000 ha. There was a large variation in median farm size within each region (Table 1), and a significant difference in median farm size between regions (p<0.005). Most farms were situated in either a mixture of hill country and flat terrain (260/542; 48%), or totally in hill country (184/542; 34%); a minority of farms were on mostly flat terrain (98/542; 18%).

Comparing the number of survey respondents in each region with the number of farms reported on the Meat and Wool database (Anonymous 2009), the distribution of farms across New Zealand was similar (Table 2). Larger farms appeared to be over-represented in the current study, with the median farm size in most regions being larger than the those reported on the Meat and Wool New Zealand database (Table 2).

The median number of dogs on each farm was six (IQR 5–8) (Table 1). There were significant differences in the median number of dogs between regions ($p<0.001$), and with terrain of the farm ($p<0.001$). Farms situated totally on hill country had more dogs ($p<0.001$) than those in either a mixture of hill country and flat terrain or totally on flat terrain. However, regression analysis ($R^2=0.03$) failed to show any correlation between the number of dogs on a farm and the size of the farm.

Working farm dogs

The median age of the population of working farm dogs surveyed (n=2,861) was 3.0 (IQR 2.0–6.0) years (Table 3). There were no significant differences in the median age across regions, farm sizes or terrain of the farm. The distribution of breed of dogs and their weights are presented in Table 3. Heading dogs were the most common type of dog in the population (1,510/2,861; 52.8%), followed by Huntaways (1,161/2,861; 40.6%). The gender distribution of all dogs showed a bias towards males (1,626/2,861; 57%). However, in older animals the percentage of males in the population decreased (Figure 1), and in animals ≥10 years old, the percentage of males to females in the population was almost equal (82/162; 51% *vs* 80/162; 49%).

The median daily level of exercise for each dog, assessed by the owners, was moderate, e.g. mustering on easy terrain (2; IQR 1–3). When asked how they rated their dogs for tiredness after a typical day’s work, 205/542 (38%) owners rated their dogs as moderately tired (score 3), 79/542 (15%) rated them very tired (score 4), and 7/542 (1%) rated them exhausted. The median number of days each dog was rested (spelled) in the previous month was 8 (IQR 5–12, range 0–30). There was a positive association between the number of dogs on a farm and perceived level of tiredness ($p<0.001$), however there was no association between the perceived level of tiredness and the number of days the dogs were rested. In addition, there were also no significant differences in perceived levels of tiredness between farms of different terrain. Sick or injured dogs were reported on 205/542 (38%) farms in the previous year. The most common cause of injury reported was trauma (150/205; 73%), with most traumatic incidents caused by livestock, fences or farm vehicles. Illnesses reported included gastrointestinal disease (23/205; 11%) and skin disease (12/205; 6%). On 105/542 (19%) farms at least one dog (a total of 149 dogs) was subject to euthanasia during the previous year. The most common reason for euthanasia reported was degenerative joint disease associated with old age (60/149; 40%). Other reasons included trauma (22/149; 15%) associated with working with livestock, and dogs that failed to perform satisfactorily (27/149; 18%).

Nutrition and feeding regime

The vast majority of owners (526/542; 97%) fed their dogs once a day at the end of the working day. The different diets fed to working dogs in this survey are presented in Table 4. Diets were remarkably consistent between peak and off-peak work periods, with different combinations of dry food and/or homekill predominating. Of owners, 328/542 (61%) and 313/542 (58%) fed only a combination of dry food and/or homekill during peak and off-peak work periods, respectively. Fewer owners fed any wet food (canned or dog roll) and/or table scraps during the two work periods (116/542 (21%) peak and 132/542 (24%) off peak), with the majority of the wet food and/or scraps still being fed in conjunction with either dry food and/or homekill (114/116 (98%) peak and 129/132 (98%) off peak). No regional variation in feeding regimes was seen in the proportions of the different types of food fed to dogs throughout the year.

Discussion

This study was the first attempt, to our knowledge, to establish information about age, breed, sex distribution and feeding practices for a population of working farm dogs in New Zealand. A questionnaire was sent to the members of the NZSDTA, a ‘special interest group’ of farmers and farm workers, which may have an increased interest in keeping their dogs in optimum condition for dog-trialling. Therefore the information collected may not be representative of the total population of working farm dogs in New Zealand. However, respondents that indicated they kept dogs for trialling and/or breeding purposes only, or had retired from farming, were placed in the un-contactable category as opposed to the no-response category, and were not included in the subsequent analysis. There may also have been sampling errors associated with the current study due to our requirement for only one dog owner per farm to complete the questionnaire. It is common on large farms that a number of shepherds, farm hands or casual staff with their own dogs work under a farm manager. Therefore, this is likely to have under-represented the number of dogs reported on the larger farms. The over-representation of large farms in the survey population may have also resulted in some bias in the responses obtained, however all regions of New Zealand appear to have been adequately represented.

At the time of this study in August 2007, the median age of a working dog was 3.0 years, which indicates that in late 2007 there was a very young population of working dogs within the NZSDTA. The numbers of dogs given away, sold or retired per year were not established by the questionnaire, but some owners indicated that a small number of their dogs were retired, and these dogs were included in the calculation of age.

There was a skewed sex ratio, with higher numbers of males compared with females. This sex ratio altered in older animals (≥10 years old), so the proportion of females to males in the population increased as the animals aged. This finding has been reported in other populations of dogs (Robinson 1967; Teclaw *et al.* 1992), and suggests different life expectancies between the sexes. Investigation of this apparent differential life expectancy between genders in populations of working dogs and pet dogs requires further investigation.

Owners with fewer dogs perceived their dogs to be less tired than owners with more dogs. However, this may simply be related to the strong positive relationship observed in the survey between the numbers of dogs kept and farm size. Assessment of the degree of tiredness of an animal is a subjective measure, so it is also difficult to gauge the consistency of the responses to this question. The majority of owners (54%: 291/542) reported their dogs moderately tired, very tired or exhausted after a typical day's work. A typical day's work, however, did not necessarily include times of extreme peak workload, where many dogs would be rated at 4 or 5 (I Singh, unpubl. obs.).

The levels of euthanasia reported in the study appeared low when the turnover of dogs in the population was considered; the fact that the sample of dogs surveyed was a young population may have been a contributing factor. Since this is the first study to gather information from a large population of working farm dogs in New Zealand it is not possible to compare our results with other studies.

The feeding regimes employed by owners for their working farm dogs remained similar throughout the year for periods of both peak and off-peak work. The majority of owners fed homekill combined with dry food, with the dry food portion fed as a 'top-up' to homekill, providing a more energy dense, nutritionally complete food source. The amount of diet fed to dogs increased in response to peak workload (I Singh, unpubl.

obs.) whereas the composition of the diet remained largely unchanged. Other dietary components, wet food (canned food and dog roll) and table scraps, were used as supplements to the homekill and/or dry food, and were only fed by a minority of owners.

Currently, there are no data concerning the energy requirements of working farm dogs in New Zealand. Current guidelines suggest that their energy needs are between 1.5 and 2.5 times greater than maintenance requirements for pet dogs (Case 2005a). Work in cold weather can further increase these energy needs by an additional 50% or more. A recent review of the scientific literature recommended a dietary protein and fat allowance for maintenance in pet dogs of 100 g/kg and 55 g/kg of diet, respectively (Anonymous 2006). Working dogs have higher requirements for dietary protein than pet animals due to increased protein synthesis and protein degradation caused by exercise (Case 2005b), however a minimum requirement has not been established. High-protein diets have been proposed to help reduce the occurrence of musculoskeletal injuries in dogs, so may be beneficial for working dogs (Reynolds *et al.* 1996). A recent study demonstrated that a low-carbohydrate, high-protein diet was advantageous to working dogs, improving apparent nutrient digestibility, delaying glucose release into the bloodstream, and reducing intestinal carbohydrate fermentation (Hill et al. 2009). Carbohydrate requirements for dogs have not been established, however the National Research Council (Anonymous 2006) set a maximum carbohydrate level in diets for dogs of 52% of the energy in the diet.

There is controversy regarding the risks of feeding homekill or a raw-meat diet to dogs. Proponents claim that a raw-meat diet increases energy and lean body mass, may help resolve certain health problems (e.g. dental, skin and joint problems), and increases resistance to internal and external parasites (Billinghurst 1993; Lonsdale 1995). However, these claims of health advantages associated with feeding raw-meat diets have not been scientifically validated (Freeman and Michel 2001); uncooked meat may contain more bacteria than cooked meat, which may in turn result in gastric upsets and ill health in dogs (Le Jeune and Hancock 2001; Stromeyer *et al* 2006). Guilford (1997) also cautioned that homekill is often deficient or marginal in many vitamins and minerals, including iodine, B vitamins, and vitamins A and E. Feeding homekill also involves feeding bones, and there are a number of reports of gastrointestinal obstruction, perforation and gastroenteritis arising from the ingestion of bones (Freeman and Michel 2001; Cave *et al* 2009).

Optimal nutrition of working farm dogs may not be achieved currently in New Zealand, with owners getting suboptimal performance from their dogs over their working lifetimes. Survey data, such as those provided in the current study, establish values for further population-based studies on the nutrition of working dogs. Assessment of current feeding practices is both vital for planning veterinary services, and identifying areas of potential improvement in the management and nutrition of working dogs in New Zealand.

Declaration of interest

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Table 1. Geographic distribution and size of 542 farms worked on by members of the New Zealand Sheep Dog Trial Association, throughout New Zealand (NZ) who responded to a questionnaire in August 2007, with the number of dogs per farm.

		Farm size (ha)			No. of dogs/farm		
Region	**No. of farms sampled**	**Median (IQR)**	**Min**	**Max**	**Median (IQR)**	**Min**	**Max**
North Island (NI)							
Northland	37	240 (32–430)	2	2,300	5 (4–6)	1	10
Auckland	9	75 (46–480)	3	360	4 (2–4)	2	10
Bay of Plenty	15	45 (18–171)	1	1,550	3 (2–4)	2	7
King Country	43	400 (63–800)	4	7,200	5 (3–7)	1	15
Central Plateau	11	413 (168–1,300)	87	2,000	6 (5–7)	4	20
Gisborne	38	730 (278–1,233)	6	7,000	8 (7–9)	2	12
Hawke’s Bay	54	471 (70–1,150)	1	3,800	6 (5–8)	2	24
Taranaki	20	400 (173–759)	16	4,000	7 (5–8)	1	13
Manawatu	54	750 (346–1,290)	3	8,000	8 (6–9)	2	46
LNI/Wairarapa	17	600 (408–1,017)	10	6,000	7 (6–8)	2	14
Total NI	298	425 (101–990)	1	8,000	6 (4–8)	1	46
South Island (SI)							
Tasman	12	400 (175–1,325)	3	3,500	6 (5–7)	1	10
Marlborough	22	727 (52–1,150)	2	2,010	6 (4–9)	2	12
Canterbury	80	440 (210–1,250)	2	27,000	6 (5–8)	2	15
Otago	67	600 (263–2,500)	2	28,000	6 (5–8)	1	15
Southland	63	400 (160–1,175)	1	12,000	6 (5–8)	1	18
Total SI	244	492 (100–1,100)	2	28,000	6 (4–8)	1	18
Total NZ	**542**	**440 (132–1,200)**	**1**	**28,000**	**6 (5–8)**	**1**	**46**

IQR = inter-quartile range; Min = minimum; Max = maximum; LNI = lower North Island

Table 2. Number, percentage and median area by region of 542 farms worked on by members of the New Zealand Sheep Dog Trial Association (NZSDTA) throughout New Zealand (NZ) who responded to a questionnaire in August 2007, compared with farms listed on the Meat and Wool New Zealand (Meat & Wool NZ) database.

	NZSDTA			Meat & Wool NZ		
Region	**N**	**%**	**Median area (ha)**	**N**	**%**	**Median area (ha)**
Upper North Island[a]	115	21.2	214	2,990	23.4	240
Central/East Coast[b]	92	17.0	641	2,340	18.3	385
Lower North Island[c]	91	16.8	600	1,430	11.2	349
Upper South Island[d]	114	21.0	450	3,260	25.5	390
Lower South Island[e]	130	24.0	486	2,760	21.6	312
Total NZ	542			12,780		

[a] Auckland, Bay of Plenty, Northland, King Country and Central Plateau
[b] Gisborne and Hawke's Bay
[c] Taranaki, Manawatu, Lower North Island and Wairarapa
[d] Canterbury, Marlborough and Tasman
[e] Otago and Southland

Table 3. The age, sex and weight of working farm dogs owned by 542 members of the New Zealand Sheep Dog Trial Association, throughout New Zealand, who responded to a questionnaire in August 2007.

Variable	n	Mean (SD)	Median (IQR)	Min	Max
Age (years)					
Male	1,626	4.1 (2.7)	3 (2–6)	1	15.5
Female	1,235	4.2 (2.9)	3 (2–6)	1	15.0
Total	2,861	4.1 (2.8)	3 (2–6)	1	15.5
Weight (kg)					
Heading dog					
Male	813	24.5 (7.1)	25 (20–29)	12	45
Female	697	20.6 (6.0)	20 (18–24)	10	40
Total	1,510	22.7 (6.9)	23 (20–25)	10	45
Huntaway					
Male	701	31.9 (7.5)	31 (28–35)	16	60
Female	460	27.5 (6.3)	30 (25–30)	15	50
Total	1,161	30.3 (7.4)	30 (28–35)	15	60
Other breeds					
Male	68	24.7 (8.3)	25(20–30)	7	45
Female	51	22.4 (8.5)	21 (17–28)	7	40
Total	119	23.7 (8.4)	23 (19–30)	7	45
Unknown	71	–	–	–	–

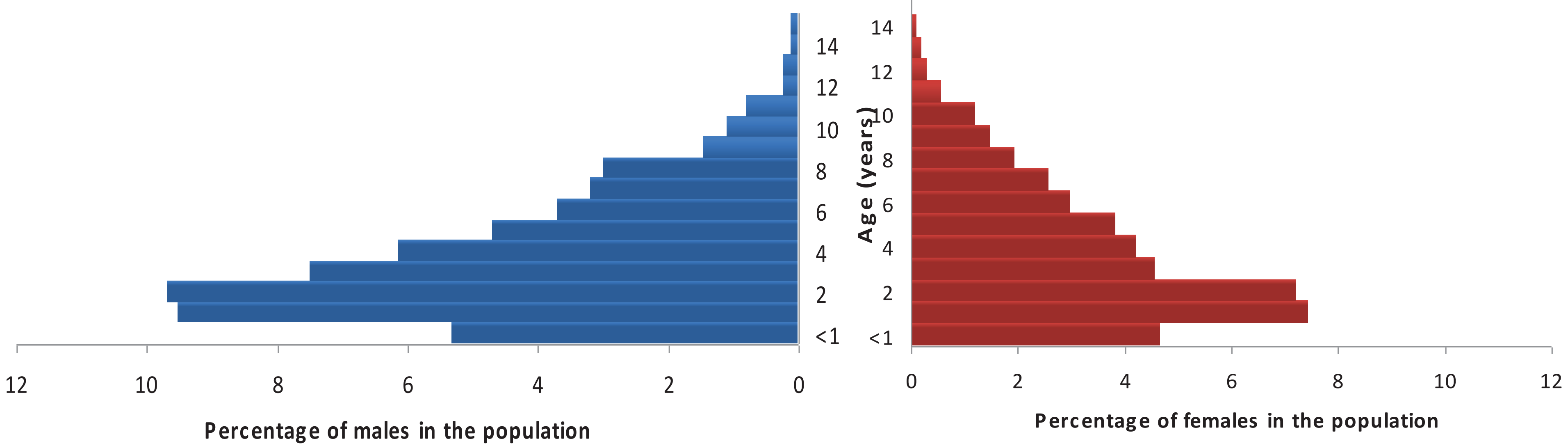
IQR = inter-quartile range; Min = minimum; Max = maximum

Table 4. Diets fed to working farm dogs owned by 542 members of the New Zealand Sheep Dog Trial Association during peak and off-peak periods of work, throughout New Zealand, who responded to a questionnaire in August 2007. Percentages refer to the proportion of all owners feeding the type of diet at each period.

Type of diet	No. (%) of owners
Peak work	
100% Dry diet	21 (3.9)
>50% Dry diet:<50% homekill	43 (7.9)
50% Dry diet:50% homekill	90 (16.6)
<50% Dry diet:>50% homekill	139 (25.6)
100% Homekill	35 (6.5)
Other[a]	116 (21.4)
Unknown	98 (18.1)
Off-peak work	
100% Dry diet	24 (4.4)
>50% Dry diet:<50% homekill	54 (10.0)
50% Dry diet:50% homekill	102 (18.8)
<50% Dry diet:>50% homekill	105 (19.4)
100% Homekill	28 (5.2)
Other[a]	132 (24.3)
Unknown	97 (17.9)

[a] Combinations of wet diet (canned and dog roll) and/or table scraps and/or dry diet and/or homekill

Figure 1. Age distribution of male (n=1,626) and female (n=1,235) working farm dogs owned by members of the New Zealand Sheep Dog Trial Association, throughout New Zealand, who responded to a questionnaire in August 2007.



CHAPTER THREE:

Digestibility of homekill (mutton carcass) and TUX Energy dog biscuits

3.1 Introduction

Feeding dogs an all meat diet (homekill) is common practice not only among farmers in New Zealand (NZ), but also in Australia and USA, with recent studies showing that 16.2% of surveyed Australians still feed their dogs bones and/or raw food as part of a main meal (Laflamme *et al.,* 2008). Results from a NZ survey (described in chapter 2), showed that 92% of farmers feed some homekill, however, the nutrient digestibility of homekill diets and the direct comparison of homekill with commercial complete and balanced diets has not been carried out. Homekill is usually fallen stock that is not suitable for human consumption. The carcasses are cleaned, gutted, cut into small pieces and frozen before being fed to working dogs. Many scientists and veterinarians are opposed to this practice. As early as 1970, editorials were written about dogs needing a balanced diet containing essential amino acids, minerals and vitamins that meat alone could not supply (Price, 1970). Many risks appear to be associated with feeding a raw meat and bone diet, the first of which is that the diet is often nutritionally inadequate. Freeman and Michel (2001) analysed dog food from three households that fed home-prepared raw dog food and found all diets had both nutrient excesses (vitamin D and E) and deficiencies (calcium, phosphorous, potassium, magnesium, manganese and zinc) when compared with Association of American Feed Control Officials (AAFCO, 2009) nutrient guidelines. Health complications can also arise from the consumption of raw bones, and although there are no published literature about the incidence of these, there are reports of intestinal obstruction leading to constipation (Cave *et al,* 2009), gastrointestinal perforation, gastroenteritis and fractured teeth in animals consuming a raw meat diet (Freeman and Michel, 2001).

The digestibility of a food is most accurately defined as the proportion which is not excreted in the faeces and which is, therefore, assumed to be digested by the animal. Digestibility trials enable a researcher to assess this. Digestibility is the amount of nutrient digested, bioavailability is the availability of these nutrients to be used in metabolic functions. This work will focus on digestibility. Digestibility studies can be used to determine the apparent or true digestibility of a feed or feed ingredient. The difference between the two methods is that apparent digestibility does not take into account endogenous protein losses, whereas true digestibility takes these into account. Apparent digestibility does not account for the microbial population in the colon , which are capable of manipulating nutrients such as protein, fibre and fat and therefore change the nutrient content of the faeces. This may lead to potential inaccuracies by over-estimating the digestibility of nutrients. True digestibility is a calculated value based on measurements of endogenous losses, which includes sloughed intestinal cell, bacteria, mucus, blood, ammonia, urea, protein, carbohydrate and fat and other nitrogen compounds in the faeces. True digestibility measurement also by-passes any dietary manipulation (i.e. fermentation) carried out by the microbial population in the colon of the dog, such as protein and fibre fermentation. There are a number of methods available to determine the digestibility of feed, and it is usually measured either by total faecal collection or ileal collection methods. The total collection method involves feeding an animal a diet and collecting all faeces produced over a given period, whereas the ileal collection method involves feeding an animal a diet and collecting digesta from the end of the ileum at a given time or over a given period.

To the authors' knowledge no controlled nutritional studies comparing homekill with commercial complete and balanced diets have been conducted in NZ. Because of the popularity of this food source (see section 2.3.3), where a majority of farmers said they fed either homekill alone or in combination with commercial prepared diets, it is important to determine the apparent nutrient digestibility of the homekill fed to farm dogs in this country. There may also be potential nutrient deficiencies/excesses associated with feeding homekill and the nutrient digestibility of amino acids, calcium and phosphorous need to be quantified to ensure that farm dogs are receiving adequate nutrition.

3.2 Aim

The aim of this study was to determine the apparent digestibility of key nutrients in homekill, TUX Energy biscuits (the most popular complete and balanced diet fed to working dogs in NZ – see section 2.3.3) and a combination of the two diets commonly fed to working farm dogs by farmers.

3.2.1:Hypothesis

The current feeding practice of farmers (i.e. 50% homekill and 50% dry dog biscuits) is more complete and balanced than a diet consisting of 100% homekill, and has comparable digestibility of key nutrients.

3.3 Methods and materials

The studies reported here (MUAEC # 04-111 – Apparent digestibility trials in dogs) were approved by, and conformed to, the requirements of the Massey University Animal Ethics Committee (Anonymous, 2009).

This trial was carried out in two parts, with trial one conducted in January 2007 and trial two conducted in September 2009.

3.3.1 Animals and housing

3.3.1.1 Animals

Three entire male and three entire female adult Harrier hounds aged between two and eight years of age with bodyweights ranging from 23.0 to 29.0 kg (25.3 ± 1.7kg mean ± SEM) obtained from the Manawatu hunt club (Palmerston North, New Zealand) were used in trial one.

A different set of dogs were utilised for trial two. Three entire male and three entire female adult Harrier hounds aged between two and eight years of age with bodyweights ranging from 17.0 to 31.0 kg (25.2 ± 3.5kg mean ± SEM) also obtained from the Manawatu hunt club (Palmerston North, New Zealand) were used in trial two.

Before the start of both trials, the dogs were wormed (Drontal, Bayer Animal Health, Leverkusen, Germany) and flea treatment (Frontline, Merial Ltd, Duluth, GA, USA) was also applied. During both trials the dogs were walked and had health checks performed daily. Health checks included checking teeth, eyes, limbs and paws for any abnormalities such as cuts, wounds or signs of infection or tenderness.

3.3.1.2 Housing

The dogs were housed individually, in 6 indoor concrete floor pens each compromising an indoor kennel (2.4m × 2.8m). This facility met both the requirements of the 'Code of Recommendations and Minimum Standards for the Welfare of Dogs (1998)' and the 'Code of Recommendations and Minimum Standards for the Care of Animals in Boarding Establishments (1993)'.

3.3.2 Diets

The diet in trial one (Diet one) consisted of 100% TUX Energy biscuits, (Nestle-Purina PetCare, Marton, NZ). Any food refusals or food spillages were collected and weighed. Water was available *ad libitum* throughout the trial.

The diets in trial two consisted of either a 50% TUX Energy: 50% Homekill mix on an ME basis (Diet two) or 100% Homekill (Diet three). The homekill diet consisted of mutton carcasses which were sourced from Keeble's Farm (AgServices, Massey University, Palmerston North). Mutton carcass in this work refers to whole trimmed and dressed carcasses, excluding head, feet, hooves, wool and organs. The trimmed carcasses were cut into suitable size to enable dogs to consume at least one piece per feeding. The mutton carcass pieces ranged from 400 g to 1.5 kg and included meat, bone, bone marrow and fat. The sheep were fresh fallen mutton that was intended to be fed to farm dogs on the University farm. The meat was cut to a suitable size and frozen for one week before being fed to the dogs as per normal farming practice. In this work, unless otherwise specified, carbohydrates refers to total carbohydrates.

3.3.2.1 Trial one

All six dogs received diet one at the same time. Each dog's daily food allowance was pre-weighed into an individual stainless steel bowl (Figure 3.1). The trial lasted for 9 days, with an initial five day adaptation period and a four day faecal collection period. Each dog received the diet exclusively over the 9 day period. The dogs were fed once a day at 08.30 during both adaptation and faecal collection periods. The energy requirement of each animal was calculated using equation 3.1. The weight of feed was calculated by dividing this figure by the metabolisable energy content of the diet.

Equation 3.1:

Metabolisable energy requirements (ME) = 132 $\times$ Weight (kg)$^{0.75}$ (Finke, 1994: AAFCO, 2009).

Figure 3.1: Individual stainless steel bowls with daily food allowance (Trial one)

3.3.2.2 Trial two

For trial two each dog's daily food allowance was again pre-weighed into an individual stainless steel bowl (Figure 3.2). Trial two lasted for 18 days and was split into 2 periods of nine days, an initial five day adaptation period and a four day collection period (as per trial one). Each dog was randomly assigned to receive one of the two diets in period one and the other diet in period two (Table 3.1). The dogs were fed once a day at 08.30 during both adaptation and faecal collection periods. The energy requirement of each dog was calculated using equation 3.1: Metabolisable energy requirements (ME) = 132 $\times$ Weight (kg)$^{0.75}$ (Finke, 1994: AAFCO, 2009). This amount was then halved, and divided by the metabolisable energy of TUX biscuits, this amount of biscuits was allocated for diet two. The amount and specific mixture of cuts of Homekill was given to the dogs, as per recommended by a farmer's practice at Keeble's Farm, Massey University. Any food refusals or food spillages were collected and weighed. Water was available *ad libitum* throughout the trial.

Figure 3.2: Individual stainless steel bowls with daily food allowance (Trial two)

Table 3.1: Food allocations for individual dogs for trial two

Dog	Sex	Period 1	Period 2
Coe	M	50% TUX:50%Homekill	100% Homekill
Eve	F	50% TUX:50%Homekill	100% Homekill
Fearless	M	50% TUX:50%Homekill	100% Homekill
Felix	M	100% Homekill	50% TUX:50%Homekill
Fidget	F	100% Homekill	50% TUX:50%Homekill
Flo	F	100% Homekill	50% TUX:50%Homekill

Representative samples of each carcass were pooled and ground (including bone), freeze dried and ground again. Representative samples included obtaining at least two cuts of forequarter, mid quarter and hind quarter from each carcass used in the trial. Forequarter included shank and shoulder, hind quarter included rump and shank. All cuts included meat and bone, with the exception of rump, as this mainly contained meat, the overall bone to meat ratio was unknown. Each dog was fed multiple carcass cuts over the trial period. Therefore individual cuts of meat were not analysed, but instead representative samples of the carcass were analysed. This ensured that what was analysed, was representative of what the dogs were fed over the trial period. The 50% diet that was submitted for analysis composed of 600 g of the sub-sample of the representative sample described and 200 g of TUX biscuits, this sample was ground together, freeze dried and ground again. The 50% diet and the representative freeze dried and ground samples were submitted to the Nutrition Laboratory, and chemical analyses were carried out using Association of Official Analytical Chemists methods (described in section 3.2.5). The nutrient profiles of the three diets are presented in Table 3.2. The nutrient profile of the diet was determined by the Nutrition Laboratory, Massey University, Palmerston North, NZ and is described in section 3.2.4. The nutrient composition for TUX Energy (from the packaging) was: crude protein 20% (min), crude fat 18% (min), crude fibre 4% (max) moisture 12% (max).

Dogs generally consumed all their daily allowance during the trial, however any refusals were weighed and the type of refusal was separately recorded (e.g.: biscuits or bone fragments).

3.3.3 Collection period

All faeces produced by each dog were collected regularly two or three times a day from 08.30 during the collection period using gloves and metal scrapers. Faeces were then weighed and stored in sealed bags at -20˚C. On completion of the trials, the faeces from each dog on each diet were pooled and then freeze-dried. Each freeze-dried faecal sample and diet sample were then ground through a 1mm sieve before analysis (Model ZM100, Retsch GmbH & Co., KG Rheinische, Haan, Germany).

3.3.4 Calculations

Apparent faecal dry matter, crude protein, fat and amino acid digestibility were calculated as shown below:

Equation 3.2:

$$\text{Apparent Faecal digestibility (\%)} = \left\{ \frac{\text{Dietary intake (g/d)} - \text{Faecal output (g/d)}}{\text{Dietary intake (g/d)}} \right\} \times 100$$

The total carbohydrate content was calculated by difference. The protein, fat and ash were summed and subtracted from the total weight of the food on a dry matter basis.

Metabolisable energy (ME) was calculated using the equation as shown below (AAFCO, 2009):

Equation 3.3:

ME = [gross energy of food consumed – gross energy of faeces collected – {(grams protein consumed – grams protein in faeces} × Correction factor for energy lost in urine)]/ amount of food consumed.

Where the correction factor for dogs = 1.25 kcal/g of digestible protein for dogs (AAFCO, 2009).

3.3.5 Chemical analysis

All freeze dried diets and pooled faecal samples from each dog were analysed for dry matter, crude protein, ash, fat and individual amino acids using Association of Official Analytical Chemists (AOAC: Anonymous, 1995) methods. Dry matter analysis was determined using a convection oven at 105°C (faeces and biscuits: AOAC 930.15 and 925.10, meat: AOAC 950.46). Protein analysis was determined using the Leco total combustion method (AOAC: 968.06). The Leco method determines the level of nitrogen in the sample. Nitrogen is multiplied by the correction factor of 6.25 to give an estimation of crude protein. Fat analysis was determined using the Soxtec extraction method for faeces and meat (AOAC: 991.36) and the acid hydrolysis/Mojonnier extraction for the biscuits (AOAC: 954.02) (Anonymous, 1995). Gross energy was determined by bomb calorimetry (Anonymous, 1995). Ash was dissolved in acidified aqueous solution, calcium and phosphorus (AOAC 968.08D) were determined by colorimetric analysis.

Amino acids were determined by hydrolysing the samples in 6 N hydrochloric acid containing phenol, for 24 h at 110 ± 2 °C under vacuum in glass tubes. A Waters ion-exchange high performance liquid chromatographic (HPLC) system was used to detect amino acids and the chromatograms were integrated using dedicated software (Millennium, Version 3.05.02, Waters, Millipore, Milford, MA, USA). The amino acids were identified and quantified using a standard amino acid mixture (Sigma, St Louis, MO, USA). The amino acids were eluted with two sodium-based buffers. Buffer A was based on citrate (pH 3.3) and buffer B on borate (pH 9.8). Cystine and methionine were analysed as cysteic acid and methionine sulphone by oxidation with performic acid for 16 h at 0 °C and neutralised with hydrobromic acid prior to hydrolysis (Ravindran *et al.,* 2007).

3.3.6 Statistical analysis

Student's *t*-tests were performed on trial one data to determine if there were any gender effects. The data were then pooled to determine apparent digestibility of nutrients. Apparent digestibility data for trial two was compared statistically using two-way analysis of variance (ANOVA) for cross over design, with diet, period, sequence effect, gender, and dog as variables. All statistical procedures were carried out with SAS 9.1 software (package (SAS/STAT Version 9.1, SAS Inst., Inc., Cary, NC, USA). Data are presented as mean (± SEM), unless otherwise stated. Significance was assumed if $p<0.05$.

3.4 Results

3.4.1 Animal information

All dogs maintained weight during trial one, and the body weights ranged from 23.0 to 29.0 kg (25.3 ± 1.7kg mean ± SEM). All dogs consumed all of the diet offered.

All dogs maintained weight during the trials in trial two and the body weights ranged from 17.0 to 31.0 kg (25.2 ± 3.5kg mean ± SEM). All dogs consumed the majority of the diet offered, and any bone fragments left were weighed and recorded.

There were no significant gender or dog effect for trial one or period, sequence effect, gender, or dog effects for trial two. Table 3.2 shows the nutrient profiles of the three dietary treatments.

Table 3.2: Nutrient profiles of the three dietary treatments.

Item	"As fed" basis (%) Diet one: TUX Energy	Diet three: Homekill	Diet two: 50% (mixed)
Moisture (%)	7.00	51.29	29.39
Carbohydrate (%)	40.71	0.39	21.80
Ash (%)	9.07	7.06	8.93
Fat (%)	21.03	20.22	18.08
Crude Protein (%)	22.20	21.04	22.40
Energy (Kcal/g)	4.77	3.00	3.70
Amino Acids (mg/100mg)			
Alanine	0.88	1.63	1.22
Arginine	0.88	1.80	1.20
Aspartic acid	0.09	2.11	1.27
Cystine	0.20	0.21	0.21
Glutamic acid	2.44	3.70	3.14
Glycine	1.59	2.07	1.89
Histidine	0.32	0.81	0.43
Isoleucine	0.45	1.03	0.65
Leucine	0.96	1.96	1.30
Lysine	0.47	1.89	0.95
Methionine	0.20	0.58	0.40
Phenylalanine	0.60	1.01	0.73
Serine	0.62	0.95	0.71
Taurine	0.03	0.11	0.06
Threonine	0.04	0.92	0.53
Tyrosine	0.40	0.83	0.52
Valine	0.60	1.17	0.83
Minerals (g/100g)	0.00	0.00	0.00
Calcium	2.72	1.82	2.96
Phosphorus	1.40	0.98	1.51

3.4.2 Apparent digestibility of diet one (trial one)

There were no significant ($p > 0.05$) gender differences in the apparent digestibility of nutrients in dogs consuming diet one, and therefore gender effects were not considered in the model and the results of the first trial are summarised in Table 3.3.

Table 3.3: Average apparent faecal digestibility of nutrients in 100% TUX Energy (diet one) in dogs.

	Dry matter basis (5)	
Nutrient	**Diet one TUX Energy**	**SEM**
Dry Matter	77.18	1.27
Organic Matter	85.99	0.50
Carbohydrate	81.62	0.71
Crude Protein	82.69	0.81
Crude Fat	97.76	0.16
Energy	86.07	0.33

3.4.3 Apparent digestibility of diets two and three (trial two)

No dog or group interactions or period, gender, or dog effects were observed for any of the parameters. Therefore, individual dogs and the sequence in which they were tested had no influence on the results of the study. The results of the second trial are summarised in Table 3.4.

Table 3.4: Average apparent digestibility of nutrients, including amino acids and minerals, in 50% homekill: 50% TUX Energy (diet two) and 100% homekill (diet three) in dogs.

Nutrient	**50% Homekill: 50% TUX (diet two)**	**SEM**	**100% Homekill (diet three)**	**SEM**	***P*-value**
Apparent Digestibility					
Dry Matter	82.81	0.69	88.16	1.09	**
Organic Matter	89.91	1.19	94.68	1.12	***
Carbohydrate	65.11	3.22	-	-	-
Crude Protein	89.99	0.84	95.35	0.29	**
Crude Fat	99.23	0.18	99.79	0.02	*
Energy	90.06	0.44	95.43	0.47	***
Amino Acids:					
Alanine	91.12	1.06	97.15	0.21	**
Arginine	93.05	0.77	98.20	0.21	**
Aspartic acid	87.46	0.97	96.84	0.25	***
Cystine	81.21	1.66	90.28	1.22	**
Glutamic acid	92.70	0.65	97.23	0.22	***
Glycine	91.79	1.38	97.25	0.36	**
Histidine	81.92	1.59	95.56	0.46	***
Isoleucine	89.76	0.67	97.06	0.23	***
Leucine	90.26	0.66	96.93	0.23	***
Lysine	89.46	0.76	97.61	0.21	***
Methionine	91.87	0.65	97.64	0.15	***
Phenylalanine	91.05	0.59	97.15	0.22	***
Serine	87.07	0.88	95.61	0.45	***
Taurine	76.12	3.45	92.66	1.44	**
Threonine	87.92	0.75	96.93	0.30	***
Tyrosine	88.31	0.67	96.58	0.33	***
Valine	88.99	0.73	96.46	0.30	***
Minerals:					
Calcium	21.49	3.99	19.07	8.42	NS
Phosphorus	29.89	4.19	29.84	7.18	NS

NS Not significant,* $p<0.05$, ** $p<0.005$, ***$p<0.0001$

Overall homekill had the highest apparent digestibility for all nutrients, except for carbohydrate which was only present in extremely low levels in homekill and calcium and phosphate (compared to the 50% (diet two) and TUX Energy biscuits (diet one: Table 3.3). There were significant differences between diet two (the 50 %diet) and diet three (100% homekill), with homekill having higher apparent digestibility for all macronutrients.

Apparent amino acid digestibility of both diets (diet two and diet three) was high, although apparent digestibility of amino acids from homekill was significantly higher than the 50% diet (diet two). There were highly significant ($p < 0.0001$) differences between the 50% diet (diet two) and homekill (diet three) for the amino acids aspartic acid, glutamic acid, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, tyrosine and valine.

There were no significant difference in the apparent digestibility of calcium or phosphorus between diets two and three (see Table 3.5b and 3.5c). Tables 3.5 a, b and c show that the 50% diet (diet two) and homekill (diet three) meet or exceed most of the minimum requirements set by AAFCO (2009). The AAFCO requirements are expressed as nutrient requirements adjusted to the energy density of the food. TUX Energy did not meet lysine, threonine, methionine and cystine minimum requirements as set by AAFCO (2009).

Tables 3.5 b and c show that the apparent digestibility of all amino acids are high, however, the apparent digestibility of calcium and phosphorus were low.

Table 3.5a: Comparison of essential amino acids and mineral concentrations in TUX Energy (diet one: g/kg DM) and requirements set by AAFCO (adjusted to the energy density of the food;2009).

	100% TUX diet (ME 3,285 kcal/kg)		
Nutrient	**AAFCO (2009) Recommendation**		**Amount in diet**
	Min	**Max**	
Amino Acids:			
Arginine	0.48		0.95
Histidine	0.17		0.34
Isoleucine	0.5		0.48
Leucine	0.56		1.03
Lysine	0.59		0.50*
Methionine & Cystine	0.40		0.42
Phenylalanine & Tyrosine	0.69		1.08
Threonine	0.45		0.40*
Valine	0.36		0.65
Minerals:			
Calcium	0.75	2.3	2.92*
Phosphorus	0.66	1.5	1.51
Ca:P ratio	1:1	2:1	1.93:1

***** Numbers in red refers to where the diet either does not meet, or exceeds AAFCO requirements.

Table 3.5b: Comparison of essential amino acids and minerals in the 50% diet (diet two: g/kg DM), apparent diet digestibility (%) and requirements set by AAFCO (adjusted to the energy density of the food;2009).

50% TUX: 50% Homekill (ME 4,049 kcal/kg)				
Nutrient	**AAFCO Recommendation**		**Amount in diet**	**Apparent Digestibility (%)**
	Minimum	**Maximum**		
Arginine	0.72		1.70	93.05
Histidine	0.25		0.61	81.92
Isoleucine	0.52		0.92	89.76
Leucine	0.84		1.84	90.26
Lysine	0.89		1.35	89.46
Methionine and Cystine	0.61		0.86	86.54
Phenylalanine and Tyrosine	1.03		1.77	89.68
Threonine	0.68		0.75	87.92
Valine	0.55		1.18	88.99
Calcium	0.85	3.54	4.19	21.49
Phosphorus	0.71	2.27	2.14	29.89
Ca:P ratio	1.2:1	2:1	1.96:1	

Table 3.5c: Comparison of essential amino acids and minerals in the Homekill diet (diet three: g/kg DM), apparent diet digestibility (%) and requirements set by AAFCO (adjusted to the energy density of the food; 2009).

	100% Homekill (ME 5,325 kcal/kg)			
Nutrient	**AAFCO Recommendation**		**Amount in diet**	**Apparent Digestibility (%)**
	minimum	**maximum**		
Arginine	1.05		3.69	98.28
Histidine	0.37		1.66	95.76
Isoleucine	0.76		2.12	97.18
Leucine	1.21		4.02	97.06
Lysine	1.29		3.87	97.72
Methionine and Cystine	0.88		1.64	94.22
Phenylalanine and Tyrosine	1.50		3.77	97.00
Threonine	0.99		1.89	97.06
Valine	0.80		2.41	96.61
Calcium	1.23	5.13	3.74	22.54
Phosphorus	1.03	3.28	2.02	32.85
Ca:P ratio	1.2:1	2:1	1.85:1	

3.4.4 Comparisons of results between trials one and two

The time between the two trials made direct comparison of nutrient digestibility between trials statistically unfeasible and therefore this analysis was not carried out, however we can compare the nutrient content of the diets between the two trials. Homekill (diet three) has the lowest amount of carbohydrates (0.80% on a dry matter basis), whereas TUX Energy (diet one) had the highest (81.62% on a dry matter basis). Homekill (diet three) was the most digestible diet of those studied; adding TUX biscuits to homekill lowered the apparent digestibility of all nutrients to a concentration in between 100% homekill and 100% TUX Energy. Figure 3.3 illustrates that TUX Energy (diet one) has lower apparent digestibility values for crude protein, fat and energy, organic matter and dry matter than the other two diets, while homekill (diet three) had the highest level of apparent digestibility for all nutrients. As expected, the apparent digestibility of all macronutrients in diet two (the 50% diet) was consistently intermediate between diet one (TUX Energy) and diet three (homekill).

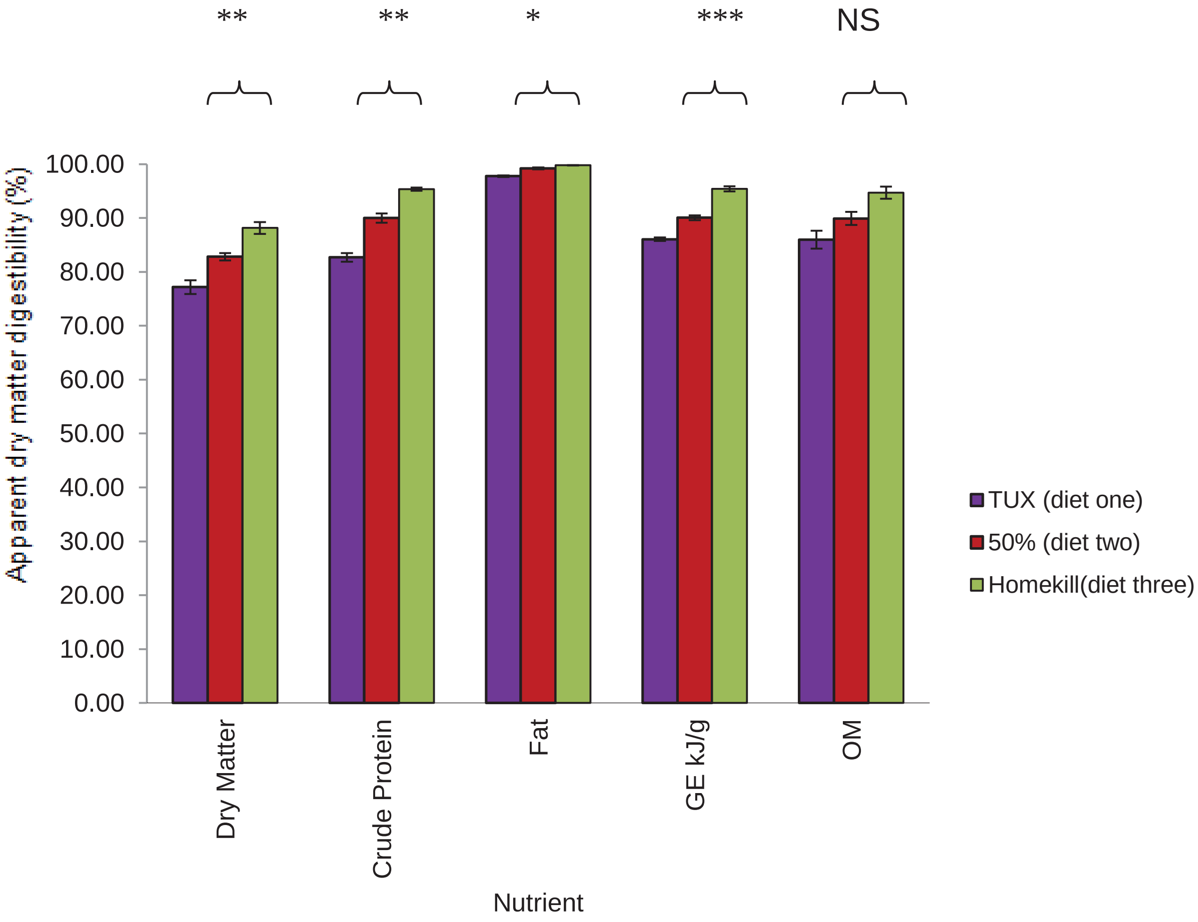


Figure 3.3: Apparent dry matter digestibility of macronutrients in three diets[‡] and *p*-values between diet two and three, where * *p*<0.05, ** *p*<0.005, ****p*<0.0001

[‡] Apparent macronutrient digestibility of diet one was established 21 months prior to the other two diets.

3.5 Discussion

This study showed that there were significant differences between diet two (which is the most common current feeding practices of farmers as identified in chapter 2) and diet three (homekill), where diet three was significantly more digestible. Historically NZ farmers have fed their working dogs a diet consisting of homekill, or fallen stock and NZ authors have suggested that this raw meat diet is the best diet to ensure that the dogs can meet the working demands placed on them (Mills *et al.,* 1964). However, there is no scientific evidence supporting this claim, and one way to ascertain the nutritional benefits of this diet, is to test the apparent digestibility. This study is the first test the apparent digestibility of common diets fed to working farm dogs in NZ.

Diets two and three met AAFCO nutritional guidelines for all tested nutrients for a dog at maintenance life stage. When combined with the apparent digestibility results shows that diet one (TUX Energy) was the least digestible, this in combination with its low nutrient content (compared to other diets in this study), made it the least desirable of all diets tested. Diet three (homekill) had the highest digestibility, as well as the highest nutrient content, making it the most adequate diet in this study. However, the quality of the meat given to working farm dogs varies according to season and the health of the sheep at the time of death. For example, stock slaughtered in summer may have higher concentrations of fat than stock slaughtered at the end of winter. It is likely that the homekill will vary in composition based on the climatic conditions experiences by the stock during its lifetime, but this is something that requires further testing. The homekill used in this study was sourced from a sheep and beef farm at Massey University, and was intended for consumption by working dogs on that farm. The period of the year the homekill was sourced for the trial, was during lambing, which is the time of year when working farm dogs are undergoing peak work. Therefore, this diet can be considered indicative of what farm dogs on this particular farm are normally feed, during peak periods of work.

The dogs used in this study are normally fed a diet consisting of homekill and occasionally biscuits, and were well adapted to the diets used in this study. There are a number of digestibility protocols with different lengths of adaptation and collection periods, however, Nott *et al.* (1994) found there were no significant differences between different collection periods (faeces collected over three time periods: days 4-7, days, 8-14 or days 15-21) in any of the variables measured in dogs, and suggested that a three day period of adaption period followed by a four day collection is sufficient to measure apparent digestibility in dogs. The digestibility protocol used in the two trials described here, of a five day adaptation and 4 day collection period was therefore considered adequate.

Analysis of all three diets indicated that when compared with minimum requirements set by AAFCO (2009), TUX Energy (diet one) was deficient in lysine, cystine and threonine. These are all essential amino acids that the dog has to receive from its diet, because it is incapable of making them itself. The AAFCO (2009) guidelines are minimum requirements for the dog at maintenance, therefore, considering that this diet had the lowest apparent digestibility results (83%), during peak periods of work, working dogs on a 100% TUX Energy diet, are most likely not receiving minimum amino acid requirements. Lysine is a first limiting amino acid in common grain ingredients used in manufactured dog food (e.g. wheat, corn and soybean), and processing can affect its availability. The free epsilon amino group reacts with reducing sugars and forms a Schiff's base and lowers the digestibility of lysine (Morris and Rogers, 1994). TUX Energy was the only diet that did not meet minimum AAFCO (2009) lysine requirements for maintenance of adult dogs. When proteins sourced from animals are combined with proteins from a plant source, a complementation of limiting amino acids is achieved and generally the overall quality of protein in the product is improved. Most animal sources of protein are rich in lysine and tryptophan, and pork products are particularly rich in histidine. These three amino acids are commonly limiting amino acids in cereal based products used in manufacturing dog food (Brown, 1989). By adding homekill to TUX Energy (diet two), the dietary lysine increased to a concentration that met minimum AAFCO (2009) recommendations.

Analysis also showed that TUX Energy (diet one) contained calcium concentrations that exceeded the maximum recommendations set by AAFCO (2009), although the calcium: phosphorus ratio was within acceptable limits. Initial analysis also showed that the 50% TUX: 50% homekill diet (diet two) also exceeded maximum calcium recommendations set by AAFCO and the calcium: phosphorus ratio (1.96:1) is near the maximum AAFCO recommendation of 2:1. In this study, the calcium and phosphorus analysis showed that the 50% diet contained more calcium and phosphorus than the individual diets. There may be various reasons that this may have occurred, such as the sample of 50% diet submitted to the laboratory may not have been a true representative sub-sample, it may have contained proportionally more bone than the homekill diet sample submitted for analysis. As mentioned previously, this is the first study of this kind, therefore the result cannot be compared with previous studies and it unclear why the 50% diet contains more calcium and phosphorus, when compared with the individual diets.

Results from the survey in chapter two indicated that most farmers do not feed 100% homekill, rather the working dog receives an average diet of 50% meat and 50% dog biscuits. This study which tested a 50% homekill and 50% TUX Energy diet indicated that adding TUX Energy to homekill (diet two) lowered the apparent digestibility of all nutrients (crude protein, crude fat and energy) to a concentration intermediate to feeding 100% homekill or feeding 100% TUX Energy. The apparent digestibility of a diet is important for working dogs, because food that has a high apparent digestibility increases the maximum possible delivery of nutrients to tissues (Toll and Reynolds, 1998). The fat apparent digestibility of all diets was very high (99.8 (diet three) *vs.* 99.2 (diet two) *vs.* 97.8% (diet one)) and although there were significant differences between diets two and three, The very high apparent digestibilities makes this significant difference have no biological relevance.

It has been recommended that the total dry matter digestibility for food fed to working dogs should exceed 80% (Downey *et al.,* 1980), in this trial diet three (88%) and diet two (83%) both exceeded a dry matter apparent digestibility of 80%, while diet one (TUX Energy) had a dry matter apparent digestibility of 77%. Apparent digestibility studies in this trial showed that homekill (diet three) was the most digestible diet in terms of dry matter, crude protein, fat and energy on a dry matter basis, followed by the 50% homekill: 50% TUX Energy diet (diet two). Downey *et al.* (1980) showed that stamina in beagles was negatively affected by low digestible dry matter and stamina increased as the energy density, digestibility and digestible fat intake increased. This suggests the higher the DM digestibility of the diet, the more nutrients the dog is able to digest from its diet, therefore, relative to a diet with low DM digestibility, the dog is able to utilise more nutrients from its diet for work. Low dry matter digestibility may also increase the faecal bulk and increase the energetic cost of running

(Toll and Reynolds, 1998). Therefore TUX Energy (diet one) may increase the energy required to run by the working dog via an increased faecal bulk, in addition to limiting the amount of nutrients the dog gets from the diet.

This trial analysed nine essential amino acids and also calcium and phosphorus. It was established that adding TUX to homekill decreased the apparent digestibility of all the nine of the 10 essential amino acids required in the diet of a dog, amino acids, but increased the apparent digestibility of calcium. Previous trials have shown that calcium absorption is low in high calcium diets and high in low calcium diets for dogs fed dry dog food (Hazewinkel *et al.,* 1991; Nap *et al.,* 1993; Kastenmayer *et al.,* 2002) and dogs can adapt to lower or higher levels of calcium intake (Gershoff *et al.,* 1957). The high calcium content of the diets combined with the low digestibility result suggests that the gastro intestinal system of the dog may have evolved and adapted to a naturally high calcium diet by not absorbing all the calcium in the diet.

One of the dogs on diet two, period one, produced negative apparent digestibility results for calcium and phosphorus, this may have been a result of bone fragments in the faeces which were subsequently analysed. Negative results have also been published in the literature (Lewis *et al.,* 1994). Calcium and phosphorus apparent digestibility found in this study are extremely low 21.49 and 29.89 % respectively (diet two) and 22.54 and 32.85 % respectively (diet three), however, low calcium and phosphorus apparent digestibility have also been found in other studies. A study by Lewis *et al*. (1994) found low calcium apparent digestibility (ranging from -2.0 to 10.7%) and phosphorus digestibility (ranging from 26.6 – 60.8%). Murray *et al.* (1999) found that phosphorus digestibility was lowest in a diet where the calcium intake was the highest, but found the result difficult to explain. However, they also reported low calcium and phosphorus digestibility in all test diets (16 - 22.6% for calcium and 48.2 – 65.8% for phosphorus respectively). Kastenmayer *et al.* (2002) also concluded that the apparent digestibility of calcium in dogs is low, but did not investigate phosphorus. These studies all report low calcium and phosphorus digestibility in a range of experimental diets, therefore the low calcium and phosphorus digestibility found in this study are not just indicative of a raw meat and bone diet but perhaps may represent the low apparent digestibility of calcium and phosphorus in the dog.

Hill (1998), Michel (2006) and Newberne (1974) have suggested that meat is deficient in essential vitamins and minerals and the calcium to phosphorus ratio is badly imbalanced, and therefore meat cannot be considered a balanced diet. However, they did not consider a normal homekill diet to consist of both meat and bone, because this study has shown that the homekill tested (diet three) did meet AAFCO (2009) minimum and maximum requirements for all the essential amino acids tested, as well as calcium, phosphorus, and the calcium: phosphorus ratio on a dry matter basis.

Homekill (diet three) contained the least amount of carbohydrate (by difference), and TUX Energy (diet one) contained the most (0.80% vs. 43.77% on a dry matter basis). The main role of carbohydrate is to supply the body with energy and replenish glycogen stores in muscles. This is important for dogs such Greyhounds that use muscle glycogen in short fast sprints (Hill *et al.,* 2005) and may be useful for the working farm dog in NZ, which need to sprint after stray sheep. However, depending on the type of work, carbohydrate may not be an essential nutrient in working dogs since studies have shown that sled dogs can live on a carbohydrate free diet (Kronfeld *et al.,* 1977). Some animals appeared to perform better when consuming an all meat diet due to an increase in oxygen carrying capacity and increased fat mobilisation (Kronfeld, 1973; Kronfeld and Hammel, 1975).

Unlike humans, healthy dogs fed a carbohydrate free diet do not develop hypoglycaemia or ketosis (Crandall, 1941; Kronfeld, 1973). However, carbohydrates are essential in other life stages such as pregnancy and lactation (Romsos *et al*., 1981). The negative aspects of feeding a carbohydrate free diet, is the probable changes to the resident microbial population in the colon of the dog which may impact on gut health (Flickinger *et al.* 2003; Sunvold *et al*., 1995). It is known that the microbial population changes with diet (Flickinger *et al.,* 2000; Swanson *et al.*, 2002a; Swanson *et al.,* 2002b; Remesy and Demigne, 1989; Torrey, 1919; Younes *et al.,* 1995). A carbohydrate free diet has negative ramifications on gut health, as it may change the microbial population to include pathogenic species and less health promoting species. Studies have shown that a change in diet will cause a change in the microbial population in the colon (Flickinger *et al.,* 2000; Swanson *et al.*, 2002a; Swanson *et al.,* 2002b; Remesy and Demigne, 1989; Younes *et al.,* 1995).

Studies have looked at the effect of fermentable fibre on microbes in the GI tract of dogs (Flickinger *et al.* 2003; Sunvold *et al*., 1995), and have shown that these fermentable fibres act as prebiotics and increase gut health by decreasing the amount of the putrefactive bacteria that would be seen in a meat-only diet (Swanson *et al.,* 2002b). Many farmers in NZ feed homekill, which not only has limited amounts of carbohydrates, but also is low in fibre. In the absence of dietary fibre there is a proliferation of putrefactive bacteria such as *Bacilli. Welchii* and *Clostridium spp.* When a low fibre diet is fed, bacteria ferment amino acids to short-chain fatty acids and ammonia to obtain energy (Russell *et al.,* 1991). Undigested protein reaches the colon of the dog and is fermented into ammonia, phenols and indoles, branched fatty acids, amines and volatile sulphur-containing compounds, these increase flactulence, faecal odour and instances of diahorea (Bakke, 1969; Miner and Hazen, 1969; Barth and Polkowski, 1974; Williams, 1984; Tabor and Tabor, 1985). Therefore, if farmers feed a meat-only diet to their dogs, they could be compromising the over-all gut health by causing proliferation of pathogenic species such as *Clostridium spp*. The proliferation of pathogenic species can displace beneficial bacteria, and studies have shown that beneficial bacteria, such as Lactobacilli increase immunity of the animal (Perdigon *et al.,* 1986). Dietary fibre helps increase gut health by selectively stimulating the growth and/or activity of one or a limited number of beneficial bacteria in the colon (Gibson & Roberfroid, 1995), but their primary benefits are maintaining regularity and promoting movement of toxins and potential carcinogens out of the intestinal tract (Davidson & McDonald, 1998), thereby increasing the health of the gut. In this study, diet three contained no fibre, as it is an all meat diet, whereas diet one contained a maximum of 4% fibre in the diet, providing at least some fermentable fibre to the microbial population in the colon of the dog.

Not only does feeding an all meat diet potentially compromise the gut health of the dog (by decreasing the number of beneficial bacteria in the gut), but it could also have the potential to cause infections from bacterial pathogens that may be present in the meat. Therefore, before feeding homekill, NZ authors have stressed the importance of either freezing meat for at least 7 days at a temperature of -10°C (but preferably -16°C), or boiling meat for a long period (Dalton, 1996: Macgregor-Redwood, 1980). Freezing will reduce the bacterial load in the raw meat, lessening the chances of infection. If meat is not properly frozen or cooked, there is an added risk of other bacterial pathogens (e.g. *Salmonella sp*), that can cause infections in both the dog and the human, resulting in diarrhoea (LeJeune and Hancock, 2001; Morley *et al.,* 2006; Strohmeyer *et al.,* 2006).

Diet three (homekill) contained 48.47% DM, therefore on an 'as is' or 'as fed' basis, a working dog would have to eat a 2.05 kg piece of mutton carcass to receive its daily requirement for amino acids, calcium and phosphorus. If a dog was consuming a 50% homekill: 50% TUX Energy diet, then it needs approximately 1 kg of meat and 400 g of TUX biscuits. This is still a large volume of food that a dog would need to consume daily to meet its maintenance requirements, and it may be a large amount of food for the animal to consume in one meal. The heaviest dog in this study (31 kg) was fed approximately 800 g of homekill and 300 g of TUX Energy biscuits and took a number of hours to finish this amount of food. However, a working dog fed at night after a hard day of work, may not have the inclination or time to finish its meal before the morning, this is often the case and there are usually uneaten biscuits in the dog kennels in the morning (I Singh, unpubl. obs.). If this dog does not consume 1 kg of meat and 400g of TUX Energy biscuits, it may not be receiving the nutrition it requires. Biscuits are more nutrient dense than homekill, as the homekill contains 51% moisture, whereas the biscuits only contained 7% moisture. Even though the dog will drink water with the biscuits, it will presumably eat all the biscuits it wants before drinking water. Whereas with a diet composed of homekill, the dog will be consuming water with the diet, and inevitably consuming a less calorie dense diet. Therefore the dog may not be able to work to its best ability, simply because it does not have enough body reserves and energy to do so.

The nutritional composition of a piece of meat depends on which part of the carcass it comes from, the age of the fallen stock (young lamb *vs.* mutton) and the season it was killed. Therefore the dog receives variable nutrition from homekill from day to day and season to season. For example, a forequarter from a sheep this year, will have different protein and fat composition to the forequarter of a sheep next year, or the previous year. The nutrient content of the sheep is also dependent on the pasture growth within the same year, if it is raised on poor pasture on the farm, it will have a poorer nutrient composition. In saying this, farmers appear to portion control based on both the workload of their dogs, and feed to how much fat/meat each cut of homekill contains (from Chapter two).

It is important to note that the minimum AAFCO (2009) requirements are for maintenance of adult dogs, not for working dogs. At present there are no minimum requirements for working farm dogs, the information generated from this study has shown that of the three diets tested in this study, the best diet of the three tested is a diet of 50% Homekill: 50% TUX Energy (diet two). The benefit of feeding biscuits with homekill ensures that the dog is receiving highly digestible protein and fat from the meat, combined with a high energy density biscuit containing vitamins and minerals (e.g. vitamin A, D, E, B vitamins, magnesium, sodium, chloride etc) which are essential for the health and well-being of the working dog and may be deficient in homekill. Biscuits also provide carbohydrates that aid recovery by replenishing glycogen stores in muscles after a hard day’s work. Fibre from the biscuits also help gut health, by ensuring a beneficial microbial population in the colon. However, the diets tested in the work described here may not be the optimal, as the energy requirements of the working dog have not been established. Establishing the requirements of a free-living subject, such as the working dog is not simple. The equipment used needs to be light enough to be unobstructive to the dog and farmer, and be able to record continuous data. From the discussion in chapter one, the best method to calibrate monitors, and therefore provide an accurate, but convenient method to estimate the energy requirements of a free living animal, would be to use doubly labelled water.

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CHAPTER FOUR:

Calibrating Actical® activity monitors with the doubly-labelled water method in working farm dogs.

4.1 Introduction

The energy requirements of working farm dogs in NZ is unknown, currently there is no literature substantiating the energy expenditure, or energy requirements of these unique athletes. This work has so far identified the current feeding practice of working farm dogs, and assessed the apparent digestibility of an example of these diets. The next step is to establish how much work these dog do, what the energy requirements of these dogs are, and if the current diet meets these needs. In order to establish the energy expenditure of working dogs a suitable method to capture how much work is conducted needs to be used. By knowing the energy requirements of these working dogs, nutritionists can then determine how many calories a working dog needs in their diet. Scientists can then build on this information and determine the levels of other essential nutrients that these unique athletes require.

Estimating energy expenditure of free-living subjects is difficult, as accurate estimates cannot usually be made in a controlled laboratory setting, making it difficult to estimate how much work a farm dog will do on a given day. There are a limited number ways of accurately measuring energy expenditure in the field, which include, isotopic wash out methods, pedometers, accelerometers, global positioning systems and heart rate monitors. One technique that is increasing in popularity is an isotopic wash out method using doubly-labelled water (DLW). This method has been validated for use in dogs (Speakman *et al.*, 2001) and provides an estimate of carbon dioxide (CO_2) production using the isotopes, heavy oxygen (^{18}O) and deuterium (^{2}H) or tritium (^{3}H) as labels. Normally these isotopes do not occur naturally in the body and oxygen is present as ^{16}O, therefore ^{18}O can be effectively used as a marker (Speakman *et al.*, 2001). The basis of the DLW method is the measurement of the decline of the two isotopes in body water, after the initial labelling of the body water pool. Heavy oxygen (^{18}O) is lost from the body as CO_2 and as water (H_2O), whereas deuterium (^{2}H) is only lost as H_2O (Speakman *et al.*, 2001). The difference in disappearance of the two isotopes from urine, plasma and saliva, is used to measure CO_2 production and thus energy expenditure during the study period. The technique assumes that the O_2 in CO_2 is in complete isotopic exchange equilibrium with the oxygen (O_2) in body water (Speakman, 2005). The major advantage of using doubly-labelled water to estimate energy expenditure is that it enables researchers to carry out field trials on animals in their natural environment, allowing them to exhibit natural behaviours. The disadvantage of the method is the cost, especially if using a large number of animals or if using animals with a large body mass, thus necessitating the use of a large volume of isotopes. In addition, the DLW method is unreliable if measurements are carried out over short periods of time because of the slow elimination rates (Pouteau *et al.,* 2002).

A newer method that is also gaining popularity is the use of activity monitors, which are relatively small and inexpensive when compared to DLW. The type of activity monitor used in this study is an Actical® activity monitor which includes an accelerometer which collects data on an individuals' movement in time periods or epochs as short as 15 s. The accelerometer reports movement data as activity counts which allows researchers to track relative physical activity between individuals. However, activity counts are arbitrary units and further research needs to be conducted in the target animals to convert activity counts into a more useful unit of measurement such as energy expenditure. The Actical® activity monitor has been successfully calibrated to establish energy expenditure in preschool children (Pfeiffer *et al.,* 2006), children aged 6 – 16 years old (Puyau *et al.*, 2002), and rhesus monkeys (Sullivan *et al.,* 2006) using indirect calorimetry. Until now activity monitors have not been calibrated to measure energy expenditure in cats or dogs, and studies using monitors to measure activity in the two species have only reported raw activity counts (Cimino-Brown *et al.,* 2010; Dow *et al.,* 2009; Hansen *et al.,* 2007; Lascelles, 2008: Vester *et al.,* 2009). Activity monitors have also been used to indirectly assess pain relief in cats with joint diseases by measuring changes in activity level before and after treatment (Lascelles, 2010; Lascelles *et al.,* 2007).

Doubly-labelled water (DLW) is the 'gold standard' for measuring energy expenditure in the field and is therefore the best method available to calibrate activity monitors to measure energy expenditure in free-living subjects (Westerterp, 1999). To date the Actical® activity monitor has not been calibrated to measure energy expenditure in dogs, therefore a combination of these two methods may be the best method to estimate the energy expenditure of working farm dogs in NZ.

4.2 Aim

The energy requirements of working farm dogs is unknown, therefore this study will calibrate the Actical® activity monitors using DLW, to measure energy expenditure in working dogs in NZ.

4.2.1: Hypothesis

Activity monitors can be calibrated using DLW to predict energy expenditure in working farm dogs in NZ.

4.3 Methods and materials

The studies reported here (MUAEC # 09-13 – Validation of DLW using farm dogs in Canterbury) were approved by, and conformed to, the requirements of the Massey University Animal Ethics Committee (Anonymous, 2009).

4.3.1 Animals

Six healthy farm dogs were used in a study conducted in September (early spring), 2009 at a mixed terrain sheep and beef farm (The Druids, Waiau, Canterbury, NZ). The dogs used were two female (Bess and Mist) and one male (Rock) Heading dog and two male (Todd and Bo) and one female (Tui) Huntaway. The animals were between 9 months and 9 years of age with bodyweights ranging from 18.8 to 28.2 kg (23.2 ± 1.12 kg mean ± SEM). Animals were fed their usual diet of 50% homekill and 50% biscuits. Water was available *ad libitum* throughout the trial. Body condition was evaluated to assess degree of leanness or obesity, using a body condition score ranging from one (emaciated) to nine (severely obese) (Laflamme, 1997). Characteristics of dogs used in the study to calibrate Actical® activity monitors with doubly-labelled water are shown in table 4.1.

Table 4.1: Characteristics of dogs used in the study to calibrate Actical® activity monitors with doubly-labelled water.

Dog No.	Name	Breed	Gender	Age (yr)	Weight (kg)	Body condition score at start (scale 1-9)
1	Tui	Huntaway	F	9.0	28.2	3.5
2	Todd	Huntaway	M	6.0	22.1	3.0
3	Rock	Heading	M	3.0	22.4	3.0
4	Bess	Heading	F	4.0	21.3	3.0
5	Mist	Heading	F	3.0	18.8	3.0
6	Bo	Huntaway	M	0.8	25.5	3.0

4.3.1.1 Animal assignment

The dogs were placed in two groups, the first group contained four animals (two Heading dogs (Rock and Bess) and two Huntaway (Tui and Todd), which remained sedentary (kept in a kennel, which contained an indoor and outdoor section, and let out twice a day for approximately 30 mins each time) for three days (period one) and then assisted with farm work for the next three days (period two). Group two contained two animals (one Heading dog (Mist) and one Huntaway (Bo)) and worked on the farm for the first period and remained sedentary in period two. The dogs were grouped according to when the farmer required them for farm work. Farm work consisted of mustering sheep and yard work, and lasted approximately 9 hours per day.

4.3.2 Doubly-labelled water protocol

Prior to injection, the dogs were weighed and a blood samples taken from the cephalic vein (3 - 5mls) to estimate background isotope enrichments (T0). A known mass of DLW (equation 4.1) was then slowly administrated subcutaneously at the back of the neck and the needle left in place for 1-2 sec before rapidly withdrawing. The volume of injectate was calculated using the formula:

Equation 4.1:

Mass of injectate (ml) = ((0.7 × BW (g)) × 350) × 650000 (from Speakman, 1997)

The syringe was weighed (to the nearest 0.0001 g) using a Mettler AE165 balance (Mettler Toledo GmbH, Greifensee, Switzerland) before and after administration. The DLW was a mixture of two parts 97% ^{18}O-enriched water (Marshall Isotopes Limited, Tel-Aviv, Israel) and one part 99.8% ^{2}H-enriched water (Cambridge Isotope Laboratory Inc., Andover, M.A., USA). The DLW was mixed by the researcher and was transported in a dark glass screw top bottle containing a rubber septum lid. Actical® activity monitors were placed around the neck of the dogs immediately after the DLW was administered, and left on for the duration of the trial.

After a 6 h equilibration period (Speakman *et al.,* 2001) blood samples were taken at 6 hours (T6), 72 h (T72) and 144 h (T144) h after the injection of DLW. The 72 and 144 h sampling times coincided with the end of periods one and two for both groups (Section 4.3.1.1).

4.3.2.1 Sample handling

All injections and blood sampling were carried out by a registered veterinarian. Blood was collected into heparinised vaccutainers and chilled until it could be centrifuged. Samples were centrifuged (Eppendorf Centrifuge 5702R) at 4°C for 10 min at 112 × *g* within 48 h of collection. The plasma was transferred to screw top glass bottles and frozen until analysis. Five dilutions of the injectate were made by injecting a weighed amount of DLW into a weighed amount of tap water to produce a 0.2% concentration of DLW (e.g. 0.2 ml of DLW was added to 99.8 ml to make 100 ml in total, and mixed), which was then transferred into a screw top glass bottle. The dilution was used to evaluate the enrichment of the isotopes in the injectate. Plasma from the dogs and infused samples of tap water were analysed using the method outlined by Prentice (1990).

4.3.2.2 Isotope analysis

The isotope ratios ^{18}O: ^{16}O and ^{2}H: ^{1}H were analysed using gas source isotope ratio mass spectrometry (Delta V Advantage Isotope, Thermo Finnigan, Massachusetts USA) using isotopically characterised cylinder gases of CO_2 and H_2 in the reference channel. These cylinder gases were characterised relative to the isotopic standards; standard mean ocean water (SMOW) and standard light arctic precipitate (SLAP) (Speakman *et al.,* 2001). Samples were run alongside three laboratory standards (including SMOW, SLAP and Tap water) for each isotope to correct delta values to parts per million. The sampling needle was flushed with ethyl acetate between each sample injection into the spectrometer. Raw results were reported using Gas isotope ratio MS Software (Isodat workshop version 2.5).

4.3.2.3 Calculations

Injectate enrichment was calculated using the DLW program (Speakman and Lemen, 1999). Isotope enrichments were converted to daily energy expenditure using a two-pool model equation (Schoeller 1988). The flux rate was estimated from the gradient of the log converted graph (k_d or k_o), and the volume of the system (from the dilution space, N), i.e.

Equation 4.2 $N \times k_d = rH_2O$ (where r is the rate) for deuterium and

Equation 4.3 $N \times k_o = rH_2O + r(CO_2)$ for oxygen

An assumption of evaporation of 25% of the water flux was made in accordance with equation 4.4 from Speakman (1997):

Equation 4.4 $rCO_2 = (N/2.078).(k_o - k_d) - 0.0062k_d.N$

Where rCO_2 is the rate of carbon dioxide production

N is the dilution space

k_o is the flux rate of oxygen

k_d is the flux rate of deuterium

k_t is the flux rate of tritium

$R_{dilspace}$ is the average dilution space ratio across all the group members

$R_{dilspace} = N_d/N_o$

$N = (N_o + (N_d/R_{dilspace}))/2$

Where N_d is the dilution space of deuterium and N_o is the dilution space of oxygen.

Equation 4.4 minimises error in a range of conditions (Visser & Schekkerman 1999; van Trigt *et al*., 2002), for example, when the subject is not subjected to extreme heat or cold and maintains an internal body temperature of 37°C (Speakman, 2007) and assuming FQ of 0.85, as recommended by Speakman (1997) for dogs with a high protein diet.

4.3.3 Actical® activity monitors protocol

The triaxial Actical® accelerometer (MiniMitter, Bend, OR, USA) contains an omnidirectional sensor capable of detecting acceleration in all directions. The sensor integrates the speed and distance of acceleration and produces an electrical current that varies in magnitude depending on the change in acceleration. An increased speed or distance of acceleration, or a change in direction, produces an increase in electrical current. The activity monitors store this information as activity counts, the minimum epoch length for this version of the Actical® activity monitor is 15 seconds. A detailed description of the Actical® activity monitors is given in chapter one, section 1.6.5

Each dog was fitted at T0 with a loose-fitting cotton collar with an activity monitor mounted (see Figure 4.1) and housed in a snug, protective and waterproof stainless steel box.

Figure 4.1: Todd (dog 2) wearing the blue cotton collar with Actical® activity monitor housed in a stainless steel box.

The monitor was programmed to store the total number of activity counts produced per 15 s. At this setting the monitors were capable of storing data for up to 11 d. Data from each activity monitor was downloaded at the end of period 2 of the study for both groups using an ActiReader telemetric communications link via a wireless link (Figure 4.2) and Actical® software (version 2.1. MiniMitter, Bend, OR, USA).

Figure 4.2: ActiReader (MiniMitter, Bend, OR, USA) docking station used to download data from Actical® activity monitors.

Figure 4.3 shows an example of the information collected from the downloaded data from Actical® activity monitors from Mist (dog 5).

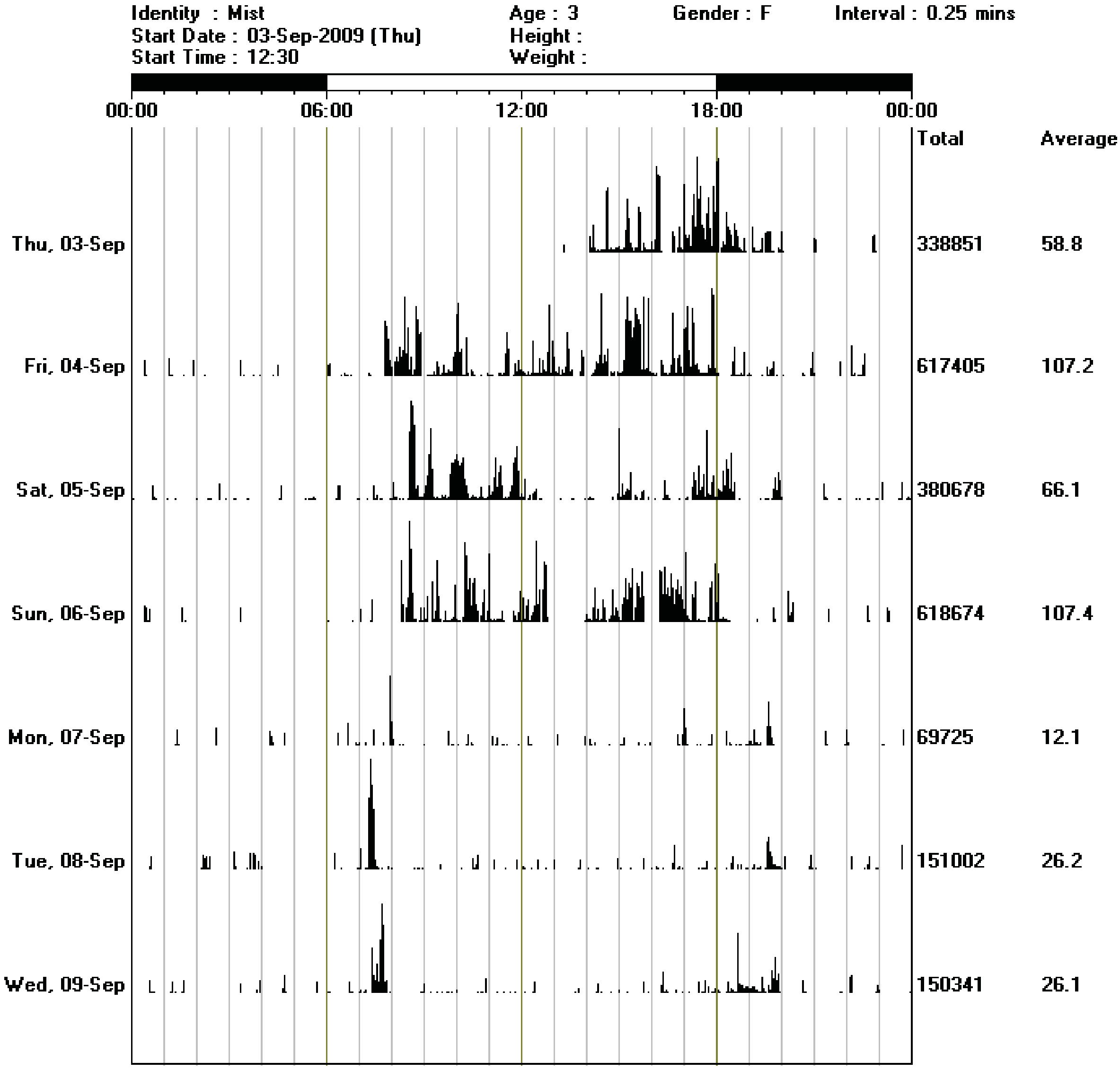

Figure 4.3: Downloaded activity data from Mist (dog five, group two), Thursday 3rd to Sunday 6th September 2009 relating to peak period (period one), and Monday 7th to Wednesday 9th September 2009 relating to off-peak period (period two).

Activity associated energy expenditure (AEE) was calculated by determining the energy expended (in kcal) per activity count. This was calculated by measuring total energy expenditure determined using the DLW method, subtracting basal metabolic rate (calculated using the National Research Council (NRC: Anonymous, 2006) equation 76 kcal/kg BW$^{0.75}$) and dividing the remaining energy expenditure by the number of activity counts which occurred during this time period. The number of calories expended per activity count was multiplied by total daily activity counts to determine daily activity-associated energy expenditure (Sullivan *et al.,* 2006).

4.3.4 Statistical analysis

An outlier test showed that Tui (dog one) was an outlier and therefore was excluded from further analysis due to abnormalities in her isotopic analysis. The rest of the data were normally distributed. There were no statistical differences between sedentary and working periods, therefore the data was pooled to give average energy expenditure during the trial period. Random–coefficient models using PROC MIXED were used to explore the relationship between activity counts and energy expenditure from the DLW method and an overall regression line was calculated. In addition, other variables were considered both one at a time and in a multivariate model. The variables considered included gender, breed, body weight and age, and interactions of the variables with activity counts. All statistical procedures were carried out with SAS 9.1 software (package SAS/STAT Version 9.1, SAS Inst., Inc., Cary, NC, USA). Data are presented as mean and associated standard error of mean (± SEM), unless otherwise stated. Significance was assumed at $p<0.05$.

4.4 Results

4.4.1 Doubly labelled water

The dilution ratios (N_D/N_O) for all the dogs were between 0.99 and 1.07, and turnover ratios for ^{18}O and ^{2}H were between 1.26 and 1.42.

Table 4.2: Average data from 5 dogs used to calculate daily energy expenditure (kcal) using the doubly labelled water method, and the average energy expenditure (EE; from DLW; 50% rest/50% working), activity-associated energy expenditure (AEE) and activity count data (from Actical® activity monitors), and calculated average basal metabolic rate ($^{\#}$BMR) for all five working dogs.

Dog data	
Bodyweight (kg)	22.14
DLW	
N_D	760
N_O	730
Dilution space	1.04
k_D (ml/hr)	0.004
k_O (ml/hr)	0.006
Turnover ratio	1.35
$r\mathrm{O}_2$	11,401
$r\mathrm{CO}_2$	9,691
EE kcal/d (DLW)	1,336
Activity monitors	
Activity counts	404,563
BMR$^{\#}$ (kcal/d)	772
AEE (kcal/d)	564
kcal/ac	0.001
kcal/BW $^{0.75}$	0.14

Where N_D: dilution space of deuterium; $N_{O:}$ Dilution space of oxygen; k_D: flux rate of deuterium; k_O: flux rate of oxygen (for specific calculations please refer to chapter one, section 1.6.6.2 Doubly labelled water)

4.4.2 Converting activity counts to energy expenditure

Data was downloaded from the dog collars and total activity counts over the 6 days were recorded. Table 4.2 illustrates the total activity counts, energy expenditure from DLW, calculated BMR, AEE, kcal per activity count and BW$^{0.75}$ 1000 activity counts per dog over the 6 day trial period.

The mean weight of the dogs was 22.14 ± 1.08 kg (range 18.8 - 25.5 kg). Activity count was 404,563 ± 30,425 (range 331,379 – 477,401). Energy expenditure (EE) as determined by DLW was 1,335.6 ± 74.01 kcal/day (range 1,121.18 – 1,522.47 kcal/day). Calculated BMR was 771.86 ± 28.29 kcal/day (range 686 to 862 kcal/day). Activity associated energy expenditure was 563.74± 53.43 kcal/day (range 435.0 to 739.9 kcal/day). The mean kcal per activity count was 0.00139 ± 0.00005 and a mean 0.14 ± 0.01 kcal (range 0.1146 – 0.1505 kcal) were expended per kg of $BW^{0.75}$per 1000 activity counts. The calculated average lean body mass was 75% of the dogs body weight.

There was no significant breed ($p > 0.7$), gender ($p > 0.2$), weight ($p > 0.6$) or dog ($p > 0.3$) effects for kcal expended per activity counts. The regression of AEE on counts was independent of breed, weight and gender, therefore regression was simplified to the following equation:

AEE (kcal/day) = (number of activity counts × 0.00164) + (-99.683)
($r^2 = 0.87$, adjusted $r^2 = 0.81$) p >0.02, standard error of the estimate (SEE = 49.34).

4.5 Discussion

Actical® activity monitors were successfully calibrated using DLW to measure energy expenditure in free-living subjects, such as working farm dogs in NZ. The equation derived from this study is suitable for dogs weighing between 18 to 26 kg. The limitation of this study is that there were a limited number of dogs and therefore a limited range of body weights studied, this suggests that if this equation was used for dogs outside of the weight range the energy requirements maybe inaccurate and may will lead to over or underestimating food requirements. However, farmers generally feed dogs to visual body cues and will adjust feeding as needed. Further studies need to be conducted to prove if this relationship (AEE (kcal/day) = (number of activity counts × 0.00164) + (-99.683)) is true for dogs of varying weight ranges. The small number of dogs used in this study may also explain why there were no significant differences in gender and breed as well.

Speakman et al. (2001) used DLW to measure energy expenditure in dogs for four days and in further studies Speakman et al. (2003) took measurements

every 24 hours for 4 days. Both studies found the timing to be long enough to accurately measure energy expenditure in dogs. The trials in this study using farm dogs were conducted in consultation with Prof. Speakman and Dr. Redman, who determined that 72 hours was sufficient time for determining energy expenditure from dogs, which had been administered DLW subcutaneously at the back of the neck (Speakman & Redman, person. comm.)". Therefore it was established with known experts that 3 days was a sufficient collection time to establish energy expenditure of working farm dogs
Results from the dogs in this study (Todd, Rock, Mist, Bess and Bo) showed close linear correlation between activity counts and EE (from DLW), for example, Mist (dog five) has the lowest activity counts (331,379) and EE (1,121 kcal/day: from DLW). There were isotope analysis errors associated with the samples obtained from Bess (dog four) with the 24 hr values for both ^{18}O and ^{2}H being less than the 48 hr values. The activity counts and energy expenditure for Bess (dog four) were all within acceptable limits, and therefore, data from Bess was included in the analyses. The study was conducted according to the availability of dogs, and also cost and time permitted for this study. However, a power analysis to estimate a sufficient sample size to evaluate an accurate equation to use activity counts to measure energy expenditure predicted that to achieve a 91% power, the number of dogs needed would be 35. The implications of this is that in this study the number of dogs used may have not have been large enough to derive the equation accurately and therefore when using this equation, the energy expenditure and energy requirement of the dogs maybe under or over estimated. The results from the five dogs used in this study showed an r^2 value of 0.87, suggesting a strong correlation between the activity associated energy expenditure and the number of activity counts per dog. Therefore, the equation may still be used to give an estimate of energy expenditure for dogs weighing between 18 to 26 kg.

Recently there has been an increase in the amount of research using activity monitors in companion animals, with many researchers using these devices for measuring raw activity counts. Raw activity counts are useful for monitoring the effect of drug therapy on animals with joint diseases (Lascelles *et al.,* 2007). There have been a few trials that have reported raw activity counts in healthy dogs. The average activity count in this study was 404,564 ± 30,426 counts/dog/d, which is twice the highest average (231,335) reported by Dow *et al.* (2009), suggesting that farm dogs are almost twice as active as pet dogs. Studies by Dow *et al.* (2009) used the same make and model of activity monitors as this study.

Activity counts are arbitrary units (Lascelles*,* 2008), and only take into account the amount of movement and subsequent physical activity of the subject. Therefore some estimate of BMR needed to be established and since BMR was not directly measured in this study, it was quantified using available equations in the literature. This study did not measure BMR in farm dogs in NZ. Such trials (as described in chapter one, section 1.6.1) would cause unnecessary stress to farm dogs due to them being in an unfamiliar environment and this would likely produce inaccurate results.

The National Research Council (NRC: Anonymous, 2006) estimated the BMR of dogs to be 76 kcal/kg BW$^{0.75}$ (after DeBeer and Hjoort 1938; Galvao 1947; Hammel *et al.* 1958; Kitchen, 1924; Kunde and Steinhaus, 1926; Lusk and Dubois 1924; Leblanc and Diamond 1986). Of these studies, Kitchen (1924) and DeBeer and Hjoort (1938) reported high BMR values (85 ± 22 kcal·kg BW$^{0.75}$ and 81 ± 4 kcal·kg BW$^{0.75}$ respectively), whereas Galvao (1947), Hammel *et al.* (1958) and Lusk and Dubois (1924) all reported very similar equations to Kleiber (1961: 70 ± 22 kcal·kg BW$^{0.}$75, 70 ± 20 kcal·kg BW$^{0.75}$ and 71 ± 12 kcal·kg BW$^{0.75}$ respectively), however, Leblanc and Diamond (1986:) reported low BMR for resting dogs (54 ± 9 kcal·kg BW$^{0.75}$). Of these studies, Galvao (1947) used the largest number of dogs (31 male dogs), with the largest weight range (3 – 28 kg) and produced a similar value for BMR as Hammel *et al.* (1958) who used 3 females with a weight range of 8 – 10 kg and Lusk and Dubois (1924) who used 11 female dogs with a weight range of 9 – 16 kg. Each of these three studies only used single genders of dogs, although when combined, similar results were obtained for both genders. Trials by Kitchen (1924) and DeBeer and Hjoort (1938) were the only studies that used both genders, with varying weights (10 – 18 kg, n = 13 and 20 – 27 kg, n = 11 respectively). Leblanc and Diamond (1986) did not specify the genders of dogs tested, but studied five dogs with an average weight of 18 ± 3 kg. The studies that used both genders produced higher BMR estimates than studies that used a single gender, and studies that researched BMR using a single gender reported results that were identical to Kleiber's inter-species BMR equation of 70 kcal/kg BW$^{0.75}$. Besides the number and genders of dogs tested, there does not seem to be any reason why there are two different groups of results. All studies used dogs that had been trained to use either a calorimetry kennel (Lusk and Dubois, 1924, Galvao 1947, Hammel *et al.,* 1958) or a specially designed respiratory mask that covered the nose and mouth of the dog (Galvao, 1947, Kitchen 1924, DeBeer and Hjort 1938). The only study that differed in feeding regime was LeBlanc and Diamond (1986), who used a variety of meal frequencies and either fed the same five dogs four small meals of 186 kcal at 1.5 h intervals, and a single large meal of 744 kcal on alternate days. This feeding regime of changing feeding frequencies may have reduced BMR in the dogs. Taken together these studies on BMR used a large number of dogs with a variety of bodyweights, therefore it would seem reasonable that the true BMR would lie between 70 – 85 kcal·kg BW$^{0.75}$.

The current study used the NRC equation 76 kcal·kg BW$^{0.75}$, to calculate BMR, it seemed reasonable to expect that active dogs will have a slightly higher BMR than inactive dogs. Kleiber's equation was a general equation for all species; whereas the equations suggested by the National Research Council (NRC, 2006) are based on data derived from dogs and therefore should be more relevant to this study. Energy expenditure of dogs could then be measured by adding the BMR of the dog with the AEE from activity monitors.

In this study, there were no significant differences between peak and off peak periods, therefore the results were pooled and reported as an average activity period. The average energy expenditure in this study, as determined by the DLW method, was 1,336 kcal/d, this is remarkably similar to the energy requirements of active dogs as recommended by the Association of American Feed Control Officials (AAFCO: Anon, 2007) and Finke (1994; ME = 132 × BW$^{0.75}$). When using the AAFCO formula quoted above, the average requirement of the dogs used in this study was 1,347 kcal/d. It must be noted, that the farm dogs used in the current study did not engage in the heavy work that is normally required from farm dogs during peak work periods. Instead, the dogs used in this study were engaged in medium to low intensity farm work. During off-peak periods, the dogs were let out of their runs for 45 minutes to an hour each day for exercise and to defecate and this higher activity during off-peak period may be the principle reason there were no significant differences between the two workloads. Therefore, the energy requirements from the current study corresponded to energy requirements of moderately active farm dogs.

Statistical analysis in this study showed that there were no significant effects of body weight, age, gender and breed on the resulting equation. However, a major limitation of this study was the low number of dogs used and the limited range of body weights of dogs, which may have contributed a non-significance difference in body weight in this study. Many of the dogs used to derive the equation were of similar weights, which may have contributed a non-significant difference in body weight. The low numbers of dogs used in this study may have also contributed to the non-significant difference in gender or breed. Despite the lack of statistical difference in the current study, body weight may be a significant factor in estimating the energy requirements for working dogs in NZ. It is highly possible that if dogs with a greater weight range had been used, there may have been a significant effect of body weight. If this is the case, then separate equations need be derived for dogs of different weight ranges, to estimate energy expenditure from activity counts. However and further studies are required to evaluate this.

There is an increasing amount of research calibrating activity monitors for use in human studies, with regression equations derived to take into account a variety of different activities, such as vacuuming and dusting (Crouter and Bassett, 2008). However, the same variety of activities does not occur in the dog, and therefore a simple equation may be sufficient. There were no breed or gender effects in the data analysis, therefore these variables did not need to be included in the regression equation. The standard error of the estimate (SEE) is reasonably high in this study compared to other studies calibrating Actical®

activity monitors, Crouter and Bassett (2008) reported SEE values of 0.149 and 0.804 in humans (depending on type of exercise). The high SEE in the current study may be due to the low number of dogs tested. However, the r^2 value is reasonably high (0.87), suggesting that there is a strong correlation between the activity-associated energy expenditure (AEE) and the number of activity counts per dog. Not all counts are for the same activity and therefore each count may not represent the same level of energy expenditure. For example, a dog scratching itself may not be the same level of energy expenditure as running up a hill at speed. This is the case in humans, where different equations are needed for different levels of exercise, and for different life stages. Further studies are required in dogs to differentiate different activities, and the counts associated with them, i.e. the ability to differentiate if a dog running up a hill vs. dogs running on flat terrain. This study did not have enough subjects to differentiate between such activities accurately. However, from the results of this study, it is suggested that to convert activity counts to AEE, the regression equation AEE = (number of activity counts × 0.00164) + (-99.683) be used.

Previous studies have calibrated activity monitors for use in humans and reported that activity counts and AEE were highly correlated. Pfeiffer *et al*. (2006) found that the Actical® monitor was a valid tool for measuring physical activity in pre-school children. The authors compared VO_2 to activity counts collected during the same period, and reported a regression derived equation. Similarly, Puyau *et al*. (2002) measured VO_2 in school children and again reported that activity monitors were a valid and useful tool to measure AEE. Child obesity levels are increasing, and trials conducted by Pfeiffer *et al*. (2006) and Puyau *et al.* (2002) aimed to calibrate activity monitors to give a useful measure of AEE in free-living children, and therefore to allow researchers to determine if a decline of physical activity is associated with the rise in child obesity. Similarly, obesity in pets is also on the rise, by calibrating activity monitors for use in dogs, it not only provides a useful for estimating energy requirements of farm dogs, but may be useful in aspects of research pertaining to activity in other populations of dogs including other working dogs, but also energy expenditure of pet dogs.

In conclusion, by using DLW, we have successfully calibrated the Actical® activity monitor for estimating AEE of Heading and Huntaway farm dogs in NZ. Previously, the only accurate method for measuring energy expenditure in free-living animals was using DLW, which is costly, especially when using a large number of dogs. The calibration of the Actical® activity monitor allows a cheaper and less involved method of estimating AEE in free-living farm dogs. The only disadvantage of using activity monitors to assess energy expenditure is that BMR still needs to be estimated. This study has provided the means to estimate energy requirements for free-living subjects, such as working farm dogs in NZ.

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CHAPTER FIVE:

Activity counts and energy expenditure of working farm dogs in New Zealand (2007-2008)

5.1 Introduction

Currently there is a gap in the literature on energy expenditure and therefore requirements of a working farm dog in New Zealand (NZ). Previous chapters have identified the feeding practices of farmers, and the digestibility of the most common diets fed to working dogs. This chapter aims to establish the energy requirements of working dogs in NZ. There are two main breeds of working dogs in NZ: the Heading dog and the Huntaway. These two breeds work together on the farm, but work in different ways. The Huntaway is a breed that is unique to NZ and evolved because of the need of farmers for a dog to scare stock from bushes and gullies, therefore the Huntaway works by barking to move stock. The Heading dog works differently, controlling stock via its body position in relation to the stock, and constantly moving around the flock to prevent stock breaking off and running in different directions. Accurately measuring energy expenditure (EE) in free-living subjects, such as the working farm dog is a difficult process. Using electrical devices, such as heart rate monitors, pedometers, geographic positioning systems and accelerometers, is of increasing interest to researchers due to their ability to remotely, and non-invasively measure physical parameters and activity levels of free living animals. Accelerometers are small and lightweight and can be housed in snug, protective weatherproof stainless steel boxes. These steel boxes can easily be attached to collars, and be used for dog studies. This arrangement is unobtrusive and appears to have no detrimental effect on the behaviour of both working and pet dogs, who are already accustomed to wearing collars.

The Actical® accelerometer includes an accelerometer and an omnidirectional device. It contains a piezoelectric biomorphic plate and seismic mass which is sensitive to movement in all directions. Movement causes a change the seismic mass to accelerate and this causes the piezoelectric sensor to generate a voltage signal. The voltage signal is amplified and passed through an analogue-to-digital converter that converts the voltage signal into a digital value called an activity count. Most studies conducted on dogs to date have reported results as activity counts (Hansen *et al.,* 2007: Dow *et al.,* 2009; Barthélémy *et al.,* 2009; Brown *et al.,* 2010). However, raw activity counts, which can be used directly to assess relative activity levels, are arbitrary measurements and give no information on energy expenditure. Chapter four described a process used to generate a regression equation which could be used to convert raw activity counts into activity-associated energy expenditure, a measurement that is more intuitive and useful for predicting feed requirements. The limitation of the study in chapter four was that there was a limited range of body weights studied, therefore this equation may not be suitable for dogs either lighter that 18 kg and heavier than 26 kg. Therefore energy requirements maybe inaccurate and result in over or underestimating food requirements. However, farmers generally feed dogs to visual body cues and will adjust feeding as needed i.e. if the dog is looking thin, then farmers will feed the dog more.

Feed requirements can be predicted from energy requirement equations (Anonymous, 2006). Predictive energy requirement equations are typically reported as allometric equations. Allometric relationships between biological variables and body mass are generally fitted to models in the form of the equation given below.

Equation 5.1:
$y = a \times BW^b$; where a is the allometric coefficient, b is the mass exponent, y is the biological trait of interest and BW is bodyweight (kg).

The allometric coefficient is a constant value that the metabolic weight of the dog is multiplied by in order to calculate energy requirements. The allometric equation can be estimated by rearranging the equation (above) so that:
$a = y/BW^b$.

5.2 Aim

The aim of this study was to use the activity monitors to estimate energy expenditure during two periods of the year; off-peak periods, where working farm dogs were working sub-optimally, and peak periods, when they were working at a maximal level for the year, and to obtain a comparison of workload between regions of NZ.

5.2.1: Hypothesis

The two main breeds of working farm dog (Heading and Huntaway dogs) have different energy requirements between peak and off peak work periods, and there are regional differences in workloads.

5.3 Materials and method

The sampling period during which all measurements were carried out stretched from August, 2007 to June, 2008.

5.3.1 Farm selection

Twenty six farmers participated in the trial. Of these, 20 were selected from the New Zealand Sheep Dog Trial Association (NZDTA) membership and six farmers were recruited following an advertisement in the Farmers Weekly Publication of August, 2007. The regions and number of farms (in brackets) used in the trial were: Northland (2); Gisborne (2); King Country (2); Taranaki (2); Hawke's Bay (including Taupo) (5); the lower North Island (including Wairarapa) (6); Canterbury (3); Otago (2) and Southland (2).

5.3.2 Background farm information

The study was conducted in nine different regions of New Zealand: Northland, Gisborne, King Country, Taranaki, Hawke's Bay (including Taupo), the lower North Island (including Wairarapa), Canterbury, Otago and Southland. At least two sheep and beef farms per region were selected and two dogs per farm were used in the trial. Each farm's terrain and size was different, so the workload of each pair of dogs varied accordingly. The estimated farmers the size of their farms and largest farm was 12,000 Ha (in Southland) and the smallest was 201 Ha (also in Southland). The size of farms were not accurately measured, some farmers did not own the property and therefore did not know exactly how large the farms were. The farm terrain varied from the flat plains of Canterbury (up to 100 m above sea level) to the steep hill country of Southland and South Wairarapa (up to 855 m above sea level).

Peak workload periods generally consisted of times where the farmer was mustering stock for shearing sheep, weaning calves and lambs, docking tails in lambs and veterinary check-ups and disease testing. Each farm had different times when these activities occurred, but generally these activities occurred within specific times of the year (Table 5.1).

Table 5.1: General activities throughout the year in the North and South Island farms in New Zealand during peak* and off peak periods.

	Autumn			Winter			Spring			Summer		
	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
North Island	Mid load			Off peak			Peak			Peak		
South Island	Peak			Off peak			Peak		Mid load		Peak	

*Peak workload periods generally consisted of times where the farmer was mustering sheep and beef for shearing sheep, weaning calves and lambs, docking tails in lambs and veterinary check-ups and disease testing.

The off-peak period of 7 days did not immediately follow or precede the 7 day peak period and were correlated to the period described in table 5.1.

5.3.3 Dog information

Farmers on each farm were asked to select what they perceived as their hardest working Heading dog and Huntaway to participate in the trial.

Breed, sex, age to the nearest year, and general health information such as weight, height and body condition was documented for each dog at the beginning of each period. Dogs were weighed on the same set of scales, where the owner was weighed with the dog, and the weight of the owner subtracted from the combined weight. The height of the dog was measured with a dressmakers tape from the top of the head to the dog's feet. Body condition was evaluated by the author, at peak and off-peak periods using a nine point BCS scale, ranging from one (emaciated) to nine (severely obese) (Laflamme, 1997). Actical® accelerometers (Minimitter Inc. Bend, OR. USA) were fitted onto the collars of two dogs from each farm for seven days, during each period (peak and off peak working periods). The accelerometers were removed from the collars at the end of the seven days and the data downloaded and saved. The accelerometers were then reprogrammed and reattached to the collars for the next set of dogs.

5.3.4 Actical® accelerometers

The Actical® accelerometer (Minimitter Inc. Bend, OR. USA) is a small (28 × 27 × 10 mm), lightweight (17 g) device that uses a piezoelectric accelerometer. The Actical® is an omnidirectional accelerometer, but is most sensitive to movement in the direction indicated by an arrow on the front of the device (Figure 5.1). It is sensitive to movements in the range of 0.5 – 3 Hz. The monitors were programmed to take readings over a 15 sec epoch.

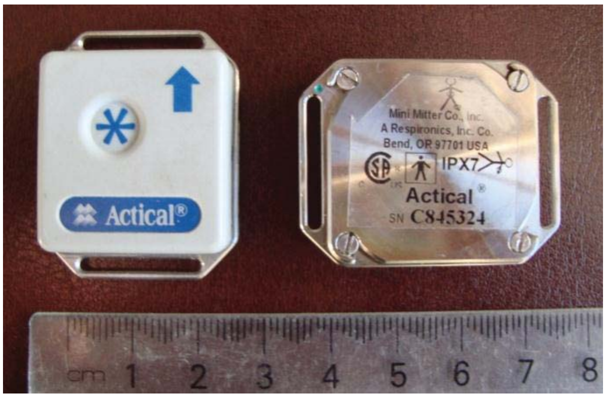

Figure 5.1: Two Actical® accelerometers used in the study

5.3.5 Data analysis

The data from each accelerometer was downloaded onto a computer using the Actical® program (version 2.1, Minimitter Inc., Bend OR. USA) and then transferred to Microsoft Excel for further data manipulation. The downloaded raw data was in the form of activity counts over each 7 day period and average activity counts per day were tallied for each dog.

5.3.6 Predicting energy expenditure in working farm dogs in NZ

Raw activity counts were converted to activity associated energy expenditure (AEE) using the formula established in chapter four. Total energy expenditure (TEE) was established by adding AEE to the basal metabolic rate (BMR). The BMR was estimated using equations suggested by NRC (2006).

5.3.7 Statistical analysis

The experiment was designed to sample all dogs during both peak and off-peak work periods. However, two Huntaway dogs sustained injuries that prevented them working, and therefore from being sampled at one of the periods.

Attempts were made to re-sample at a later date, but this proved unsuccessful. The two injured dogs were from the Hawke's Bay region and the King Country, and both dogs had sustained work related injuries. The final dataset included information from 24 Heading dogs sand 28 Huntaway's sampled during both peak and off-peak periods. Data from the two injured dogs was removed from the dataset. A test of normality was carried out using the Shapiro-Wilk test for the activity counts and energy requirements, and the natural log of the data was used for factorial analysis and ANOVA, but presented using untransformed values. A two-way factorial analysis of variance (factors = gender, breed, region, and gender × breed) was conducted to test for differences in energy requirements of the working farm dogs. Least square means were used to establish if there were breed, regional and gender differences within peak and off-peak periods of work. The model accounted for any individual dog, breed and gender effects. Paired t-tests were conducted to assess if there were differences in peak and off-peak periods for both breeds of working dog. All statistical procedures were carried out with SAS 9.1 software (package SAS/STAT Version 9.1, SAS Inst., Inc., Cary, NC, USA). Data are presented as mean (± SEM), unless otherwise stated. Significance was assumed if $p<0.05$.

5.4 Results

5.4.1 Dog information

The raw data for off-peak and peak work for each individual dog is shown in Appendix 5.1a and 5.1b respectively. Table 5.2 shows the average temperatures (from the National Institute of Water and Atmospheric Research NZ) in the regions during peak and off peak periods of work.

Table 5.2: Average temperatures (°C) in each region during peak and off-peak periods of time (from the National Institute of Water and Atmospheric Research NZ)

	Temperature (°C)							
	Off peak		**SD**		**Peak**		**SD**	
	min	**max**	**min**	**max**	**min**	**max**	**min**	**max**
Northland	12^{a}	18^{a}	1.25	1.49	13^{a}	26^{a}	2.34	1.79
Gisborne	10^{ab}	18^{a}	2.88	1.55	16^{a}	25^{a}	4.11	2.43
King Country	9^{ab}	16^{ab}	2.13	2.65	8^{b}	25^{a}	2.29	1.50
Taranaki	6^{ab}	13^{b}	1.32	1.32	4^{c}	16	1.69	1.15
HB/Taupo	3.8^{b}	18^{ab}	5.66	4.46	13^{a}	24^{a}	5.03	4.96
LNI/Wairarapa	4^{b}	16^{ab}	3.86	3.85	7^{ab}	23^{a}	3.84	3.97
Canterbury	-0.9^{b}	14^{ab}	4.13	5.19	0.3^{bc}	27^{ab}	7.20	10.84
Otago	10^{ab}	19^{ab}	3.20	5.33	8^{bc}	25^{a}	2.98	5.07
Southland	5^{b}	15^{b}	2.52	2.95	12^{a}	28^{a}	3.00	3.56

Means with different subscripts within each column are different ($p<0.05$).

There were significant ($p<0.05$) differences in off-peak temperatures, with Canterbury as the coldest region, and Otago as the warmest. There were also significant ($p<0.05$) differences in peak temperatures, with Canterbury as the coldest region and Southland as the warmest.

The median age of the dogs sampled in the study was 3.75 (interquartile range (IQR): 3.25)) years, with a range of 1 to 12 years.

When the sample population is divided into breed and sex, the population consisted of 8 (15%) female Heading dogs, 16 (31%) male Heading dogs, 7 (14%) female Huntaways and 21 (40%) male Huntaways. There were no ($p>0.05$) differences in the age profile and BCS during peak and off-peak work periods between the two populations of Heading dogs and Huntaways.

The average (±SEM) height of Heading dogs was 70.6 ± 1.4 cm, with the average height of female and male Heading dogs 68.6 ± 3.3 cm and 71.5 ± 1.4 cm respectively. The average height of Huntaways was 78.4 ± 1.6 cm, with the average height of female and male Huntaways 75.1 ± 3.7 cm and 79.4 ± 1.8 respectively.

The average (± SEM) BCS of all dogs on a nine point scale was 4.0 ± 0.12 during off-peak and 3.0 ± 0.13 during peak workload (Laflamme, 1997). The sample consisted of 37 (71%) male and 15 (29%) female dogs.

Figures 5.2 and 5.3 show examples of the body condition of the same Heading dog and Huntaway in the study during off-peak and peak periods respectively.

Figure 5.2: A body condition score of 4, for a Heading dog (top) and Huntaway (bottom) during off-peak periods of work

Figure 5.3: Body condition score of 3, of the same dogs (Heading dog (top) and Huntaway (bottom)) during peak periods of work.

Heading dog:

The average weight of Heading dogs during off-peak and peak work was 19.9 ± 0.6 kg and 19.8 ± 0.6 kg respectively. During off-peak workloads the average female Heading dog weight was 18.1 ± 0.9 kg with males 2.8 kg heavier (20.8 ± 0.7 kg). Similarly during peak periods the average female Heading dog weight was 18.1 ± 0.8 kg, and males were 2.6 kg heavier (20.7 ± 0.6 kg).

There was no effect of age on the weight of Heading dogs, for example, the oldest dog was 12 years old and weighed 18.3 kg and the youngest dog was 1 year old and weighed 18.2 kg.

Huntaways:

The average weight for Huntaways during off-peak work was 31.9 ± 0.9 and 31.5 ± 1.0 during peak work periods. During off-peak workloads the average Huntaway weight of females was 26.1 ± 1.5, with males 33.5 ± 0.8 kg. During peak periods the average weight of Huntaway females was 25.6 ± 1.6 kg, with males again 7.5 kg heavier (33.1 ± 1.0 kg). The average weight of both genders was 31.5 ± 1.0 kg.

There was also no effect of age on the weight of Huntaways; the oldest male dog was 12 years old and weighed 42.1 kg and the youngest was 1.5 years old and weighed 35.9 kg. The oldest female Huntaway was 7.5 years old and weighed 28 kg and the youngest was 2 years old and weighed 35.6 kg.

5.4.2 Activity counts

The Shapiro-Wilk test of normality showed that the activity counts were highly skewed (off-peak $p < 0.0002$, peak $p < 0.0001$). The natural log of the data was used to transform the skewed data to a symmetric distribution for further analysis. The Shapiro-Wilk test of normality then confirmed that the natural log of both off-peak and peak activity counts) were normally distributed ($p<0.07$ and $p<0.6$ respectively).

Heading dogs and Huntaways:

The average number of activity counts for working farm dogs in this study during peak work versus the off-peak period was 610,014 ± 45,383 and 397,151 ± 26,862 respectively. This indicated that during the off peak period the dogs were working at 65% of their peak work period demand. The activity data showed that during off peak periods, the dogs, on average, had periods between 30 min to 1 h of activity, which occurred as either a single period of activity, or two activity periods per day. During peak periods of work, the dogs were active for an average of 9 hours per day.

Statistical analysis of the natural log transformed data showed that during the peak work period, there were no significant ($p>0.05$) differences in activity counts between breed and gender, however there were significant differences ($p<0.05$) in activity counts recorded between regions. Working farm dogs in Canterbury had higher average activity counts per day than dogs in the Southland regions ($p<0.05$). Dogs in Southland were the least active during peak periods and were less active than dogs in the Gisborne, Canterbury, Otago and Lower North Island (LNI)/Wairarapa regions ($p<0.05$) (see Table 5.1).

During off-peak period, there were no significant differences in activity counts between breed, gender or regions.

The average activity counts during the peak and off-peak periods for dogs in the nine regions sampled are shown in Table 5.3. The region with the highest daily activity in peak work was Canterbury, with 850,000 activity counts. This was approximately 475,000 more counts than Southland (375,000), the region with the least amount of activity counts per dog. The seasonal fluctuation in workload measured from the proportion of activity counts between peak and off-peak periods, is lowest in Hawkes Bay (including Taupo) where the dogs work 76% of maximum peak workload during off-peak periods and greatest in dogs in the Gisborne region where their workload is 42% of peak periods.

Table 5.3: Mean (± SEM) daily activity count per dog and the number of dogs sampled (n) on farms in different regions around NZ

		Workload per day	
Region	n	Peak	Off-peak
Northland	4	663,001^{ab} (288,781))	412,410 (203,650
Gisborne	4	702,989^{a} (155,073)	303,722 (191,853)
King Country	5	552,199^{ab} (236,625)	402,650 (201,853)
Taranaki	4	527,648^{ab} (98,494)	419,023 (285,316)
*HB/Taupo	9	541,085^{ab} (178,584)	425,999 (141,435)
$^{\#}$LNI/Wairarapa	12	693,633^{a} (207,271)	559,091 (263,070)
Canterbury	6	851,483^{a} (349,079)	422,800 (119,522)
Otago	4	584,779 ^{a} (149.667)	337,230 (243,150)
Southland	4	373,309^{b} (70,290)	291,434 (161,981)
NZ Average	52	610,014	397,151

$^{\#}$LNI: Lower North Island, *HB: Hawke's Bay. Means with different subscripts within each column are different (p<0.05).

There were no differences in the number of activity counts between Heading dogs and Huntaways (Table 5.4). Student T-test showed there were highly significant differences in activity counts between peak and off-peak periods in both Heading (p<0.0001) and Huntaways (p<0.0001). This suggests that both breeds will most likely require more energy during peak *vs.* off-peak periods.

Table 5.4: Mean (± SEM) daily activity counts per breed of working farm dogs in NZ, percentage activity relative to peak activity and the number of dog's sampled (n) during peak and off-peak work periods.

	Workload per day			
Breed	Peak	N	Off-peak	% of peak
Heading	700,225 (700,225)	24	448,212 (40,749)	64
Huntaway	626,286 (46,767)	28	370,735 (30,574)	59

Heading dogs:

Statistical analysis of the natural log transformed data showed that there were significant (p<0.05) differences between regions during peak and off-peak periods. There were no differences across regions in the activity counts between male and female Heading dogs during off-peak periods, however during peak periods of work, female Heading dogs were significantly more active (p<0.05) than male dogs (835,672 ± 62,035 vs. 599,177 ± 44,669 counts respectively). The region with the highest daily activity during peak periods was LNI/Wairarapa (848,773 ± 68,262 counts) and the region with the lowest daily activity was Southland (468,031 ± 116,141 counts). During off-peak periods, the region that had Heading dogs with the highest daily activity was Northland (566,132 ± 145,676 counts) and the region with the least activity was Gisborne (281,485 ± 145,676 counts). Table 5.5 shows the daily activity counts from Heading dogs in different regions of NZ.

Table 5.5: Mean (± SEM) daily activity counts per Heading dog, percentage activity relative to peak activity and the number of dogs sampled (n) during peak and off-peak work periods on farms from different regions around NZ.

		Workload per day		
Region	**n**	**Peak**	**Off-peak**	**% of peak**
Northland	2	854,406^{b} (215,729)	566,132^{a} (60,073)	66.3
Gisborne	2	670,29^{a} (19,810)	281,485^{b} (94,519)	42
King Country	2	605,260^{ab} (229,816)	422,968^{ab} (156,449)	69.9
Taranaki	2	685,343^{a} (150,115)	497,435^{ac} (132,721)	72.6
*HB/Taupo	4	583,367^{b} (51,571)	442,253^{ac} (12,391)	75.8
#LNI/Wairarapa	6	848,773^{b} (77,487)	565,293^{b} (121,355)	66.6
Canterbury	2	770,079^{ab} (1,804)	306,217^{bc} (294,687)	39.8
Otago	2	636,235^{a} (20,638)	384,521^{b} (212,727)	60.4
Southland	2	468,031^{ab} (38,036)	339,401^{b} (120,709)	72.5
NZ Average	24	700,225	448,212	64

#LNI: Lower North Island, *HB: Hawke's Bay

Where a is significantly ($p<0.05$) different to b and c, and b is significantly ($p<0.05$) different to c

Huntaways:

Statistical analysis of the natural log transformed data showed that there were no significant differences in either the activity counts between male and female Huntaways during either peak or off-peak periods, or activity levels of Huntaways in different regions of NZ. There were differences ($p<0.05$) in the activity of dogs between regions, with dogs in Canterbury more active than dogs in Southland (892,185 ± 134,704 vs. 326,874 ± 169,499 counts) during peak periods. There were also significant differences ($p<0.05$) between regions during off-peak periods. Table 5.6 shows the activity counts per day from Huntaways in different regions of NZ.

Table 5.6: Mean (± SEM) daily activity counts per Huntaway, percentage activity relative to peak activity and the number of dog's sampled (n) during peak and off-peak work periods on farms from different regions around NZ.

		Workload per day		
Region	**N**	**Peak**	**Off-peak**	**% of peak**
Northland		471,597^{ab}	258,690^{b}	
	2	(72,672)	(106,493)	54.9
Gisborne		735,688^{b}	325,959^{ab}	
	2	(183,141)	(171,381)	44.3
King Country		642,628^{a}	428,846^{ab}	
	3	(143,351)	(113,794)	66.7
Taranaki		472,605^{a}	237,960^{b}	
	2	(78,988)	(33,763)	50.4
*HB/Taupo		564,045^{ab}	341,851^{ab}	
	5	(90,962)	(77,194)	60.6
$^{\#}$LNI/Wairarapa		673,581^{ab}	465,725^{a}	
	6	(77,054)	(44,921)	69.1
Canterbury		892,185^{a}	458,582^{a}	
	4	(186,127)	(50,535)	53.9
Otago		582,069^{ab}	289,940^{ab}	
	2	(178,066)	(197,376)	49.8
Southland		326,874^{ab}	220,489^{b}	
	2	(14,186)	(92,976)	67.5
NZ Average	28	626,286	370,735	59.2

$^{\#}$LNI: Lower North Island, *HB: Hawke's Bay
Means with different subscripts within each column are different (p<0.05).

5.4.3 Energy expenditure of working farm dogs in NZ (kcal/kg BW$^{0.75}$)

The Shapiro-Wilk test of normality showed that the energy requirement kcal/kg BW$^{0.75}$ was highly skewed (off-peak $p < 0.0003$, peak $p < 0.0001$). The natural log of the data was used to transform the skewed data to a symmetric distribution for further analysis. The Shapiro-Wilk test of normality then confirmed that the natural log of both off-peak and peak energy requirements (kcal/kg BW$^{0.75}$) were normally distributed (p=0.2 and p=0.1 respectively).

Heading dogs and Huntaways:

Statistical analysis of the natural log transformed data showed that during the off-peak work period, there were no significant differences in energy expenditure between genders or between regions of NZ. However, there were differences between breeds (p<0.005), with Heading dogs expending more energy per kg of metabolic bodyweight than Huntaways (144 ± 7.5 *vs.* 114 ± 3.8 kcal/kg $BW^{0.75}$ respectively).

During the peak work period, there were breed ($p<0.0001$), gender ($p<0.005$) and regional ($p<0.05$) differences of the natural log transformed data for the energy requirements of a working farm dogs in NZ (kcal/kg $BW^{0.75}$).

Farm dogs in Southland required less energy (kcal/kg $BW^{0.75}$) during peak work periods than Canterbury ($p<0.001$), Gisborne, Hawkes Bay, King Country and Northland ($p<0.05$). Farm dogs in LNI (including Wairarapa) and Canterbury required more energy than any other region (191 ± 14.2 and 191 ± 25 respectively). The region with the lowest energy expenditure per kg of bodyweight during peak periods was Southland (128 ± 12). Table 5.7 shows the average energy expenditure (kcal/kg $BW^{0.75}$) for each region during off-peak and peak periods.

Heading dogs expended 23% more energy per kg metabolic bodyweight than Huntaways (191 ± 9 *vs.* 148 ± 6 kcal/kg $BW^{0.75}$ respectively). The overall female population expended more energy than males during peak periods (193 ± 6 *vs.* 158 ± 6 respectively). When comparing Actical® counts, there were no significant differences between activity counts in the peak periods of work between the female and male population. The average activity counts for the female and male population during peak periods was 735,984 ± 71,222 and 635,323 ± 34,147.

During peak periods of work, Heading dogs had higher energy requirements than Huntaways in all regions. Heading dogs with the highest energy expenditure came from Northland (233 ± 46 kcal/kg $BW^{0.75}$) and the Huntaways with the highest energy expenditure came from Canterbury (178 ± 23 kcal/kg $BW^{0.75}$). The working dogs in Southland required the least amount of energy during the peak working periods when compared to other regions in the country (Heading dogs; 147 ± 13 $kcal^{-1}\cdot kg\ BW^{0.75}$, and Huntaways; 109 ± 2.5 kcal/kg $BW^{0.75}$).

Table 5.7: Mean (± SEM) energy expenditure (kcal/kg BW$^{0.75}$) of both breeds of working farm dogs and number of animals (n) sampled in each region of NZ.

		Energy requirement (kcal/kg BW$^{0.75}$	
Region		**Peak**	**Off-peak**
	N	Mean (±SEM)	Mean (±SEM)
Northland	4	179^{ac} (36.7)	134 (21.2)
Gisborne	4	168^{ac} (10.5)	112 (11.9)
King Country	5	153^{bc} (12.6)	126 (10.5)
Taranaki	4	151^{bc} (18.5)	121 (16.7)
HB/Taupo	9	154^{c} (10).3	125 (7.9)
LNI/Wairarapa	12	191^{a} (14.2)	149 (12.7)
Canterbury	6	191^{ac} (24.9)	124 (24.9)
Otago	4	157^{c} (9.7)	112 (15.1)
Southland	4	128^{b} (12.2)	112 (14.6)
NZ Average	52	168 (6.2)	128 (4.5)

$^{\#}$LNI: Lower North Island, *HB: Hawke's Bay. Means with different subscripts within each column are different (p<0.05).

Student T-test showed that when comparing between periods within breeds, there were highly significant differences in energy expenditure between peak and off-peak periods in both Heading (p<0.0001) and Huntaways (p<0.0001). Both breeds required more energy during peak *vs.* off-peak periods.

Heading dogs:

Statistical analysis of the natural log transformed data showed that during off-peak work periods there were no significant differences in the energy expenditure of female and male Heading dogs. During peak work periods, female heading dogs expended 23% more energy than male Heading dogs (230 ± 20.0 *vs*. 175 ± 7.5 kcal/kg BW$^{0.75}$ respectively; p<0.005). There were also significant differences in the energy expenditure of Heading dogs in different regions during peak work periods, but not during off-peak periods. Heading dogs in the lower north island (LNI including Wairarapa), expended higher amounts of energy (p<0.05) than Gisborne, King Country, Taranaki, Hawke's Bay (including Taupo), Otago and Southland.

Heading dog energy expenditure during the peak work period ranged from 148.5 ± 13.0 $\text{kcal}^{-1}\cdot\text{kg BW}^{0.75}$ in Southland to 237.3 ± 48.1 $\text{kcal/kg BW}^{0.75}$ in Northland. During the off-peak work period energy expenditure was lower and ranged from 113.9 ± 19.5 $\text{kcal}^{-1}\cdot\text{kg BW}^{0.75}$ in Gisborne to 172.0 ± 23.4 $\text{kcal/kg BW}^{0.75}$ in the LNI (including Wairarapa; Table 5.8).

Table 5.8: Mean (± SEM) energy expenditure ($\text{kcal/kg BW}^{0.75}$) of Heading dogs and number of animals (n) sampled in each region of NZ

Region		**Peak**	**Off-peak**
	N	Mean (±SEM)	Mean (±SEM)
Northland	2	233^{ab} (46.4)	168 (12.8)
Gisborne	2	172^{b} (9.9)	113 (18.9)
King Country	2	164^{b} (29.9)	136 (22.2)
Taranaki	2	177^{b} (23.2)	146 (19.6)
HB/Taupo	4	170^{b} (12.2)	144 (3.3)
LNI/Wairarapa	6	225^{a} (15.5)	169 (22.5)
Canterbury	2	215^{ab} (71.9)	121 (6.9)
Otago	2	173^{b} (1.8)	120 (27.3)
Southland	2	147^{b} (12.7)	126 (25.9)
NZ Average	24	191 (9.3)	144 (7.76)

[#]LNI: Lower North Island, *HB: Hawke's Bay. Means with different subscripts within each column are different ($p<0.05$).

Huntaways:

Statistical analysis of the natural log transformed data showed that there were no significant differences in the energy expenditure of female and male Huntaways during off-peak (114 $\text{kcal/kg BW}^{0.75}$) or peak (148 $\text{kcal}^{/}\text{kg BW}^{0.75}$) work periods. There were no significant differences in energy expenditure of Huntaways in different regions of NZ during the peak or off-peak work periods. Table 5.9 shows the energy requirements of Huntaway dogs in different regions of NZ.

Table 5.9: Mean (± SEM) energy expenditure (kcal/kg $BW^{0.75}$) of Huntaways and number of animals (n) sampled in each region of NZ

Region		**Energy requirement (kcal-1kgBW0.75** **Peak**	 **Off-peak**
	N	Mean (±SEM)	Mean (±SEM)
Northland	2	126 (16.2)	101 (15.5)
Gisborne	2	165 (23.4)	110 (22.0)
King Country	3	146 (12.6)	119 (12.1)
Taranaki	2	124 (9.4)	96 (4.0)
HB/Taupo	5	141 (14.1)	109 (9.1)
LNI/Wairarapa	6	158 (14).0	128 (6.1)
Canterbury	4	179 (23.2)	125 (7.7)
Otago	2	142 (9.2)	103 (21.8)
Southland	2	109 (2.5)	98 (14.2)
NZ Average	28	148 (6.3)	114 (3.8)

#LNI: Lower North Island, *HB: Hawke's Bay. Means with different subscripts within each column are different (*p*<0.05).

5.5 Discussion

It is well known that NZ farm dogs are willing and obedient workers and that without these dogs, the NZ farmer would not be able to manage their stock as efficiently (Longton and Hart, 1976). Farmers can increase the health and welfare of the animal by providing the nutrients that it requires to achieve tasks expected of it. However, nutritionists are unaware of the energy requirements of these animals. Estimating energy expenditure in free-living subjects is difficult, although there are scientific methods that can achieve this. The most accurate method of assessing energy expenditure is the doubly labelled water method. However, this method can be costly, especially when used for a large number of dogs. A newer and less expensive method is to calibrate, and use accelerometers. Accelerometers have been calibrated to measure energy expenditure in various subjects (see chapter one, section 1.6.5). The Actical® accelerometer has been calibrated to estimate energy expenditure in working farm dogs of NZ (Chapter four). Peak and off-peak periods were determined by each individual farmer, depending on their judgement of farm workload.

Accelerometers measure the activity of a dog as activity counts, and therefore, activity counts on their own are only useful when comparing activity levels. This is the first study that has estimated the energy expenditure of farm dogs working on a range of farms across NZ. This study has proved the hypothesis and shown that when energy expenditure is assessed using Actical® activity monitors, there were significant differences in the energy requirements of Heading and Huntaway dogs during both off peak and peak periods of work. This current study sampled a wide range of farms the different regions of NZ, so the estimates of overall energy expenditure in the two breeds can therefore be considered as accurate and robust as we could make them. The range of values is likely to be representative of most of the working farm dog population in NZ. Farmers generally agreed that 7 day sampling period would be sufficient amount of time to collect data over, as peak work in particular was generally concentrated to either when farmers could hire shearers, when vets were available, or when the truck was available to take stock to meat works. However, weather did play a significant part in affecting work, as shearing could not be done if it rained, because the wool would be too wet. If this occurred, then sampling of peak work on that farm was rescheduled for a later date. All farms in this study were sheep and beef farms, the size of the farm was not accurately measured in this study, and temperature between regions showed no significant variance, therefore the variable of interest was identified as region. Analysis was therefore conducted to verify if there were differences in energy requirements of dogs in different regions of NZ. Different regions in NZ showed significant differences in the amount of work performed by working dogs during peak periods of work.

This study showed that during the off-peak work period, there were no significant differences in energy expenditure between genders or between regions of NZ. Results showed that there were differences between breeds ($p<0.005$), with Heading dogs expending more energy per kg of metabolic bodyweight than Huntaways (144 ± 7.5 vs. 114 ± 3.8 kcal/kg BW0.75 respectively). However, results from raw activity counts showed that there were no significant differences between breeds, which could suggest that there either may be a body weight effect, or one activity count in a Heading dog may not be the same as one activity count in a Huntaway dog. An interesting finding of this study was the differences in energy requirements of female and male dogs during peak periods of work, with females requiring significantly ($p<0.005$) more energy than males. The reasons why females would require more is unclear, as published literature states that females have generally lower requirements than their male counterparts. A study conducted by Finke (1991) measured energy requirements of adult kennel dogs of both sexes, this study showed that generally females required less energy than male dogs. The study conducted by Finke did not concentrate on gender differences and therefore, it is unclear if the differences were significant. Female mammals are metabolically more resistant to famine and feast than males (Widdowson, 1976). This may be due to differences in physiology (Durnin, 1976), with females having a greater tendency towards fat deposition than males (Dugdale and Payne, 1977). Therefore, it may be that female working dogs have more energy reserves to call upon during peak periods of work. However as body fat mass was not measured in this study, it is difficult to come to any conclusions. One possible reason may be that the difference could be a function of the small sample size ($n=15$ females vs $n=37$ males respectively).

Using Actical® activity monitors, this current study has shown that dogs were less active during off-peak work periods than peak periods as was expected. The region that had the largest seasonal difference in activity between the peak and off-peak work period was Gisborne, where dogs worked at 57% of peak work levels during the off-peak period (based on activity counts on Table 5.3). The region with the smallest seasonal difference between the peak and off-peak periods was the Hawkes Bay (including Taupo) followed closely by Taranaki and LNI (including Wairarapa), where dogs still worked at about 76% of their peak workload. This difference in the amount of work during peak and off-peak periods highlights the off-peak drop off in activity in Gisborne. It maybe that Gisborne farms are smaller in size, or contain less stock units, however there is no literature available regarding regional differences in work and none of these theories have been studied, and therefore cannot be substantiated. Another possibility is that the effect of region is a secondary effect of some other underlying cause, such as differences in management practices in different regions, terrain, farm size and stock units. This study is unable to tease apart the data and further research is required to understand the effect of region. Because this is the first study to measure energy expenditure of working farm dogs, there is little data in the published literature to compare with the findings of this thesis. It is, however, important to note that this study only recorded activity over two weeks of the year and therefore the results provide a snapshot of the activity of the dogs at maximum and minimum levels of work.

This study did not measure the difference in raw counts generated by Actical® devices when the dogs were walking on flat terrain or running up hills, and further studies need to be conducted to establish the difference in raw activity counts when dogs carry out different activities. Other researchers have reported activity counts in dogs using the same model of accelerometer as this study. Cimino-Brown *et al.* (2010) reported activity counts using the Actical® accelerometer for a range of activities, such as lying down, walking laps and trotting laps, each activity was carried out for a 3 minute period. Pet animals wore the accelerometers on their collars and were guided through each activity in turn. Analysis of the data from the current study showed that farm dogs on average produced 823 activity counts every 3 minutes during off-peak periods and 1306 activity counts every 3 minutes during peak periods. These off-peak values found in this study were similar to median values (809 activity counts) of pet dogs trotting laps on flat terrain (Cimino-Brown *et al.* 2010). Dow *et al.* (2009) reported a very wide range of activity counts per day for pet dogs using Actical® accelerometers 58,495 to 833,070. The dogs wore the accelerometers for two weeks, and their movement was sampled every minute. In the current study, the same model accelerometer was used for seven days and each dog's movement was sampled every 15 seconds. The study found that daily activity counts of NZ farm dogs ranged from 69,531 to 915,146 during off-peak periods and 312,688 to 1,367,553 during peak periods. The range of activity counts of NZ farm dogs during off-peak periods, although fractionally higher, were comparable to pet dogs trotting and climbing stairs. Pet dogs have a higher range of activity counts when the owner was available for interaction (during weekends), and the range of activity counts recorded at these times were comparable to activity counts for NZ farm dogs during peak work periods when farm dogs are also generally in the company of the farmer for the duration of the day. Generally, in the population studied, during off-peak periods, dogs are kennelled and let out for exercise, once or twice a day. The majority of the data from activity monitors in this study show activity for about 1 h during off-peak periods of work, half in the morning and half in the evening. There are a few exceptions, occasionally in the weekend the dogs aren't let out, but the vast majority of the time they were. However despite the attempts in this study to sample as wide variety of farms as possible, the data may not reflect the behaviour of the majority farmers. This activity period is similar to the pet dog, when owners are not home, when the dog will sleep during the day and is taken for a walk when the owner has time. The activity counts of the pet dog during weekends were in the lower to middle range of farm dogs during peak periods. Dow *et al*. (2009) also reported the median activity count for each day of the week, which ranged from 182,076 to 231,335 counts. The median number of activity counts recorded in this study was 395,251 per day during off-peak periods and 627,137 per day during peak periods. This suggests that the majority of pet dogs are not as active, on any given day, as working NZ farm dogs.

The accelerometers generated raw activity counts, which were then converted into activity associated energy expenditure (AEE) using the equation derived in chapter four. However, this only gave us AEE, so the basal metabolic rate of dogs needed to be estimated using predictive equations suggested by NRC (Anonymous, 2006 (76 x $BW^{0.75}$ kcal/kg) so we could estimate total energy requirements. The calculation used to predict the energy requirement of the animal incorporates the use of body weight; therefore it is quite reasonable that the activity counts could differ for total energy expenditure (AEE + BMR). This may explain why there were no significant differences in activity counts between breeds during peak periods of work, but there were significant breed differences ($p<0.05$) for energy requirements of the working dogs.

This study showed that there were significant differences in the level of work between the two breeds of dogs. Heading dogs expended more energy than Huntaways during both off-peak ($p<0.005$) and peak ($p<0.0001$) periods. There were significant differences in energy expenditure for Heading dogs between regions during peak periods. The LNI (including Wairarapa) had higher energy requirements for Heading dogs during the peak period and therefore, had higher energy requirements than Gisborne, Hawkes Bay (including Taupo), Otago and Southland ($p<0.05$). A limitation in this study is that it is presumed that one Heading dog count =1 Huntaway count, if this is not the case, the implication is that the estimates of energy expenditure are not accurate and the estimates in this thesis is incorrect, however, further studies need to be conducted to prove or disprove this assumption.

The sheep herding dog is generally a nervous dog (Willis, 1995), and this trait is utilised by the farmer to effectively herd sheep. However, this trait also means that dogs, such as the Heading dog may move more frequently than the more relaxed Huntaway. This is also reflected in the different ways these two different breeds work, the Huntaway typically barks at sheep and can control the flock from some distance away. The Heading dog controls stock with its body position and by staring down stock, therefore has to be constantly moving around to control the mob or flock of sheep and therefore covers much larger distances than the Huntaway. These are personal observations of the author, as currently there is no scientific literature which describes the working behaviour of farm dogs in NZ.

A flaw in the study design was that terrain was not accurately measured during data collection. A possible explanation for the regional differences in activity reported in this study may be due to the terrain and the size of the farms selected in that region. Even though terrain was not accurately assessed in the study, from the information provided by farmers, the terrain of the farms selected in Wairarapa were steeper than farms in other parts of the country and, therefore the dogs may have had to work harder running up the steeper terrain. Farmers from Gisborne claimed that Gisborne has hotter summers than the rest of the country and therefore, to compensate for the heat, mustering can only be done in the early morning and late afternoon to avoid heat exhaustion. However, data from the National Institute of Water and Atmospheric Research

NZ (NIWA: Table 5.2) shows that, with the exception of Taranaki, all other regions had similar recorded temperatures during the peak periods of work. It is possible that region may not be the variable of interest, and the reason why there are significant differences between regions is because of some underlying variable that has not yet been tested, such as farm management practices and techniques. Further studies need to be conducted to confirm if the regional differences are true, or they are secondary effects.

When looking at the energy requirements of the Heading dog during peak periods, Northland had the highest recorded energy expenditure (237 ± 48.1 kcal/kg $BW^{0.75}$), while Southland had the lowest (148 ± 13 kcal/kg $BW^{0.75}$). There are a number of variables that may affect the large degree of variation found in this study. For example, one Heading dog in Northland working a 600 hectare farm recorded the highest daily energy expenditure and, as a result, this increased the average for the region. In this case, the farmer who worked this farm did not have had shepherds to help him with the mustering at that time; therefore his dogs were subjected to heavier workloads.

There are many other factors that can affect energy expenditure that were not accounted for in this study. One of them was the number of dogs that worked each farm. One would expect that because of the style of farming and the farm terrain in Southland (large hill country), that working farm dogs in Southland would have had the highest energy expenditure, however, this study has shown otherwise. There is no published data on the characteristics of farms in NZ, however it appears that large hill country stations tend to have more farm-hands and shepherds, and each have their own dogs, and this decreases the overall workload per dog (I. Singh, pers. Obs). These larger stations often have well established tracks that allow vehicles onto most of the paddocks. This allows dogs to ride on the back of the vehicle when going to the paddock, thereby conserving energy. The median size of farms in Southland identified in by the survey (chapter two) was 400 ha (IQR: 1040 ha) and the median size of farms in Northland was 240 ha (IQR: 398), therefore the larger farms do not necessarily have the largest workload per dog. The large variation in results within regions shows that even though farms are in the same region - and therefore subject to similar environmental conditions and terrain - the amount of work a particular breed, or an individual dog does on these farms varies greatly. Farmers have their favourite dogs, and use these dogs more frequently. These dogs are often the ones chosen when there is a challenging or a hard day of work anticipated. This would cause high variation in workload between individual dogs within farms. However, in this study, farmers chose their best/favourite dogs to participate in the study, thereby minimising this source of error between the two sample periods.

The median age of working dogs in this study was 3.75 (IQR: 3.25) years. This is similar to the median age found in the survey conducted in chapter two, from a much larger population of farm dogs (n=2,861) owned by New Zealand Sheep Dog Trial Association members (see section 2.3.2). There are two possible reasons why there is a young population of working dogs in NZ. Firstly, farmers were asked to choose their two best/favourite dogs in this study. The farmers may have preferred younger dogs that were more agile and quicker than their older counterparts, and value these characteristics when working long, hard days. The second reason could be that farm dogs are retired before reaching old age due to reasons such as health or injuries. Either way, the population of farm dogs owned by the NZSDTA was young, with a median age of 3 to 4 years.

The body condition score (BCS) provides a semi-quantitative assessment of body condition (Laflamme, 1997) and is useful for estimating the body condition of animals in the field. The BCS scale validated by Laflamme (1997) was used to visually determine if farm dogs lost condition during peak periods when compared with off-peak periods of work. Generally the dogs gained condition during off-peak periods, where they had some minimal fat covering (BCS four), compared to peak work periods where they were thinner, with no palpable fat (BCS three). Additionally individual dogs lost between 10 – 500 g (0.06 – 1.94%) of bodyweight from off-peak to peak periods, and on average Huntaways lost more (1.29%) than Heading dogs (0.65%), which seems reasonable as Huntaways have more total bodyweight to lose. Laflamme

(1997) stated that there was an increase of approximately 5% body weight for each unit increase in BSC. This either suggests inaccuracies in establishing the weight of the dogs in this study, or perhaps more likely, that the percent difference for each unit increase in BSC maybe different in working dogs than pet, or kennelled dogs. This could be a function of the working dogs losing fat mass and gaining muscle mass from work, as it well known that muscle weighs more than fat. It is unlikely that the difference has arisen from weighing the dogs, as the farmers weighed themselves first, confirmed that that is their normal weight, they then weighed themselves holding the dogs.

Studies have shown that the major source of fuel used for muscular work by sled dogs comes from the metabolism of free fatty acids (Hammel *et al.,* 1977: Paul and Issekutz, 1967: Kronfeld, 1973). This suggests that dogs in the current study use their meagre fat deposits built up during the off-peak work period to perform the tasks expected of them during the peak work period. According to the nine-point condition system of dogs, the ideal BCS is five, and therefore these farm dogs were underweight according to this scale during both peak and off-peak work periods. However, studies in Greyhounds have shown that restricted feeding (85% *vs.* 100% of maintenance requirements) resulted in increased speed performance and a BCS of 3.5 (Hill *et al.,* 2005). Restrictive feeding has also been shown to increase longevity in Labradors (Kealy *et al*., 2002). Kealy *et al.* (2002) recommended that dogs should be fed to maintain a BCS of less than five for good health and longevity. The ideal BCS has not been validated for working farm dogs in NZ.

This study has shown that Heading and Huntaway dogs require significantly more energy during peak periods of work when compared with off peak periods of work. However this study was unable to measure the effect that geography and terrain had on energy requirements. It is possible that geography and terrain of the farm that the dog is working on, may affect the energy expenditure. It maybe that steeper farms require the farmer to ride on a horse, rather than a quad bike, therefore the dog may have to walk or run up the hill, rather than getting a ride on a bike. Global positioning system (GPS) collars are gaining popularity with scientists to measure livestock behaviour (Turner *et al*.,

2000) and canine behaviour during tracking scent studies (Wilson, 2008). The use of these collars, in conjunction with activity monitors may increase the accuracy of establishing energy requirements, by validating each other i.e. the distance covered each day by a dog will validate the activity counts, and both forms of data will help establish the dogs daily energy requirements. Not only will devices such as GPS and activity monitors increase accuracy of measurement, but it may also help establish previously undocumented working behaviour of working farm dogs in NZ.

5.6 References

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5.7 Appendix 1: Raw data from all dogs using BMR = 76 × BW$^{0.75}$ during off-peak period of work

Region	Breed	Gender	Weight (kg)	Activity counts per day	BMR (Kcal/d)	AEE (kcal/day)	EE (kcal/day)
Southland	Heading	M	23.2	218,691	803	259	1,062
	Heading	F	17.6	460,110	653	655	1,308
	Huntaway	M	34.3	127,513	1,077	109	1,187
	Huntaway	F	25.9	313,465	873	414	1,287
	Heading	F	23.7	171,794	816	182	9,98
	Heading	M	22.5	597,249	785	880	1,665
	Huntaway	F	22.9	925,64	796	52	848
	Huntaway	M	35.0	487,316	1,094	700	1,793
Canterbury	Heading	F	15.3	308,021	588	405	993
	Heading	M	22.6	304,413	788	400	1,187
	Huntaway	M	31.5	444,986	1,011	630	1,641
	Huntaway	M	31.2	468,299	1,003	668	1,672
	Huntaway	M	31.0	623,827	998	923	1,922
	Huntaway	M	39.2	387,255	1,191	535	1,726
LNI/Wairarapa	Heading	M	19.3	435,737	700	615	1,315
	Heading	F	15.7	770,382	599	1,164	1,763
	Heading	M	19.7	787,679	711	1,192	1,903
	Heading	F	18.3	915,146	672	1,401	2,074
	Heading	M	14.4	215,861	562	254	816
	Heading	M	19.8	266,952	713	338	1,051
	Huntaway	M	27.5	513,362	913	742	1,655
	Huntaway	M	32.5	448,922	1,034	637	1,671
	Huntaway	F	31.0	375,987	998	517	1,515

	Huntaway	F	31.0	665,579	998	992	1,990
	Huntaway	F	21.8	389,875	767	540	1,306
	Huntaway	M	39.4	400,627	1,195	557	1,753
HB/Taupo	Heading	M	20.9	422,123	743	593	1,335
	Heading	F	16.5	422,279	622	593	1,215
	Heading	M	21.0	451,485	746	641	1,386
	Heading	M	18.7	473,125	683	676	1,360
	Huntaway	M	32.6	528,254	1,037	767	1,804
	Huntaway	F	25.5	69,531	862	14	877
	Huntaway	M	34.1	441,561	1,072	624	1,697
	Huntaway	M	34.7	345,836	1,087	467	1,554
	Huntaway	M	31.5	324,075	1,011	432	1,442
Taranaki	Heading	M	21.0	364,714	746	498	1,244
	Heading	M	22.6	630,156	788	934	1,722
	Huntaway	M	34.7	271,724	1,087	346	1,433
	Huntaway	M	35.5	204,197	1,105	235	1,341
King Country	Heading	M	22.6	579,417	788	851	1,638
	Heading	M	18.6	266,519	681	337	1,018
	Huntaway	M	30.9	384,776	996	531	1,527
	Huntaway	M	35.9	644,247	1,115	957	2,072
	Huntaway	M	32.9	257,515	1,044	323	1,367
Gisborne	Heading	M	24.8	186,966	845	207	1,052
	Heading	F	19.2	376,004	697	517	1,214
	Huntaway	M	28.8	154,578	945	154	1,099
	Huntaway	F	29.6	497,341	964	716	1,680
Northland	Heading	F	18.2	626,205	670	927	1,597

	Heading	M	19.2	506,059	697	730	1,427
	Huntaway	M	42.1	152,197	1,256	150	1,406
	Huntaway	M	28.9	365,182	947	499	1,447

#LNI: Lower North Island, *HB: Hawke’s Bay

Appendix 2: Raw data from all dogs using BMR = 76 × BW$^{0.75}$ during peak period of work

Region	Breed	Gender	Weight (kg)	Activity counts per day	BMR (Kcal/d)	AEE (kcal/day)	EE (kcal/day)
Southland	Heading	M	22.7	429,995	790	606	1,396
	Heading	F	18.0	506,068	664	730	1,394
	Huntaway	M	36.6	341,060	1131	460	1,591
	Huntaway	F	25.9	312,688	873	413	1,286
	Heading	F	21.3	656,873	754	978	1,731
	Heading	M	25.3	615,597	857	910	1,767
	Huntaway	F	21.3	404,003	754	563	1,316
	Huntaway	M	37.8	760,134	1159	1147	2,306
Canterbury	Heading	F	15.5	1,064,766	594	1647	2,240
	Heading	M	22.0	475,392	772	680	1,452
	Huntaway	M	31.5	1,367,553	1011	2143	3,154
	Huntaway	M	34.2	480,046	1075	688	1,762
	Huntaway	M	29.0	955,142	950	1467	2,417
	Huntaway	M	38.4	766,001	1172	1157	2,329
LNI/Wairarapa	Heading	M	17.4	672,751	647	1004	1,651
	Heading	F	17.3	1,062,412	645	1643	2,287
	Heading	M	21.3	778,357	754	1177	1,930
	Heading	F	18.5	1,103,972	678	1711	2,389
	Heading	M	15.3	803,476	588	1218	1,806
	Heading	M	20.3	671,669	727	1002	1,729
	Huntaway	M	27.4	547,823	910	799	1,709
	Huntaway	M	30.2	696,136	979	1042	2,021

	Huntaway	F	30.6	377,310	989	519	1,508
	Huntaway	F	30.6	848,200	989	1291	2,280
	Huntaway	F	20.7	881,527	738	1346	2,084
	Huntaway	M	40.8	690,488	1227	1033	2,260
HB/Taupo	Heading	M	18.8	715,544	686	1074	1,760
	Heading	F	16.4	609,564	619	900	1,519
	Heading	M	21.5	479,521	759	687	1,446
	Heading	M	21.1	528,839	748	768	1,516
	Huntaway	M	26.7	899,299	893	1375	2,268
	Huntaway	F	26.2	533,310	880	775	1,655
	Huntaway	M	34.6	573,580	1084	841	1,925
	Huntaway	M	36.4	444,008	1126	628	1,755
	Huntaway	M	31.6	370,031	1013	507	1,520
Taranaki	Heading	M	21.4	535,228	756	778	1,534
	Heading	M	22.1	835,458	775	1270	2,045
	Huntaway	M	33.8	551,592	1065	805	1,870
	Huntaway	M	34.2	393,617	1075	546	1,621
King Country	Heading	M	23.7	835,075	816	1270	2,086
	Heading	M	18.3	375,444	672	516	1,188
	Huntaway	M	29.7	497,716	967	717	1,683
	Huntaway	M	36.9	927,314	1138	1421	2,559
	Huntaway	M	29.2	502,854	955	725	1,680
Gisborne	Heading	M	25.4	650,481	860	967	1,827
	Heading	F	21.0	690,102	746	1032	1,778
	Huntaway	M	28.3	552,547	933	806	1,739
	Huntaway	F	29.0	918,829	950	1407	2,357

Northland	Heading	F	16.4	1,070,135	619	1655	2,275
	Heading	M	17.6	638,676	653	948	1,601
	Huntaway	M	41.3	398,924	1238	555	1,793
	Huntaway	M	27.3	544,269	908	793	1,701

[#] LNI: Lower North Island, *HB: Hawke’s Bay

CHAPTER SIX:

Estimating energy requirements of working farm dogs in New Zealand: Heading dogs *vs.* Huntaways

6.1 Introduction

Chapter five attempted to assess the workloads of Heading and Huntaway dogs during peak and off peak times of the year. The information that activity monitors cannot provide is the distance travelled and the terrain that the dogs covered in a working day. Anecdotally farm dogs are said to work hard, however no studies have established exactly how hard these dogs work. There is an abundance of published literature regarding nutrition and energy requirements of Greyhounds, sled dogs and an increasing amount of literature on hunting dogs (Table 6.1 below). However, it is unknown if results from these studies of other dog breeds can be extrapolated to the NZ working farm dog. Greyhounds are well-known for their sprinting ability, while sled dogs are endurance athletes. The work of a NZ farm dog is a blend of both activities and it seems reasonable to hypothesise that their energy requirements would lie somewhere in the middle.

Table 6.1: Published literature regarding nutrition and energy requirements of Greyhounds, sled dogs and hunting dogs.

Grey Hound	Sled dogs	Hunting dogs
Hill *et al.,* 1996; 1998; 1998a; 2000 2001a; 2001b; 2005 Marshall *et al.,* 2002	Baskin *et al.,* 2000 Brown *et al.*, 2009 Chew *et al.,* 2000 Dunlap *et al.*, 2006 Gerth *et al.*, 2010 Hammel *et al.*, 1977 Hill, 1998 Hinchcliff *et al.,* 1996; 1997 Kronfeld, 1973 Kronfeld *et al.*, 1977 McKenzie *et al.*, 2005 Piercy *et al.*, 2000, 2001 Reinhart and Bolser, 1996 Reynolds *et al.*, 1994; 1995a; 1995b; 1996; 1997; 1999 Taylor, 1957 Taylor *et al.*, 1959	Ahlstrom *et al.*, 2006a; 2006b Davenport *et al.*, 2001 Pasquini *et al.*, 2010

Historically the range of methods available to measure the energy expenditure of free-living subjects was limited, and the studied subject commonly needed to be in a laboratory setting. More recently the validation and development of doubly-labelled water (DLW) techniques in humans and animals has enabled researchers to study free-living subjects. Activity monitors are also becoming increasingly popular in studies that estimate the energy expenditure of free-living subjects and are particularly popular in studies involving children, because of the unobtrusive nature of the activity monitors (Puyau *et al.*, 2002; Pfeiffer *et al.,* 2006). Geographical positioning systems (GPS) used to track animal movement are normally incorporated into collars which use microelectronics to calculate the position of the animal relative to 24 orbiting satellites (Wells, 1986). There are three different types of GPS collars, 1) collars that store information and need to be retrieved in order to download information, and do not have a transmitting device that lets the researcher know the whereabouts of the animal and collar for retrieval, 2) collars that store and transmit data to a satellite to be retrieved by a data management centre or 3) collars that store information and provide the researcher with information as to the whereabouts of the collar for retrieval (Biggs *et al.,* 2001). The type of collars used in this study store information and need to be retrieved in order to download information; the collars do not have a transmitting device that lets the researcher know the whereabouts of the animal and collar for retrieval.

Geographical positioning systems have traditionally been used to track free-living wild animals (Rutter *et al.*, 1997; Blake *et al.,* 2001; Girard *et al.,* 2002; Jay, 2002; Anderson and Frederick, 2003; Soisalo and Cavalcanti, 2006; Schofield *et al.,* 2007). The use of GPS technologies has more recently expanded to assist in studies of livestock behaviour (Turner *et* al., 2000) and canine behaviour during tracking scent studies (Wilson, 2008). Another study has recently used GPS to measure the workload of seven Australian Collie and Kelpie dogs during mustering sessions (Hampson and McGowan, 2007). By using a combination of these emerging technologies, the current study aimed to estimate the energy requirements and workloads of working farm dogs in NZ.

6.2 Aim

The aim of this study is to estimate the energy requirements and workload of working farm dogs using Actical® activity monitors and Sirtrack® GPS animal tracking collars. The GPS collars will help establish much required workload information, such as the distance and altitude covered by a working farm dog in a working day.

6.2.1: Hypothesis

Using a combination of activity monitors and global position system collars (GPS) will give more information on the work and working behaviour of working farm dogs by providing the distance covered by dogs in a working day.

6.3 Methods and materials

The sampling period spanned from April 2009 to April 2010.

6.3.1 Farm selection

Dogs from 27 farmers from the New Zealand Sheep Dog Trial Association (NZDTA) participated in this trial.

6.3.2 Farm background information

This study was carried out on a different set of farms and subsequently different set of dogs from Chapter five. This study used 27 sheep and beef farms that were divided between eight different regions of New Zealand (Gisborne; King Country; Central Plateau; Hawke’s Bay; Lower North Island, including Wairarapa; Marlborough, including Abel Tasman; Canterbury and Otago). The regions and number of farms (in brackets) used in the trial were: Gisborne (2); King Country (1); Central Plateau (4); Hawke’s Bay (5); the Lower North Island (including Wairarapa) (2); Marlborough (including Abel Tasman) (6); Canterbury (4) and Otago (3). Two dogs per farm were used to measure energy requirements and distance covered during peak and off-peak periods of work. Each farm’s terrain and size was different and so the dog’s workload varied between farms. The largest farm was 30,351 Ha in King Country and the smallest was 121 Ha in the Central Plateau. The farm terrains varied from mixed terrain (both hilly and flat) in Otago and Canterbury to steep hill country in

Marlborough/Abel Tasman, Table 6.2 shows the physical characteristics and number of farms surveyed in each region during this trial. Appendix 6.1 gives information on individual farms (sizes, terrain and maximum height above sea level).

Table 6.2: Number and characteristics of surveyed farms in each region.

Region	Farms (N)	Average Size (Ha)	Terrain	Maximum Height (above sea level)
Gisborne	2	440	Mixed	500
King Country	1	30,351	Mixed	175
Central Plateau	3	3,317	Mixed	900
HB*	5	1,988	Mixed	1,000
LNI#/Wairarapa	2	1,367	Mixed	500
Marlborough/AT^	6	1,229	Hill	958
Canterbury	4	1,130	Mixed	707
Otago	3	13,900	Mixed	1,460
NZ Average	27	3,984		527

^ AT: Abel Tasman, #LNI: Lower North Island, *HB: Hawke's Bay

Peak workload periods generally consisted of times where the farmer was mustering stock for shearing, weaning calves and lambs, docking tails in lambs and veterinary check-ups and disease testing. Each farm had different times when these activities occurred, but generally these activities occurred within specific times of the year (Table 6.3)

Table 6.3: General activities throughout the year in the North and South Island farms in New Zealand during peak* and off peak periods.

	Autumn			Winter			Spring			Summer		
	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
North Island	Mid load			Off peak			Peak			Peak		
South Island	Peak			Off peak			Peak		Mid load		Peak	

*Peak workload periods generally consisted of times where the farmer was mustering sheep and beef for shearing sheep, weaning calves and lambs, docking tails in lambs and veterinary check-ups and disease testing.

The off-peak period of 3 days did not immediately follow or preceded the 3 day peak period and generally correlated to the period described in table 6.3.

6.3.3 Dog information

Farmers were asked to choose their two best dogs (one Heading dog and one Huntaway) to participate in the trial. One farm in Hawke’s Bay did not use Heading dogs and, therefore, two Huntaway’s were chosen.

General health information such as weight, height and body condition was documented for each dog at the beginning of each period. Dogs were weighed on scales, where the owner would be weighed with the dog, and the weight of the owner subtracted from the combined weight. The height of the dog was measured with a dressmakers tape from the top of the head to the dog’s feet. Body condition was evaluated at peak and off-peak periods to assess each dog’s degree of leanness or obesity, using a nine point body condition score scale ranging from one (emaciated) to nine (severely obese) (Laflamme, 1997). Actical® activity collars and Sirtrack® GPS collars were fitted onto the two chosen dogs from each farm, to record activity and positional data for three days during the peak period and three days during the off-peak period. The collars were then removed and the data was downloaded and saved. The activity monitors were then reprogrammed and reattached to the next pair of dogs. Figure 6.1 shows both a Heading dog and a Huntaway wearing both activity and GPS collars.

Figure 6.1: Flash (from Marlborough) a Heading dog (left), and Lucas (from Marlborough) a Huntaway (right) wearing both the activity monitors and GPS collars.

6.3.4 Actical® activity monitors

The Actical® activity monitors used in the study were the same as those used in Chapter 4 (section 4.3.3) and Chapter 5 (section 5.2.4). Data was collected every 15 seconds for three days.

The metabolic bodyweight of each dog ($BW^{0.75}$) was divided by its estimated total energy expenditure (TEE) from the activity monitors to work out the allometric equation for energy requirements.

6.3.5 Sirtrack® GPS collars

Two different sizes of GPS collars were commissioned from Sirtrack® Ltd. (Havelock North, NZ) for use in the study. One collar weighed 245 g with a circumference of 270 – 380 mm for use on Heading dogs, and the other weighed 300 g with a circumference of 380 – 520 mm for use on the larger Huntaway's. The collars could be manually switched on or off, and were programmed to take a reading every 30 s, with a battery life of 36 h. The batteries were replaced after the three day data collection phase. The GPS collars were satellite systems that collected and stored co-ordinates in the receiver located in the collar, this meant that collars had to be retrieved in order to download data. Figure 6.2 shows both the GPS (black) and activity collars (blue).

Figure 6.2: The Sirtrack® GPS collars (black) and Actical® activity monitor collars (blue).

6.3.6 Data analysis

The data from the Actical® activity monitors was downloaded using Actical® software (version 2.1. MiniMitter, Bend, OR, USA) and then transferred to Microsoft Excel for analysis. The data included raw activity counts over each three day period and the average activity counts per day were tallied for each dog. Raw activity counts were converted into activity-associated energy expenditure (AEE: kcal/day) using the formula (0.00164 × raw activity counts (per day)) + (-99.683) (Section 4.4.2). The activity associated energy expenditure (AEE) was then added to the basal metabolic rate (BMR) of the farm dogs. The BMR of individual dogs was calculated using the formula proposed by NRC (Anonymous, 2006).

Geographical positioning data was downloaded using Sirtrack$^{®}$ GPS Logger software programme (version 5.1.3, Sirtrack$^{®}$, Ltd, Havelock North, NZ). Figure 6.3 shows the Sirtrack$^{®}$ data logger downloading interface. Co-ordinates were then plotted and analysed using ArchMap$^{\text{TM}}$ (GIS software version 9.2, ESRI, Redwood, CA, USA).

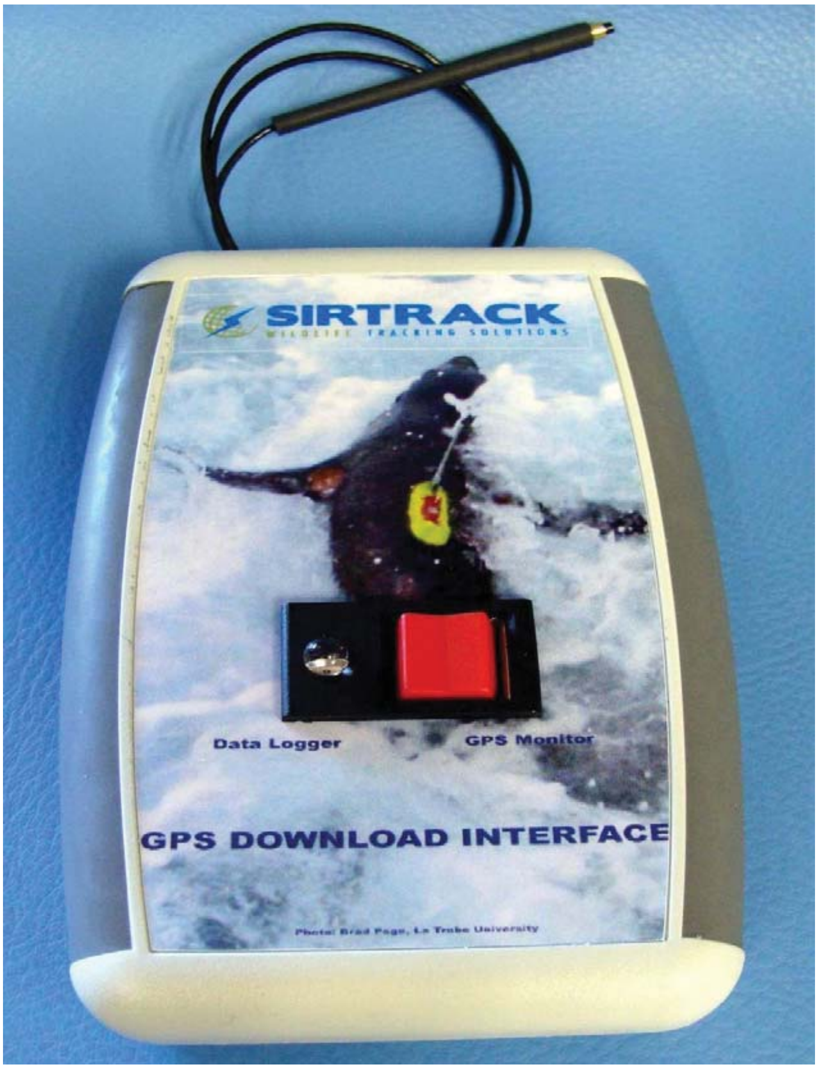

Figure 6.3: Sirtrack$^{®}$ data logger downloading interface

6.3.7 Static GPS test of accuracy

Static accuracy is a measure of how accurate the GPS collars are, and quantifies GPS receiver error. These errors are referred to as circular error probable (CEP) and are expressed as radial distance of error locations from the true location. The CEP is a radius of a circle that contains the known percentile of points around a known location (Turner *et al*., 2000). For example, CEP calculated at one degree of freedom is determined by graphically locating all data points located in the 95th percentile (95% CEP). In order to obtain the CEP and therefore static error, the collars were left in a paddock undisturbed for 48 h. Positional data from them were then downloaded and co-ordinates were plotted and analysed using ArchMap^{TM} (GIS software version 9.2, ESRI, Redwood, CA, USA).

6.3.7.1 Geographical positioning system (GPS) data analysis

The positions of a Heading dog and Huntaway on a typical working day during off-peak work; and the same two dogs during a typical day during a peak work are shown in figures 6.4a and 6.4b respectively.

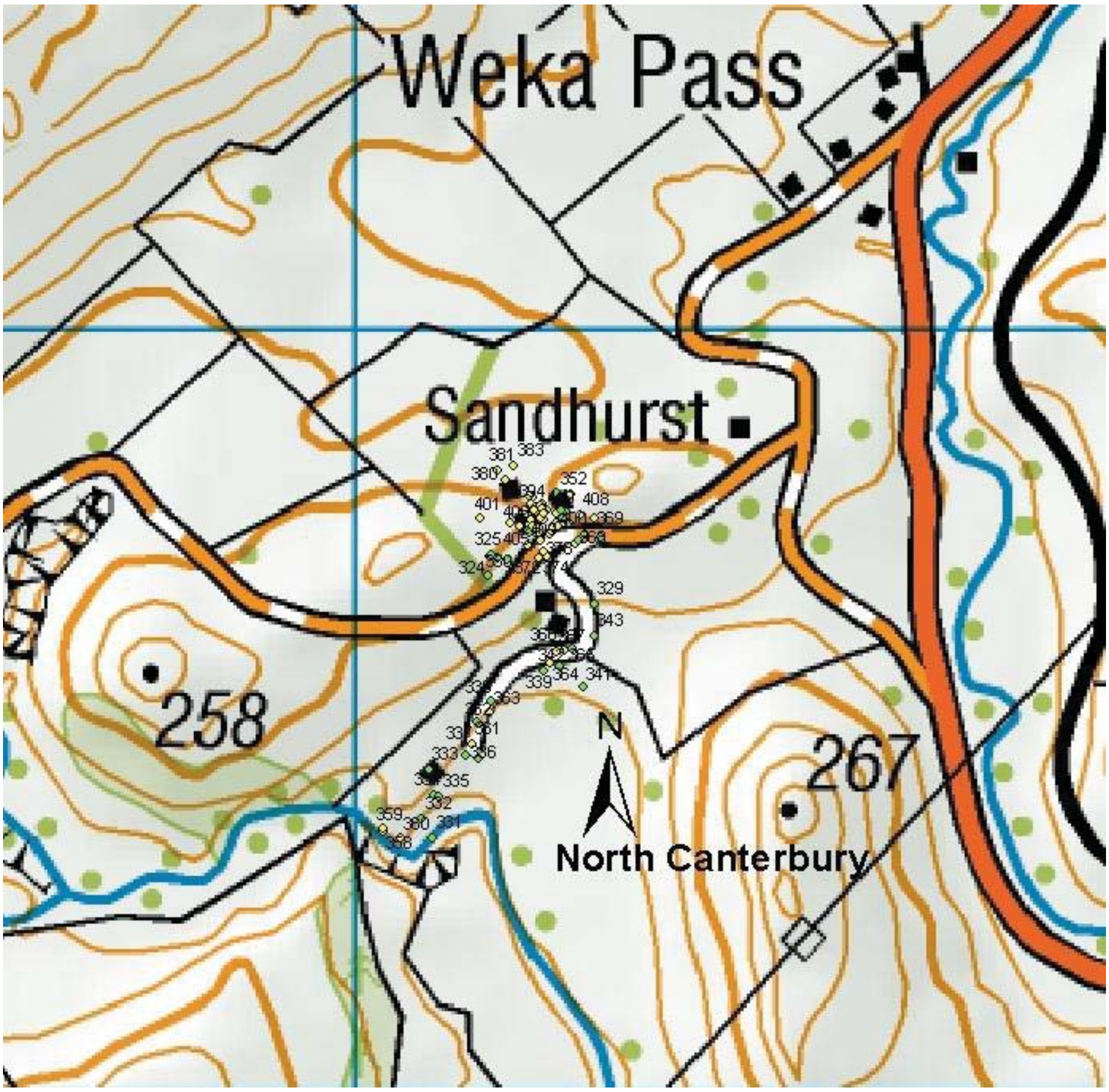

Figure 6.4a: Positional data from a typical off-peak period day for a Heading dog (yellow) and Huntaway (green) on the same farm in North Canterbury. Each coloured dot is a 30 second reading.

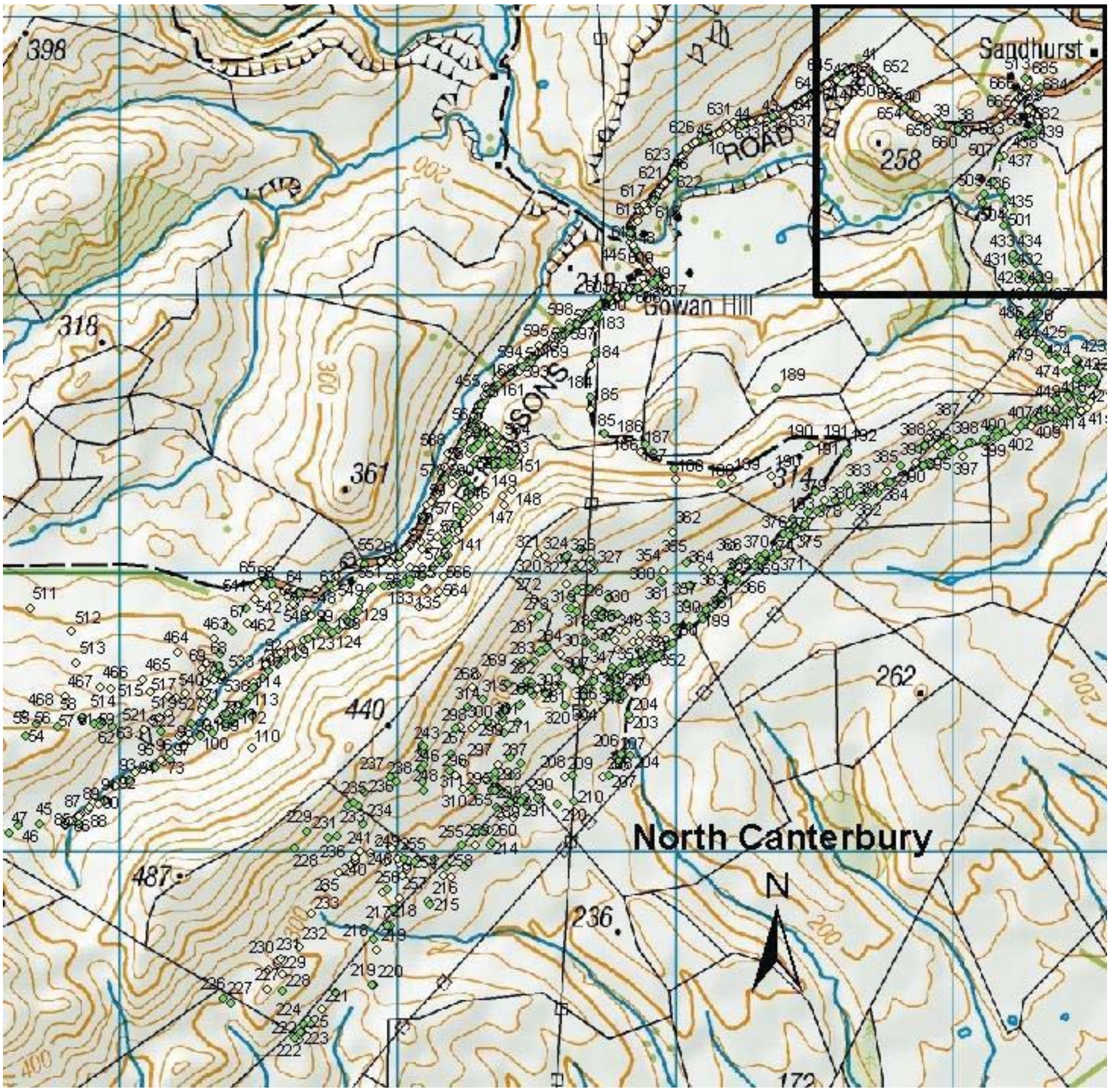

Figure 6.4b: Positional data from a typical peak period day for a Heading dog (yellow) and Huntaway (green) in North Canterbury (the same dogs and same farm as figure 6.4a). The box on the top right hand side of the map shows area covered in Figure 6.4a. Each coloured dot is a 30 second reading.

The majority of farm dogs are able to ride on a quad bike, trailer or on the back of utility vehicles to and from paddocks (Figure 6.5). This is a potential source of error when estimating the distance the dogs walked, trotted or ran during normal work. During the analysis of GPS data, measurements therefore had to be filtered and some data deleted. Previous studies (Hampton and McGowan, 2007) have shown that the maximum speed of a farm dog was 43.7 km/h therefore this study assumed that any speeds above 43.7 km/h were indicative of the dog riding in a trailer, utility vehicle or quad bike and were deleted. Data that suggested that both dogs were travelling on the same path below 43.7

km/h, either on quad bikes, trailers or utility vehicles on main roads (see Figure 6.6a), or on tracks (Figure 6.6b) were also deleted. In contrast, an example of data showing both dogs during normal farm work travelling on different paths used to measure the daily distance covered is shown in Figure 6.6c.

Figure 6.5: Dogs on the back of a quad bike and on a trailer: a typical setup used by farmers in NZ to transport a team of dogs to and from paddocks.

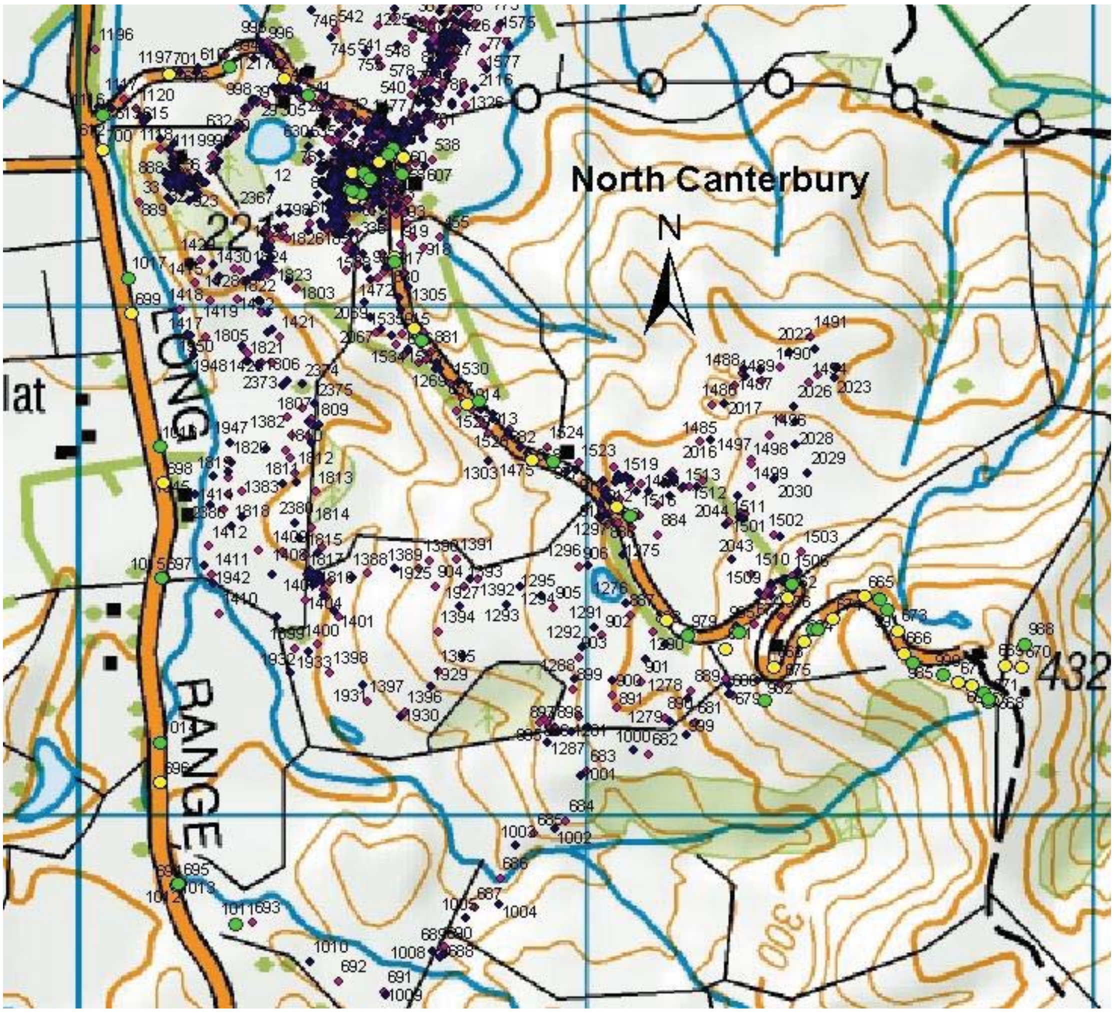

Figure 6.6a: An example of a Heading dog (yellow) and Huntaway (green) travelling on a main road, and on the same path at speeds above 43.7 km/h. Data such as the ones outlined by yellow and green dots were deleted from the analysis of the distance that dogs covered during daily work.

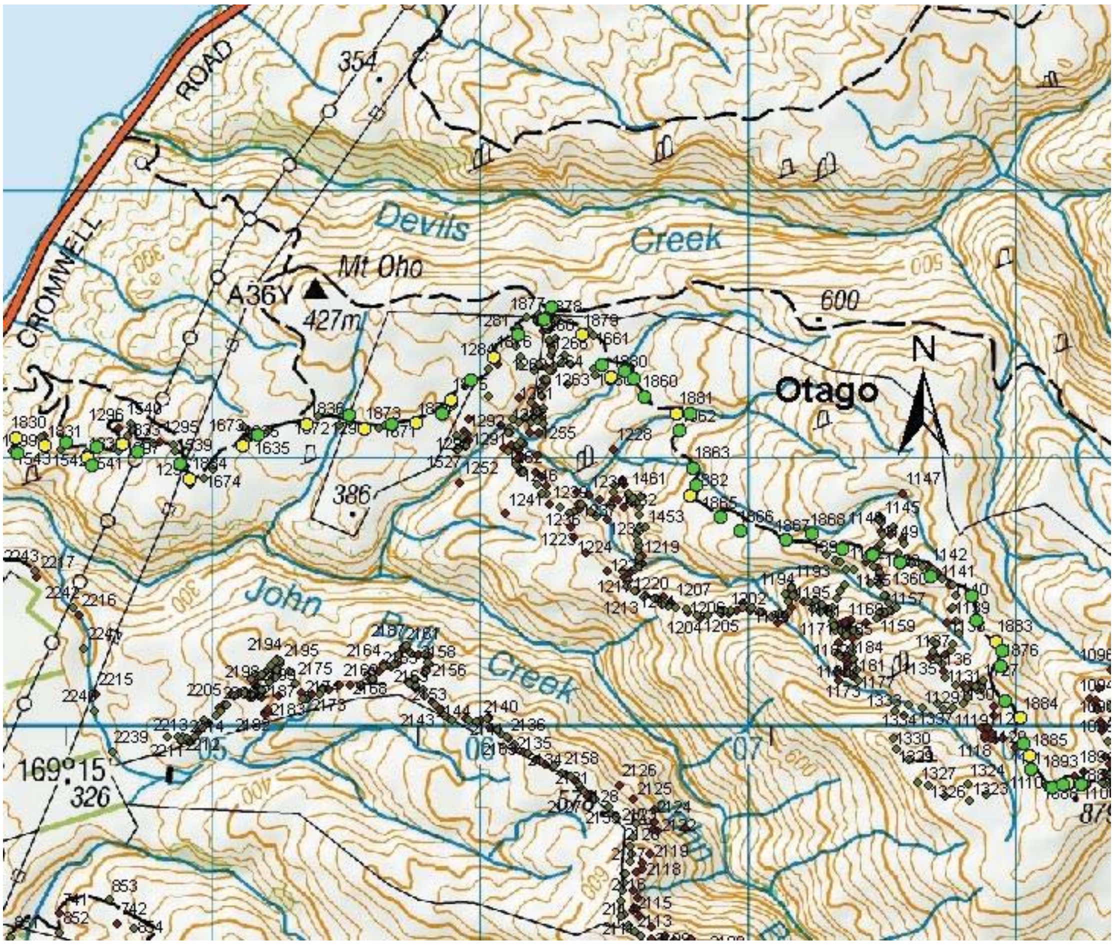

Figure 6.6b: An example of a Heading dog (yellow) and Huntaway (green) travelling on a track, and on the same path at speeds above 43.7 km/h. Data such as this was deleted from the analysis of the distance that dogs covered during daily work.

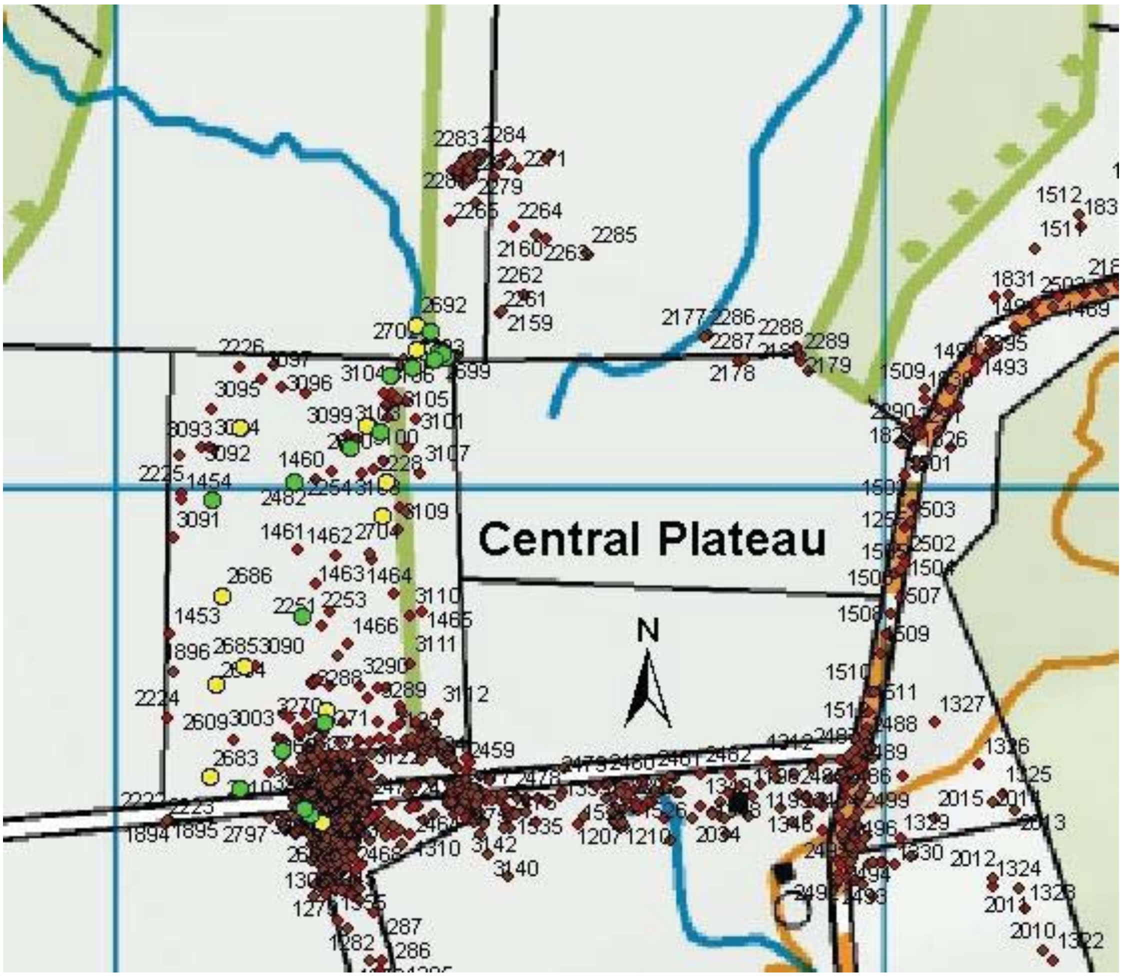

Figure 6.6c: An example of a Heading dog (yellow) and Huntaway (green) working normally to muster sheep and travelling via different routes. The brown and red dots represent the position of the dogs during other periods.

Activity count data could also be used to further distinguish relevant GPS data. By comparing activity counts with distance travelled over a certain time period, it was easy to distinguish work from transportation. Two dogs fitted with GPS and activity monitors were transported on a trailer on a gravel road at speeds of 0 – 30 km/h for 35 minutes in order to estimate the number of activity counts produced per minute on the Actical® monitors during this type of activity. When dogs were travelling in a trailer at a speed of ≤33.5 km/h for 35 minutes, the activity monitors recorded an average of 567 activity counts/min. However, if a dog was running for the same period of time at similar speeds (0 – 27.8 km/h, they generated at least 5347 activity counts/min. Therefore this process (comparing GPS data with activity counts) provided a further sensitive tool to distinguish between dogs that were running or travelling on a trailer.

By using a combination of these processes, it was possible to obtain an estimate of the distance covered by each dog, during periods of peak and off-peak work.

It has been established that the accuracy of GPS collar position is affected by the number of satellites from which the signal is received (Wells, 1986; Rempel *et al.,* 1995; Witte and Wilson, 2005). The best trajectory is when there are four satellites visible, this enables the calculation of a three dimensional fix (longitude, latitude and elevation). If only three or less satellites are visible, the elevation is estimated and a two dimensional location is calculated and may provide incorrect positions (Wells, 1986). Therefore all GPS co-ordinates calculated from three satellites or less in the current study were removed from all analyses to provide a more accurate data set.

6.3.8 Statistical analysis

A test of normality was carried out using the Shapiro-Wilk test for the activity counts and the energy requirements, and the natural log of the data was used for factorial and ANOVA analysis, but presented using untransformed values. A two-way factorial analysis of variance (factors = gender, breed, region and gender × breed) was conducted to test for differences in energy requirements of working farm dogs. Least square means was used to establish if there were breed, regional and gender differences within peak and off-peak periods of work. The model accounted for any individual dog, breed and gender effects. Paired t-tests were conducted to assess if there were differences in peak and off-peak periods for both breeds of working dog. The t-test was conducted to determine statistical difference between North and South islands for distance covered per day for each of the breeds. The paired t-test was used to determine if speed (km/h; off-peak/peak %) and energy expenditure (off-peak/peak %) data were comparable. All statistical procedures were carried out with SAS 9.1 software (package SAS/STAT Version 9.1, SAS Inst., Inc., Cary, NC, USA). Data are presented as mean (± SEM), unless otherwise stated. Significance was assumed if $p < 0.05$. Data from one Huntaway in the Central Plateau region was discarded due to an abnormality in activity count recording, where the graph showed continuous activity 24 hours a day for the 3 full days and nights, resulting in activity counts in the one million range every day. The other dog sampled on this farm showed clear day night rhythms.

To combine the data from both seasons, a PROC MIXED analysis which included farms as a random effect nested within region was carried out.

6.4 Results

6.4.1 Dog information

Heading dogs and Huntaways:

Twenty six Heading dogs and 27 Huntaways were sampled in this trial. The median age of the 53 dogs sampled was 4.50 ± 0.27 years, with a range of 1.5 to 7.5 years. The sample consisted of 38 (72%) male and 15 (28%) female dogs. Of the 53 dogs, 9 (17%) were female Heading dogs, 17 (32%) were male Heading dogs, 5 (9%) were female Huntaways and 22 (41%) were male Huntaways. The average body condition score on a nine point scale (Laflamme, 1997) was 3.5 ± 0.09 during off-peak periods and 3.0 ± 0.07 during peak periods.

Heading dogs:

During off-peak periods the average bodyweight of Heading dogs was 21.72 ± 0.74 kg, and quite similar between two sexes, 19.28 ± 1.18 kg and 22.81 ± 0.82 kg for female and male respectively. During peak periods the average bodyweight of the same dogs was 23.20 ± 1.28 kg with females and males being 20.17 ± 1.42 kg and 24.53 ± 1.65 kg respectively.

Huntaways:

During off-peak periods the average bodyweight of Huntaways was 31.44 ± 0.96 kg with much more distinct sex differences, females and males Huntaway had an average bodyweight of 27.83 ± 1.38 and 32.65 ± 1.08 kg respectively. The average bodyweight of Huntaways during peak periods was 31.90 ± 0.83 kg with female and males 28.27 ± 1.64 kg and 33.11 ± 0.82 kg respectively.

6.4.2 Activity counts

The Shapiro-Wilk test of normality showed that the activity counts were highly skewed (off-peak $p < 0.0001$, peak $p < 0.0001$). The natural log of the data was used to transform the skewed data to a symmetric distribution for further analysis. The Shapiro-Wilk test of normality then confirmed that the natural log of both off-peak and peak energy activity counts were normally distributed ($p<0.1$ and $p<0.1$ respectively).

Heading dogs and Huntaways:
Statistical analysis of the natural log transformed data showed that there were no significant differences in breed or gender and breed interactions ($p>0.05$) during off-peak or peak periods. There were regional differences in the amount of activity counts per day during off-peak and peak periods ($p<0.05$). Table 6.4 shows the activity counts of dogs, during the peak and off-peak work periods, in each region and Appendix 6.7a and 6.7b show raw data for off-peak and peak work for each individual dog.

On average during off-peak periods, dogs in Hawke's Bay had higher activity counts than Central Plateau, Canterbury, Marlborough/AT and Otago (600,290 vs. 282,891, 357,422, 284,364 and 318,533 counts per day respectively; $p < 0.05$), and dogs in Gisborne had higher activity counts than Marlborough/AT (524,525 vs. 284,364 counts per day; $p < 0.05$).

On average, dogs in Hawke's Bay, Otago and King Country had higher activity counts than Gisborne, Canterbury, Marlborough/AT (2,601, 2,540 and 2670 kcal/day vs. 2,119, 2,154, and 2,180 kcal/day respectively; $p < 0.05$).

Based on the proportion of activity counts during off-peak periods, dogs in Otago work 70% less during off-peak than peak periods (318,533 *vs.* 1,050,766) and Gisborne had the smallest difference between peak and off-peak workloads (794,287 *vs.* 524,525). Dogs in the King Country had the highest activity counts (1,139,585 activity counts) in the sample and also recorded 345,298 more activity counts than Gisborne, which was the region with the least amount of activity counts per dog (794,287). The average activity count for the NZ farm dog during the peak work period was 927,392 ± 50,570 activity counts which compared with 417,365 ± 31,162 activity counts during the off-peak period (Table 6.4).

Table 6.4: Mean (±SEM) activity counts per dog per day obtained from farms in different regions around NZ

		Workload per day (counts per day)		
Region	**n**	**Peak (±SEM)**	**Off-peak (±SEM)**	**% of peak**
Gisborne	4	794,287^{ac} (140,643)	524,525^{a} (53,717)	66
King Country	2	1,139,585^{bc} (151,463)	371,145^{b} (41,358)	32.6
Central Plateau	7	942,044^{c} (182,425)	282,891 ^{bc} (64,872)	30
HB*	10	1,072,103^{bc} (89,346)	600,290^{a} (110,089)	56
LNI[#]/Wairarapa	4	972,076^{c} (208,573)	526,422^{a} (60,920)	54.2
Marlborough/AT^	12	848,158^{c} (126,712)	284,364^{c} (40,196)	33.5
Canterbury	8	865,870^{ac} (69,146)	357,422^{bc} (81,065)	41.3
Otago	6	1,050,766^{c} (180,472)	318,533^{bc} (23,116)	30.3
NZ Average	53	927,392 (50,570)	417,057 (31,162)	45

*HB = Hawke's Bay, [#]LNI = Lower North Island, ^AT = Abel Tasman. Means with different subscripts within each column are different (*p*<0.05).

There were no significant differences in the amount of activity counts between Heading dogs and Huntaway (Table 6.5), both breeds worked proportionally less during off-peak periods (46% *vs.* 44% of peak levels respectively of each breed)

Table 6.5: Mean (±SEM) activity counts per day from different breeds of working farm dogs in NZ

		Workload per day (counts per day)		
Breed	**N**	**Peak (±SEM)**	**Off-peak (±SEM)**	**% of peak**
Heading	26	957,048 (86,327)	422,967 (49,586)	44.2
Huntaway	27	898,833 (55,459)	411,365 (39,157)	45.8

Heading dogs:

Statistical analysis of the natural log transformed data showed that there were no significant differences between genders in the number of activity counts during peak or off-peak periods. There were significant ($p<0.05$) differences across regions during peak and off-peak periods. The region with the highest daily activity during peak periods was Otago (1,152,903 ± 295,363 counts per day), and the region with the lowest daily activity was Canterbury (754,968 ± 253,320 counts per day). During off-peak periods, the region that had Heading dogs with the highest daily activity was Hawke's Bay (649,397 ± 130,108 counts per day) and the region with the least activity was Otago (279,801 ± 147,427 counts per day). Table 6.6 shows the daily activity counts from Heading dogs in different regions of NZ.

Table 6.6: Mean (±SEM) daily activity counts per Heading dog and the number of dogs sampled (n) during peak and off-peak work periods on farms from different regions around NZ.

	Workload per day			
Region	**N**	**Peak (±SEM)**	**Off-peak (±SEM)**	**% of peak**
Gisborne	2	766,730^{ab} (289,878)	546,315^{a} (123,493)	71.3
King Country	1	988,122 (n/a)	338,223 (n/a)	34.2
Central Plateau	4	989,116^{ab} (261,838)	449,013^{ab} (67,003)	45.4
HB*	4	1,133,652^{a} (185,094)	649,397^{a} (251,182)	57.3
LNI$^{\#}$/Wairarapa	2	968,055^{ab} (348,121)	622,651^{a} (80,708)	64.3
Marlborough/AT^	6	901,435^{ab} (235,796)	321,562^{b} (65,669)	35.7
Canterbury	4	754,968^{b} (127,966)	302,294^{b} (90,782)	40
Otago	3	1,152,903^{ab} (377,798)	279,810^{b} (30,497)	24.3
NZ Average	26	957,048 (86,327)	422,967 (49,586)	44.2

*HB = Hawke's Bay, $^{\#}$LNI = Lower North Island, ^AT = Abel Tasman. Means with different subscripts within each column are different ($p<0.05$).

Huntaways:

Statistical analysis of the natural log transformed data showed that there were significant differences ($p<0.05$) across regions during peak and off-peak activity levels. There were no significant differences in the activity counts between male and female Huntaways, or activity levels of Huntaways in different regions of NZ during peak or off peak periods of work. The region with the highest daily activity during peak periods was Hawke's Bay (1,034,224 ± 120,419 counts per day) and the region with the lowest daily activity was Canterbury (478,015 ± 548,464 counts per day). During off-peak periods, the region that had Huntaway dogs with the highest daily activity was Hawke's Bay (564,741 ± 81,082 counts per day) and the region with the least activity was Marlborough including Abel Tasman (246,345 ± 89,419 counts per day). Table 6.7 shows the daily activity counts from Huntaways in different regions of NZ.

Table 6.7: Mean (±SEM) daily activity counts per Huntaway and the number of dog's sampled (n) during peak and off-peak work periods on farms from different regions around NZ.

		Workload per day (counts per day)		
Region	**n**	**Peak (±SEM)**	**Off-peak (±SEM)**	**% of peak**
Gisborne	2	520,273 (184,386)^{ab}	501,504 (41,301)^{ab}	62.9
King Country	1	998,935 (n/a)	402,836 (n/a)	32
Central Plateau	3	848,920 (300,362)^{ab}	382,973 (138,686)^{ab}	45.1
HB*	6	1,034,224 (97,606)^{a}	564,741 (102,419)^{a}	54.6
LNI#/Wairarapa	2	674,526 (373,858)^{ab}	428,962 (18,402)^{a}	45.4
Marlborough/AT^	6	593,834 (116,729)^{ab}	246,345 (48,970)^{b}	32.1
Canterbury	4	478,015 (131,087)^{b}	419,327 (289,175)^{a}	54.4
Otago	3	659,669 (101,596)^{ab}	344,777 (21,261)^{a}	37.2
NZ Average	27	876,065 (53,810)	420,361 (38,774)	40.4

*HB = Hawke's Bay, #LNI = Lower North Island, ^AT = Abel Tasman. Means with different subscripts within each column are different ($p<0.05$).

6.4.3 Assessing estimated energy requirement using Actical® Activity monitors

The Shapiro-Wilk test of normality showed that the energy requirement kcal/kg BW$^{0.75}$ was highly skewed (off-peak $p < 0.0001$, peak $p < 0.0001$). The natural log of the data was used to transform the skewed data to a symmetric distribution for further analysis. The Shapiro-Wilk test of normality then confirmed that the natural log of both off-peak and peak energy requirements (kcal/kg BW$^{0.75}$) were normally distributed ($p<0.5$ and $p<0.3$ respectively).

Factorial analysis showed that during off-peak periods, there were no differences between gender and breed in the amount of energy expended (kcal/kg BW$^{0.75}$) and there were no significant gender and breed interactions ($p>0.05$), there were significant regional differences ($p<0.05$). Table 6.8 below shows the regional differences in the energy requirements (kcal/kg BW$^{0.75}$) of both breeds of working dogs in NZ. There were regional differences in the amount of energy expended (kcal/d), with dogs in the Hawke's Bay region using more energy than dogs in Canterbury, Marlborough/AT and Otago ($p<0.05$). In addition, dogs in the LNI area used more energy than dogs in Marlborough/AT ($p<0.05$).

Statistical analysis of the natural log transformed data showed that there were no differences in gender or breed in the energy requirements of working farm dogs (kcal/kg BW$^{0.75}$) during peak periods ($p>0.05$). Also, there were no gender and breed interactions ($p>0.05$). There were significant differences ($p<0.05$) across regions during peak periods.

Table 6.8: Mean (±SEM) regional differences in the energy requirements (kcal/kg BW$^{0.75}$) of both breeds of working farm dogs during peak and off-peak periods.

Region	N	Peak (kcal/kg BW$^{0.75}$) Mean (±SEM)	Off-peak (kcal/kg BW$^{0.75}$) Mean (±SEM)
Gisborne	4	178^{ac} (21.9)	141^{ac} (10.8)
King Country	2	227^{bc} (7.3)	116^{bc} (5.4)
Central Plateau	8	222^{c} (42)	129^{c} (8.4)
HB*	10	217^{bc} (16.2)	156^{ac} (21.5)
LNI#/Wairarapa	4	214^{c} (31.9)	151^{a} (13.3)
Marlborough/AT^	12	194^{c} (25.7)	110^{b} (7.6)
Canterbury	8	169^{ac} (14.9)	116^{bc} (10.2)
Otago	6	214^{c} (29.4)	112^{b} (3.5)
NZ Average	54	202 (10.1)	128 (5.4)

*HB = Hawke's Bay, #LNI = Lower North Island, ^AT = Abel Tasman. Means with different subscripts within each column are different (p<0.05).

Table 6.9 and 6.10 below show the regional differences in the energy requirements of Heading and Huntaway dogs respectively.

Table 6.9: Mean (±SEM) regional differences in the energy requirement (kcal/kg BW$^{0.75}$) of Heading dogs during peak and off-peak periods.

		Energy requirement (kcal/kg BW$^{0.75}$)	
Region		Peak	Off-peak
	n	Mean (± SEM)	Mean (± SEM)
Gisborne	2	193^{ab} (45.2)	154^{a} (18.6)
King Country	1	234 (n/a)	122 (n/a)
Central Plateau	4	255^{ab} (78.2)	139^{a} (5.8)
HB*	4	254^{a} (29.4)	183^{a} (51.2)
LNI#/Wairarapa	2	234^{ab} (50.7)	173^{a} (5.6)
Marlborough/AT^	6	218^{ab} (49.3)	121^{b} (13.4)
Canterbury	4	181^{b} (29.7)	115^{b} (15.6)
Otago	3	238^{ab} (59.6)	109^{b} (6.2)
NZ Average	26	226 (18.2)	137 (9.5)

*HB = Hawke's Bay, #LNI = Lower North Island, ^AT = Abel Tasman. n/a – not applicable, as only one dog was sampled. Means with different subscripts within each column are different (p<0.05).

Table 6.10: Mean (±SEM) regional differences in the energy requirement (kcal/kg BW$^{0.75}$) of Huntaway dogs during peak and off-peak periods.

		Energy requirement (kcal/kg BW$^{0.75}$)	
Region		**Peak**	**Off-peak**
	n	**Mean (± SEM)**	**Mean (± SEM)**
Gisborne	2	162^{ab} (18.9)	128^{a} (3.3)
King Country	1	219 (n/a)	111 (n/a)
Central Plateau	3	177^{ab} (40.5)	115^{ab} (16.3)
HB*	6	192^{a} (11.4)	138^{a} (13.6)
LNI#/Wairarapa	2	195^{ab} (52.5)	128^{a} (1.5)
Marlborough/AT^	6	170^{ab} (15.8)	100^{b} (5.8)
Canterbury	4	157^{b} (7.8)	117^{a} (15.6)
Otago	3	191^{a} (14.4)	116^{b} (2.8)
NZ Average	27	179 (7.2)	122 (5.0)

*HB = Hawke's Bay, #LNI = Lower North Island, ^AT = Abel Tasman. n/a – not applicable, as only one dog was sampled. Means with different subscripts within each column are different (p<0.05).

The average off-peak energy requirements for Heading dogs over all regions was 137 ± 10 kcal/kg BW$^{0.75}$, compared with 122 ± 5 kcal/kg BW$^{0.75}$ for Huntaways. During peak periods, the energy requirements for Heading dogs was 226 ± 18 kcal/kg kcal/kg BW$^{0.75}$ and the energy requirements for the Huntaways was 179 ± 7 kcal/kg kcal/kg BW$^{0.75}$.

6.4.4 Comparison of energy requirements of farm dogs during two different seasons (2007-2008 and 2009-2010)

There were no differences in energy requirements (kcal·kg BW$^{0.75}$) between the two seasons for Heading or Huntaway dogs in Otago, Canterbury, LNI/Wairarapa, King Country or Gisborne (p>0.05). Table 6.11 and 6.12 show the regional differences in the energy requirement of the Heading and Huntaway dogs, respectively, for both seasons (2007-08 and 2009-10). Generally, the energy requirements during peak periods in 2009-10 were higher than 2007-08. Most of the energy requirements during off-peak periods were also higher in 2009-10.

Table 6.11: Mean (±SEM) regional, peak, off-peak and workload differences in energy requirements (kcal^{-1}·kg BW$^{0.75}$) of Heading dogs: a comparison between seasons 2007-2008 (in green) and 2009-2010 (in black).

Region		**Energy requirement (kcal^{-1}·kg BW$^{0.75}$)**	
		Peak	**Off-peak**
	N	**Mean (±SEM)**	**Mean (±SEM)**
Northland	2	233 (46)	168 (13)
Gisborne	2	172 (10)	113 (19)
Gisborne	2	193 (45)	154 (19)
King Country	2	164 (30)	136 (22)
King Country	1	234 (n/a)	122 (n/a)
Taranaki	2	177 (23)	146 (20)
Central Plateau	4	255 (78)	139 (6)
*HB/Taupo	4	170 (12)	144 (3)
*HB	4	254 (29)	183 (51)
#LNI/Wairarapa	6	225 (15)	169 (22)
#LNI/Wairarapa	2	234 (51)	173 (6)
Marlborough/^AT	6	218 (49)	121 (13)
Canterbury	2	215 (72)	122.1 (7)
Canterbury	4	181 (30)	115 (16)
Otago	2	173 (2)	120 (27)
Otago	3	238 (60)	109 (6)
Southland	2	147 (13)	126 (26)
NZ (2007/2008)	24	191 (9)	144 (7)
NZ (2009/2010)	26	226 (18)	137 (10)

^AT = Abel Tasman #LNI = Lower North Island, *HB = Hawke's Bay

Table 6.12: Mean (±SEM) regional, peak, off-peak and workload differences in energy requirements ($kcal^{-1} \cdot kg\ BW^{0.75}$) of Huntaway dogs: a comparison between years 2007-2008 (in green) and 2009-2010 (in black).

		Energy requirement ($kcal^{-1} \cdot kg\ BW^{0.75}$)	
Region		**Peak**	**Off-peak**
	N	**Mean (±SEM)**	**Mean (±SEM)**
Northland	2	126 (16)	101 (15)
Gisborne	2	165 (23)	110 (22)
Gisborne	2	162 (19)	128 (3)
King Country	3	146 (13)	119 (12)
King Country	1	219 (n/a)	111 (n/a/)
Central Plateau	3	177 (41)	115 (16)
Taranaki	2	124 (9)	96 (4)
*HB/Taupo	5	141 (14)	109 (9)
*HB	6	192 (11)	138 (14)
#LNI/Wairarapa	6	158 (14)	128 (6)
#LNI/Wairarapa	2	195 (52)	128 (1)
Marlborough/^AT	6	170 (16)	100 (6)
Canterbury	4	179 (23)	125 (8)
Canterbury	4	157 (8)	117 (16)
Otago	2	142 (9)	103 (22)
Otago	3	191 (14)	116 (3)
Southland	2	109 (3)	98.0 (14)
NZ (2007/2008)	28	148 (6)	114 (4)
NZ (2009/2010)	27	179 (7)	122 (5)

^AT = Abel Tasman #LNI = Lower North Island, *HB = Hawke's Bay

Statistical analysis of the natural log transformed data showed that there were no gender differences in the energy requirements of farm dogs in the season 2009-10 ($p>0.05$). However, there were significant gender and breed differences during the peak period in season 2007-2008, where female dogs had higher energy requirements than males ($p<0.05$), and Heading dogs had higher requirements than Huntaways ($p<0.05$). During 2007-08, the dogs lost weight from off-peak to peak periods, however in 2009-10 the dogs actually gained weight. In 2007-08, Heading dogs weighed an average of 19.94 kg during off-peak periods and 19.80 kg during peak periods, while Huntaways weighed an average of 31.88 kg during off-peak and 31.47 kg during peak periods. In 2009-10 Heading dogs weighed 21.72 kg during off-peak and 23.20 kg during peak periods, while Huntaways weighed 31.44 kg and 31.90 kg during off-peak and peak periods, respectively. The average weight of Heading dogs during off-peak and peak period, over both seasons was 20.8 ± 0.49 kg and 21.6 kg ± 0.75 kg respectively. The average weight of Huntaway dogs during off-peak and peak period, over both seasons was 31.6 ± 0.65 kg and 31.7 kg ± 0.64 kg respectively.

The relative proportions of female and male Heading and Huntaway dogs were not different between the two years (28% female: 72% male in both years). In 2007-08 the gender distribution of both breeds in the sample population was 15% (8) female Heading, 31% (16) male Heading, 14% (7) female Huntaway and 40% (21) male Huntaway, and in 2009-10, it was only slightly different (17% (9) female Heading, 32% (17) male Heading, 9% (5) female Huntaway and 41% (21) male Huntaway. Body score condition on a nine-point scale did not change dramatically between years, although dogs were 0.5 points leaner during off-peak periods in 2009-10 *vs.* 2007-08 (3.5 vs. 4.0) and had the same body condition scores during peak periods for both years (3.0 vs. 3.0).

The median age (± SEM) of the dogs varied between the two study years. In 2007-08, it was 3.75 ± 0.36 (range 1-12) years while in 2009-10 it was to 4.5 ± 0.25 (range 1.5-7.5) years.

When the energy requirements from both years were combined, statistical analysis of the natural log transformed data showed that there were no differences in gender and no gender and breed interactions for both the peak and off-peak periods (p>0.05). There were breed differences in the energy requirement for both the peak and off-peak periods (p<0.05), and there were differences between regions during off-peak (p<0.05), but not peak periods (p>0.05). Table 6.13 and 6.14 show that on average, Heading dogs generally worked harder than Huntaways during both the peak and off-peak periods (15% and 16% more respectively: p<0.01).

During peak periods the average energy requirement for Heading and Huntaway dogs in the North Island was 214 ± 12 and 163 ± 7 $\text{kcal}^{-1}\cdot\text{kg BW}^{0.75}$ while Heading and Huntaway dogs in the South Island used an average of 201

± 20 and 164 ± 8 $\text{kcal}^{-1}\cdot\text{kg BW}^{0.75}$. The overall average energy requirement for Heading dogs in NZ during peak periods was 209 ± 11 $\text{kcal}^{-1}\cdot\text{kg BW}^{0.75}$ and for Huntaways it was 163 ± 5 $\text{kcal}^{-1}\cdot\text{kg BW}^{0.75}$.

Generally, working farm dogs across NZ required an average of 30% more energy from their diets during peak periods compared with off-peak periods. Heading dogs and Huntaways in the North Island required 28% and 26% more energy than during off-peak periods, and Heading dogs and Huntaways in the South Island required 41% and 33% more energy from their diets in peak periods compared with off-peak periods.

During off-peak periods there were differences between the energy requirements ($p<0.05$), with dogs in the LNI having higher energy requirements (26%) than dogs in Southland, and dogs in the Hawke's Bay region having higher energy requirements (23%) than dogs in Otago. There were also differences between the energy requirement during the off-peak period ($p<0.01$), with dogs in the LNI/Wairarapa requiring more energy from their diet than dogs in Canterbury, Marlborough/AT and Otago (21%, 26% and 27% more respectively). Dogs in the Hawke's Bay region also had higher energy requirements (22%) than dogs in Marlborough/AT ($p<0.01$).

Table 6.13: Mean (±SEM) regional differences in the energy requirement (kcal^{-1}·kg BW$^{0.75}$) of Heading dogs during peak and off-peak periods in 2007-08 and 2009-10.

Region		**Energy requirement (kcal^{-1}·kg BW$^{0.75}$)**	
		Peak	**Off-peak**
	N	**Mean (±SEM)**	**Mean (±SEM)**
Northland	2	237.3^{a} (48.1)	170.7^{b} (13.3)
Gisborne	4	185.2^{a} (20.6)	135.1^{b} (16.6)
King Country	3	190.6^{a} (30.0)	132.2^{b} (14.1)
Taranaki	2	180.2^{a} (24.1)	148.1^{b} (20.4)
Central Plateau	4	261.0^{b} (80.9)	139.9^{a} (6.1)
*HB	8	215.2^{a} (21.9)	165.7^{ab} (25.7)
$^{\#}$LNI/Wairarapa	8	231.5^{ab} (15.5)	173.0^{b} (17.2)
Marlborough/^AT	6	222.4^{a} (51.1)	121.2^{ab} (13.8)
Canterbury	6	195.6^{a} (28.3)	117.7^{b} (10.4)
Otago	5	213.9^{a} (38.3)	115.7^{b} (11.8)
Southland	2	148.5^{b} (13.0)	127.2^{a} (26.7)
NZ Average	50	212.8 (11.0)	142.2 (6.3)

^AT = Abel Tasman, $^{\#}$LNI = Lower North Island, *HB = Hawke's Bay. Means with different subscripts within each column are different (p<0.05).

Table 6.14 Mean (±SEM) regional differences in the energy requirement (kcal^{-1}·kg BW$^{0.75}$) of Huntaway dogs during peak and off-peak periods in 2007-08 and 2009-10.

Region		**Energy requirement (kcal^{-1}·kg BW$^{0.75}$)**	
		Peak	**Off-peak**
	N	**Mean (±SEM)**	**Mean (±SEM)**
Northland	2	127.4^{ab} (16.7)	100.8^{b} (16.0)
Gisborne	4	166.3^{b} (12.8)	120.1^{b} (10.8)
King Country	4	166.6^{a} (21.2)	117.9^{ab} (9.1)
Taranaki	2	125.1^{b} (125.1)	96.3^{b} (96.3)
Central Plateau	3	179.8^{b} (42.0)	115.9^{a} (17.0)
*HB	11	171.3^{ab} (12.1)	126.1^{ab} (9.6)
$^{\#}$LNI/Wairarapa	8	169.4^{ab} (16.0)	129.2^{ab} (4.6)
Marlborough/^AT	6	172.8^{a} (16.4)	100.3^{b} (6.1)
Canterbury	8	169.7^{ab} (12.9)	122.6^{a} (8.5)
Otago	5	173.9^{b} (15.1)	111.4^{a} (8.1)
Southland	2	107.4^{ab} (112.6)	83.3^{b} (112.5)
NZ Average	55	162.5 (6.0)	115.2 (3.7)

^AT = Abel Tasman, $^{\#}$LNI = Lower North Island, *HB = Hawke's Bay. Means with different subscripts within each column are different (p<0.05).

6.4.5 Accuracy of GPS collars

The accuracy of the GPS collar used for the Huntaways was determined using a static test (Section 6.2.7). The results from the test are shown in Figure 6.7. The test showed that 70% of the readings (1898 out of 2712) over 48 h were within 15.4 m of the central point, and 95% (2576 out of 2712) of readings were within 32.2 m. Therefore, the test established that 95% of the time the true position of each Huntaway dog will be within a radius of 32.2 m from the recording given by the GPS collar.

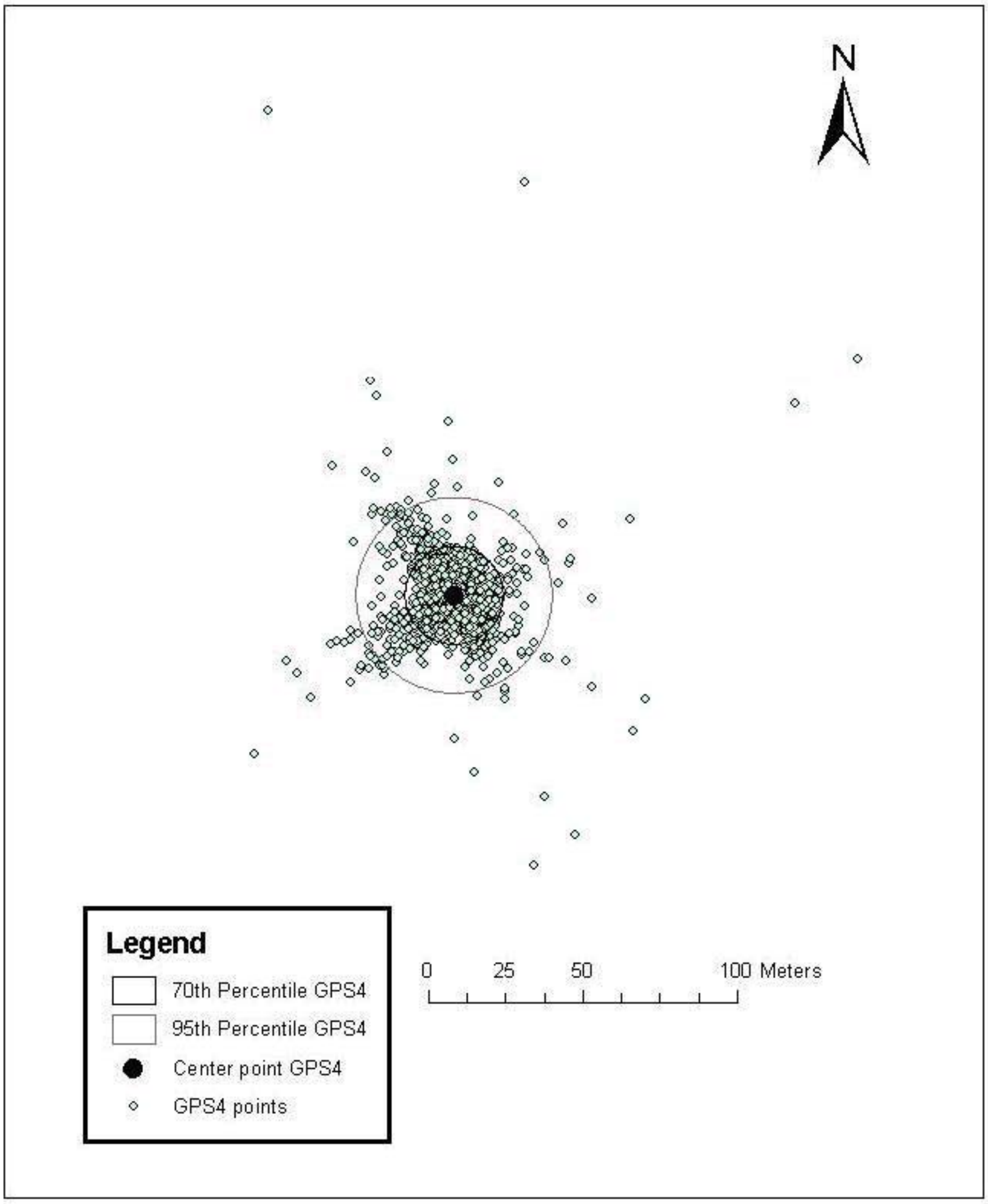

Figure 6.7: Static GPS test showing data points without differential correction for the Huntaway dog unit. 2,712 readings were recorded over 48 h of continuous use. The inner circle enclosed 70% of readings and has a radius of 15.4 m. The outer circle enclosed 95% of readings and has a radius of 32.2 m.

The accuracy of the GPS collar used for the Heading dogs was determined using the same static test. Results from this study are shown in Figure 6.8. The test showed that 70% of the readings (1960 out of 2800) over 48 h were within 17.3 m of the central point and 95% (2660 out of 2800) of readings were within 35.4 m of the central point. Therefore, for the second collar, 95% of the time the true position of the Heading dog will be within a radius of 35.4 m from the recording given by the GPS collar.

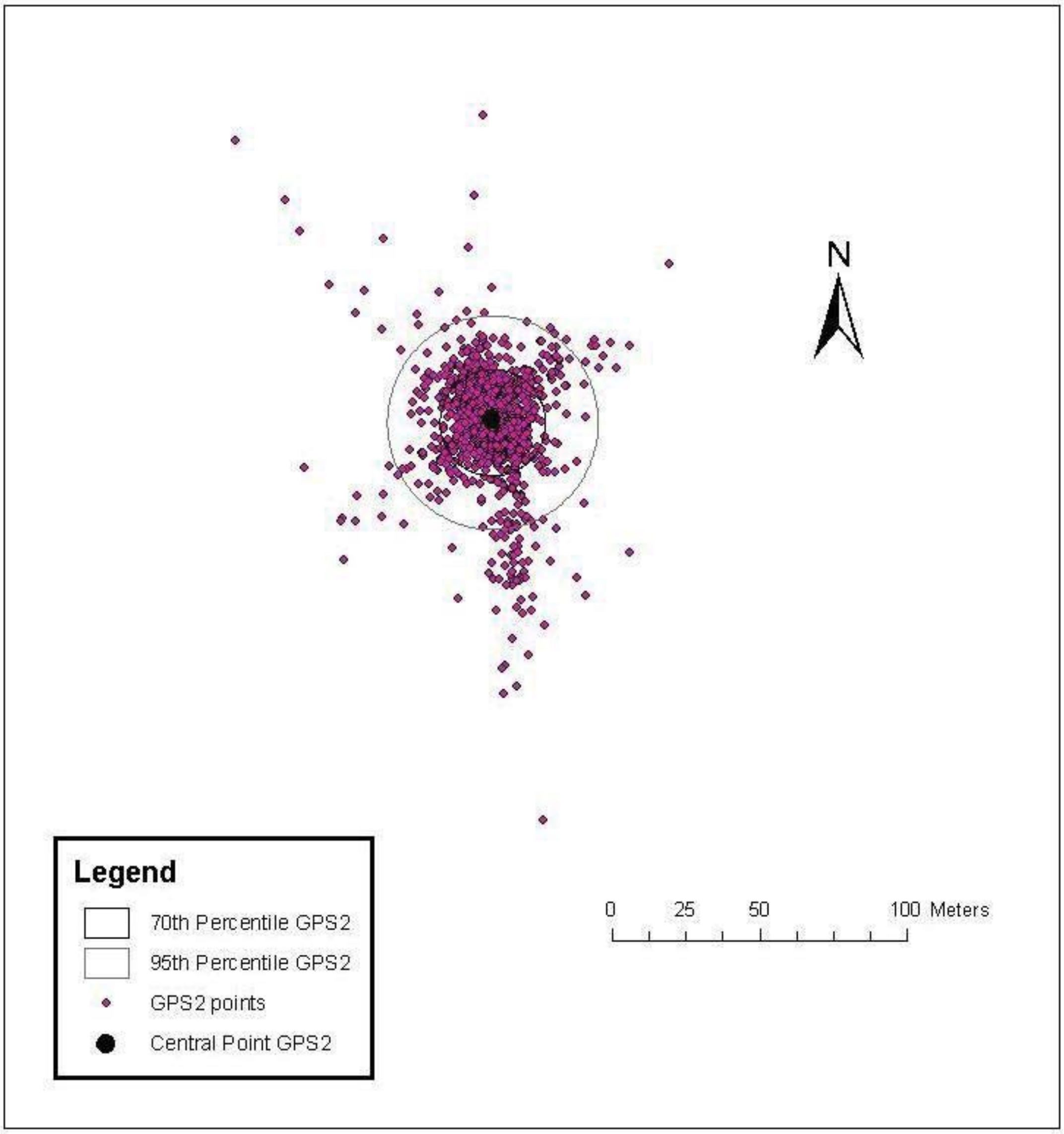

Figure 6.8: Static GPS test showing data points without differential correction for the Heading dog unit. 2,800 readings were recorded over 48 hrs of continuous use. The inner circle enclosed 70% of readings and has a radius of 17.3 m. The outer circle enclosed 95% of readings and has a radius of 35.4 m.

6.4.5.1 GPS Distance and speed data

The data from the GPS collars showed that dogs covered 10 ± 0.7 km/d during off-peak periods and 20 ± 1.3 km/d during peak periods. The average distance covered by the different breeds did not differ ($p > 0.05$).

Paired t-tests showed that there were no differences ($p > 0.05$) between the proportion of workload (off-peak/peak) and the proportion of distance covered (off-peak/peak), meaning that the proportions of energy expended between peak and off-peak periods corresponded to the proportion of distance that the dogs covered between the two periods. Table 6.15 shows that Heading dogs covered an average of 2.8 km/h during peak periods, suggesting for example, over an 8 h working day, these dogs can cover up to 22.4 km. Similarly, Table 6.16 shows that Huntaways covered up to 2.5 km/h during peak periods, suggesting over an 8 h working day they can cover between 19 to 20 km. Heading dogs and Huntaways on farms in the Gisborne region covered the least distance in an hour (1.8 km/h), which corresponded to 14.4 km during an 8 h working day.

Data from GPS, in association with discussions with farmers established that dogs were frequently given a ride up to the paddock on utility vehicles or quad bikes and the dogs then drove the sheep down the hill. Mustering sessions lasted between 2 – 4 h and on the steepest farm studied, dogs travelled down an altitude of 1,000 m, whereas the shortest distance travelled by dogs during peak periods was a difference in altitude of 50 m in Canterbury.

Table 6.15 Mean total energy expenditure (TEE) (kcal/d) and mean speed (km/h) of Heading dogs during peak and off-peak periods in different regions.

		Workload per day (kcal/day)			Average Speed (km/h)		
Region	**N**	**Peak**	**Off-peak**	**workload (% of peak)**	**Peak**	**Off-peak**	**Relative speed (% of peak)**
Gisborne	2	1,928	1,537	79.7	1.8	1.2	68
King Country	1	2,253	1,173	52.1	2.8	0.7	23.6
Central Plateau	4	2,268	1,390	61.3	2.2	1	48.0
HB*	4	2,526	1,705	67.5	2	1.1	53.8
LNI/Wairarapa#	2	2,212	1,612	72.9	2.2	1.7	77.4
Marlborough/AT^	6	2,195	1,163	53.0	1.9	1.1	57.3
Canterbury	4	2,060	1,183	57.4	1.9	0.9	44.3
Otago	3	2,647	1,235	46.7	2.8	1.4	50.0
NZ Average	26	2,272	1,357	59.7	2.1	1.1	52.4

*HB = Hawke's Bay, #LNI = Lower North Island, ^AT = Abel Tasman

Table 6.16 Mean total energy expenditure (TEE) (kcal/d) and mean speed (km/h) of Huntaways during peak and off-peak periods in different regions.

		Workload per day (kcal/day)			Average Speed (km/h)		
Region	**N**	**Peak**	**Off-peak**	**workload % of peak**	**Peak**	**Off-peak**	**Relative speed (off-peak % of peak)**
Gisborne	2	2,310	1,816	78.6	1.8	1.1	61.2
King Country	1	3,088	1,831	59.3	2.5	1.6	64.5
Central Plateau	3	2,278	1,492	65.5	2.3	1.1	48.1
HB[*]	6	2,651	1,880	70.9	2.2	1.4	62.0
LNI[#]/Wairarapa	2	2,454	1,521	62.0	2	1.6	79.1
Marlborough/AT^	6	2,165	1,277	59.0	2	1.3	62.2
Canterbury	4	2,248	1,663	74.0	2.3	1.1	48.8
Otago	3	2,434	1,390	57.1	2.4	1.1	47.2
NZ Average	27	2,336	1,571	67.3	2.1	1.2	57.1

*HB = Hawke's Bay, [#]LNI = Lower North Island, ^AT = Abel Tasman

The average farm size in each region in the current study and the average total number of dogs on each farm are shown in Table 6.17. The largest farm in the study was in the King Country (30,351 ha), and it also had the highest number of dogs working on it (n = 48). The smallest farm in this study was in the Central Plateau (121 ha), and had the lowest number of dogs working on it (n = 4). The highest altitude that dogs worked in the study was on a farm in Otago (200 - 1460 m above sea level), and dogs covered 0.4 km/h more on this farm than the average of dogs in farms in all other regions of the country. The lowest altitude that dogs worked in this study was on a farm in Canterbury (100 - 150 m above sea level).

Table 6.17 Comparison of farm feature (farm size and total number of dogs per farm) and workload (mean energy requirement and mean speed) of dogs during peak and off-peak periods across different regions.

Region	Farm size (ha:n)	Average dog number per farm	Altitude covered (m above sea level)	Peak		Off-peak	
				Energy requirement (kcal/kg $BW^{0.75}$)	Speed (km/h)	Energy requirement (kcal/kg $BW^{0.75}$)	Speed (km/h)
Gisborne	1,549 (2)	18	300	178	1.8	141	1.2
King Country	30,351 (1)	48	155	227	2.6	116	1.1
Central Plateau	3,317 (4)	15	107	222	2.3	129	1.1
HB*	1,988 (5)	19	304	217	2.1	156	1.3
LNI#/Wairarapa	1,367 (2)	9	310	214	2.1	151	1.7
Marlborough/AT^	1,229 (6)	9	411	194	1.9	110	1.2
Canterbury	1,130 (4)	15	319	169	2.1	116	1
Otago	12,100 (3)	13	538	214	2.6	112	1.3
NZ Average	3,984 (27)	16	321	202	2.2	128	1.1

*HB = Hawke's Bay, #LNI = Lower North Island, ^AT = Abel Tasman

6.5 Discussion

It is difficult to quantify the energy expenditure and therefore the energy requirements of free-living subjects, especially ones that are running around the isolated farmland in NZ. However, new and innovative technology that has recently emerged has enabled studies to be carried out that would have been unachievable a few years ago. Until now there has been a lack of data in the literature about the energy requirements, and the workload of working farm dogs. By using activity monitors and GPS collars on dogs, we have been able to estimate the energy requirements, gather information on the workload of Heading and Huntaway dogs in NZ, and look at regional differences in work patterns. The limitation of the study in chapter four was that there was a limited range of body weights studied, therefore this equation may not be suitable for dogs either lighter that 18 kg and heavier than 26 kg. Therefore energy requirements using activity monitors maybe inaccurate and result in over or underestimating food requirements. However, farmers generally feed dogs to visual body cues and will adjust feeding as needed.

As expected, the mean energy requirements for Heading dogs and Huntaways changed according to peak and off-peak periods, with dogs requiring more energy from their diets during peak periods. Previous studies in other dog breeds have shown that Greyhounds require between 150-190 kcal/kg BW$^{0.75}$ (Grandjean and Paragon, 1993; Hill *et al.*, 2000) and sled dogs require between 120-137 kcal/kg BW$^{0.75}$ while training (5-8 km/d: Durrer and Hannan, 1962; Grandjean and Paragon, 1993; Brown *et al.,* 2009). A 20 kg sled dog participating in the Iditarod race can expend between 9000 - 11200 kcal/d (Grandjean and Paragon, 1993; Hinchcliff *et al.*, 1996), which is equivalent to 950-1184 kcal/kg BW$^{0.75}$ and can be considered a measure of extreme physical activity. Campbell and Donaldson (1981) found that Antarctic sled dogs travelling 10.9 km/d over a gently-undulating ice-shelf, at an average temperature of -19.8 °C and a mean wind speed of 6.4 m/s had a total energy expenditure of 413 kcal/kg BW$^{0.75}$. The amount of energy expended by Heading dogs and Huntaways in NZ is equivalent to sled dogs training over distances of 5 – 8 km/d during off-peak periods, and equivalent to sled dogs training over distances of 10 – 20 km/d during peak periods. The energy requirements of working farm dogs in NZ are similar to racing Greyhounds, where farm dogs during peak periods may require between 179 to 226 kcal/kg BW$^{0.75}$ and Greyhounds require between 150-190 kcal/kg BW$^{0.75}$ (Grandjean and Paragon, 1993; Hill *et al.*, 2000). Therefore as a rough estimate, the requirements of NZ farm dogs are similar to racing Greyhounds and sled dogs in training for longer races, but considerably lower than the Iditarod level of energy expenditure.

The distances covered by farm dogs in this study (10 ± 0.7 km/d during off-peak periods and 20 ± 1.3 km/d during peak periods) also corresponded to distances that sled dogs cover while training (Grandjean and Paragon, 1993a), and they are also similar to data obtained from Australian cattle dogs. Hampson and McGowan (2007) found that farm dogs in Australia covered distances between 13.3 and 30.2 km during a mustering session (ranging from 1 h 59 min to 4 h 24 min), with an average distance covered of 20.1 ± 5.6 km during a mustering session. The maximum working speed of these dogs was 43.7 km/h and the average maximum speed was 34 ± 5.1 km/h. The mustering sessions in the study in Australia lasted between 1 h 59 min to 4 h 24 min, with an average of 3 h 2 min. Although mustering sessions in NZ take a similar length of time (2 to 4 h from data obtained from activity monitors and GPS data), farm dogs in NZ are also used to control flock in yards, and the majority of data obtained in this study showed dogs in NZ were actively working for 8 – 10 hours a day during the three day monitoring period. Generally, farmers use their dogs to muster in the early morning and/or early evening, to avoid the hottest part of the day and shearing and yard work is generally performed between mustering sessions (I. Singh, personal obs).

This study has assumed an 8 h working day, as different farms worked different hours and even the same farm worked different hours on different days. This appeared to be dependent on weather and when shearers/veterinarians were available. In order to compare between regions, distance data obtained from the GPS collars were transformed to distance travelled per hour, because dogs that worked for longer covered more distance than dogs that could only work half a day due to the weather.

An interesting finding was that when comparing North and South Islands, for TEE, dogs in the North Island had higher energy expenditures than in the South Island, yet dogs in the North Island covered less distance. The GPS were programmed to record at 30 second intervals which is relatively insensitive and may have produced large errors when added to the collar GPS 95% confidence interval. This error may have missed much of the Heading dogs movements involved in the type of work they perform. For instance, sprinting after a stray sheep to get it back in the flock, this may take less than 30 seconds. Also Heading dogs weave from side to side behind the flock; again this can occur within 30 seconds. All of these movements may have been missed. There was a compromise with data collection using the GPS collars; the choice was either collecting 12 hours of data for 3 days, to give a total of 36 h data collection, or a shorter length between reading, and fewer hours of data. In order to obtain a representative distance and altitude covered, it was critical to get more hours of work data rather than to capture the intricate working behavioural information of the farm dogs in NZ. However, this study has indicated that GPS may be a way to establish the working behaviour of a dog, however shorter interval between records is required (i.e. shorter than 30 seconds).

The GPS units had an accuracy of 32.2 m for the Huntaway unit and 35.4 m for the Heading dog unit. This means we can be 95% sure that the dog was within the 32.2 or 35.4 m radius of the co-ordinates obtained by the GPS collar. This is referred to as the circular error probable (Turner *et al.,* 2000) and is a measure of static accuracy. This assessment of GPS error focuses on the individual co-ordinates relative to their true position and is not a measure of distance, which was the focus in this study. Many GPS units have better dynamic accuracy than static accuracy (Werner *et al.,* 2003). Ganskopp and Johnson (2002) suggest that when the collars are moved 10 to 90 m, the GPS error is almost zero. They found that there are a series of over and underestimations of distance measured from dynamic units that compensate for one another over time. They also suggested that with stationary collars, the GPS error does not have the opportunity to even out, suggesting that the units used in this study likely had better accuracy than that found in the static accuracy assessment. Therefore the GPS collars used in this study may not be as inaccurate as suggested by the static accuracy test. Another potential error was if three or less satellites were used to generate a GPS co-ordinate. In this study all data collected that had three or less satellites was discarded. This is because satellite availability affects the precision of GPS location, and it is preferable to use data where there are more than three satellites available (Wells, 1986; Moen *et al.,* 1997). Steiner *et al.* (2000) also found that satellite quality affected tracking of dogs and caused imprecise position fixes. It is unclear why there are inconsistencies in the distance and energy expenditure data, perhaps dynamic accuracy of these collars were not as accurate as studies that have used a different type of GPS collar.

Activity monitors were used in this study to measure activity and energy expenditure in working farm dogs. In this study, we could not distinguish between running and walking with the activity monitors, to establish this would require further studies. The study showed that Heading dogs are more active than Huntaways in peak periods. The results from 2009-10, were similar to results from 2007-08 (Chapter 5) and also showed that Heading dogs were more active than Huntaway dogs during both peak and off-peak periods. Heading dogs and Huntaways were generally more active during the 2009-10 season than the 2007-08 season and accumulated more activity counts during both peak and off-peak periods.

Estimated TEE in 2009-10 during the off-peak period was 1,369 ± 82 kcal/d and 1,583 ± 73 kcal/d for Heading dogs and Huntaways respectively. During peak periods, the energy requirements increased to 2,313 ± 138 kcal/d and 2,375 ± 84 kcal/d for Heading dogs and Huntaways respectively. There was higher variation in the estimated TEE during the peak period than the off-peak period in both breeds. This is reflective of the different amounts of work that each individual dog did. Each farm had a different terrain, size and number of stock units and it is therefore reasonable to assume that the amount of work between farms varied; especially in peak periods as the large SEM suggests.

There were significant regional differences in the estimated TEE during off-peak periods. Dogs in the Hawke's Bay region expended higher amounts of energy than Canterbury, Otago ($p<0.05$) and Marlborough/AT ($p<0.01$), and dogs in Gisborne used higher amounts of energy than Marlborough/AT ($p<0.05$). The regions with the highest and lowest energy expenditure during off-peak period were Hawke's Bay and Marlborough/AT, respectively. During peak periods there were significant regional differences, with Hawke's Bay, Otago and King Country regions expending higher amounts of energy than Gisborne, Canterbury and Marlborough/AT ($p<0.05$). The farms in Hawke's Bay were 1,988 ha in size on average and they had an average of 19 dogs working on them. In Marlborough/AT the average farm size was 1,229 ha and they had on average only nine dogs working on them, therefore a dog in Marlborough/AT dogs was responsible for 137 ha while each dog in Hawke's Bay covered 104 ha. Dogs in the Hawke's Bay region covered 0.1 km/h less than those in Marlborough/AT during off-peak periods (1.3 *vs.* 1.2), suggesting that dogs in Hawke's Bay theoretically expended less energy.

When metabolic bodyweight is taken into account and energy requirements are expressed as an allometric equation, there were no significant differences between genders, breeds and regions during peak work periods. The two different breeds of dogs have different temperaments, the Heading dog is generally a nervous dog, and this helps with its ability to effectively herd sheep. However, this trait also means that the Heading dog moves more than the more relaxed Huntaway. This is also reflected in the different ways these two different breeds work, the Huntaway typically barks to sheep and can control the flock from some distance away. The Heading dog controls stock with its body position in relation to the stock, *i.e.* by staring down stock, therefore has to constantly be moving around to control the mob of sheep and therefore covering larger distances than the Huntaway.

During off peak periods of work, there were no significant breed or gender differences, but there were regional differences in energy requirements, with dogs in the Lower North Island (including Wairarapa) requiring the most energy (156 ± 22 kcal/kg $BW^{0.75}$) and Marlborough including Abel Tasman requiring the least (110 ± 13 kcal/kg $BW^{0.75}$) in 2009-10. It is difficult to make conclusions about why there are regional differences. It was interesting that when the two seasons were combined; Heading dogs in the South island required 45% more energy during peak work periods than off-peak periods (compared to 34% more energy in dogs in the North Island).

This study has shown that when data for the two years (2007-08 and 2009-10) were combined, the average energy requirements for Heading dogs and Huntaways changed according to peak and off-peak periods, with dogs requiring more energy from their diets during peak periods.

It was interesting that the farm sampled in King Country had the largest average farm size (30,351 ha), the most dogs per farm (48) and each covered the greatest distance (2.6 km/h). Although dogs in this region had a higher than average energy requirement, it was not the region with the highest energy requirement. Farms in the Central Plateau were smaller than the average farm size studied (3,317 ha vs. 3,984 ha), and the dogs had above national average running/walking speed (2.3 km/h), and appeared to work in the flattest terrain (relative to sea level), yet the dogs had the highest estimated workload during peak periods of work. The reason for the differences in energy expenditure is unclear and further concentrated research needs to be conducted into regional differences in energy requirements and if or how terrain and size of farm affects these requirements.

There was no correlation between the amount of work a dog carried out and the relative altitudes that the dogs worked at. However, a major factor affecting this could be the way each farm was managed. As mentioned previously (Section 2.5.4 and this chapter), larger farms have established tracks that vehicles can be driven on and as technology has advanced, farmers now have the option of using a quad bike that dogs can sit on, or trailers for the dogs which are towed behind the bike (Figure 6.5). Therefore, dogs use less energy by not having to run up hills to get to the paddocks containing the sheep.

This study has used emerging technology, such as activity monitors and GPS units to show ‘how hard’ a working farm dog works. Factors such as farm size, the altitude that the dog covers in a day, the number of stock and the number of shepherds working on the farm all affect the amount of work a single dog does. Further work needs to be conducted in order to further refine the energy requirements of the working dogs and also if the range in altitude covered in a day affects energy requirements.

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6.7 Appendix 1: Individual farm sizes, terrain and maximum height above sea level

Region	Farm size (ha)	Terrain	Maximum height (m above sea level)
Gisborne	2,717	Hill	300
	380	Hill	500
King Country	30,351	Mixed	175
Central Plateau	8,700	Mixed	800
	121	Mixed	500
	445	Hill	729
	4,000	Hill	900
*HB	809	Mixed	440
	631	Mixed	220
	2,833	Hill	100
	4,046	Hill	300
	1,619	Hill	1000
#LNI/Wairarapa	2,023	Mixed	400
	710	Hill	500
Marlborough/^AT	800	Hill	290
	800	Hill	200
	1,457	Hill	452
	1,214	Hill	958
	1,600	Hill	180
	1,500	Hill	935
Canterbury	364	Hill	370
	1,255	Mixed	400
	500	Mixed	150
	2,400	Mixed	707
Otago	24,000	Hill	1,460
	8,500	Mixed	600
	3,800	Mixed	662

^AT = Abel Tasman, #LNI = Lower North Island, *HB = Hawke's Bay

Appendix 2: Raw data for all dogs using BMR = 76 × $BW^{0.75}$ during off-peak period of work

Region	Breed	Gender	Weight (kg)	Activity counts per day	BMR (kcal/d)	AEE (kcal/day)	EE (kcal/day)	Speed (km/h)
Gisborne	Heading	M	22.0	661,372	772	1,011	1,783	0.98
	Heading	M	20.7	414,386	738	592	1,329	1.48
	Huntaway	M	33.0	469,869	1,046	686	1,732	1.21
	Huntaway	M	35.6	552,472	1,108	826	1,934	1.03
King Country	Heading	M	20.5	329,787	732	448	1,180	0.66
	Huntaway	M	42.0	412,503	1,254	588	1,842	1.61
Central Plateau	Heading	M	27.1	568,504	903	854	1,756	1.97
	Heading	F	23.7	484,554	816	711	1,527	0.86
	Heading	F	13.5	256,794	535	324	859	0.34
	Heading	M	21.5	486,199	759	714	1,472	1.03
	Huntaway	M	29.0	515,811	950	764	1,714	1.83
	Huntaway	M	37.1	527,426	1,142	784	1926	1.29
	Huntaway	F	23.0	105,681	798	67	865	0.08
***HB**	Heading	F	16.9	303,421	633	403	1,036	
	Heading	M	24.0	467,886	824	682	1,507	0.99
	Heading	F	17.2	1,399,268	642	2,266	2,908	1.59
	Heading	F	24.3	443,883	832	642	1,473	0.61
	Huntaway	M	42.0	234,564	1,254	286	1,540	0.83
	Huntaway	M	36.0	481,483	1,117	706	1,823	1.06
	Huntaway	F	33.	886,678	1,056	1,394	2,450	1.37

	Huntaway	F	32.0	349,167	1,023	481	1,503	0.61
	Huntaway	M	26.1	691,084	878	1,062	1,940	2.26
	Huntaway	F	30.7	745,469	991	1,154	2,146	2.11
#LNI/Wairarapa	Heading	M	21.8	694,923	767	1,068	1,835	1.61
	Heading	M	17.2	533,507	642	794	1,436	1.87
	Huntaway	M	27.8	457,031	920	664	1,584	1.58
	Huntaway	M	26.3	420,227	883	601	1,484	1.58
Marlborough/^AT	Heading	M	26.5	283,780	888	369	1,257	0.44
	Heading	M	24.0	274,361	824	353	1,178	
	Heading	M	21.2	174,241	751	183	934	1.04
	Heading	M	17.5	634,136	650	965	1,615	1.31
	Heading	F	18.0	265,508	664	338	1,003	1.56
	Heading	M	19.0	263,602	692	335	1,027	1.06
	Huntaway	M	27.0	234,666	900	286	1,186	0.58
	Huntaway	F	28.0	180,900	925	195	1,120	1.95
	Huntaway	M	37.6	313,910	1,154	421	1,575	0.90
	Huntaway	M	30.7	458,830	991	667	1,658	1.70
	Huntaway	M	24.0	116,441	824	85	909	1.43
	Huntaway	M	30.2	211,990	979	247	1227	0.95
Canterbury	Heading	F	20.8	542,427	740	809	1549	0.47
	Heading	F	25.3	198,085	857	224	1081	0.79
	Heading	M	21.6	131,533	761	111	872	1.07
	Heading	M	22.7	337,131	790	460	1251	1.12

Otago	Huntaway	M	37.4	183,150	1,149	198	1348	1.06
	Huntaway	M	32.5	506,026	1,034	747	1782	1.04
	Huntaway	M	30.4	204,890	984	235	1219	1.09
	Huntaway	M	36.7	783,240	1,133	1,219	2352	1.24
	Heading	F	31.1	223,603	1,001	267	1268	1.48
	Heading	M	22.6	298,800	788	395	1183	1.11
	Heading	M	24.0	325,463	824	440	1264	1.58
	Huntaway	M	26.1	340,451	878	466	1343	1.57
	Huntaway	M	27.8	396,214	920	561	1481	1.12
	Huntaway	M	28.1	326,667	928	442	1370	0.73

^AT = Abel Tasman, #LNI = Lower North Island, *HB = Hawke's Bay

Appendix 3: Raw data for all dogs using BMR = 76 × BW$^{0.75}$ during peak period of work

Region	Breed	Gender	Weight (kg)	Activity counts per day	BMR (kcal/d)	AEE (kcal/day)	EE (kcal/day)	Speed (km/h)
Gisborne	Heading	M	22.0	1,066,066	772	1,699	2,471	0.08
	Heading	M	20.7	486,310	738	714	1,451	0.00
	Huntaway	M	33.0	628,000	1,046	955	2,001	0.06
	Huntaway	M	35.6	996,772	1,108	1,582	2,689	0.05
King Country	Heading	M	20.5	988,122	732	1,567	2,299	0.14
	Huntaway	M	34.0	1,291,047	1,070	2,082	3,152	0.07
Central Plateau	Heading	M	26.7	982,923	893	1,558	2,451	0.12
	Heading	F	23.5	587,660	811	886	1,697	0.08
	Heading	F	12.5	1,730,721	505	2,829	3,335	0.00
	Heading	M	22.0	655,158	772	1,001	1,773	0.07
	Huntaway	M	28.7	1,434,560	942	2,326	3,268	0.11
	Huntaway	M	37.5	671,947	1,152	1,029	2,181	0.04
	Huntaway	F	25.5	440,252	862	635	1,498	0.08
***HB**	Heading	F	19.0	847,458	692	1,328	2,019	0.11
	Heading	M	23.0	797,154	798	1,242	2,040	0.08
	Heading	F	19.0	1,305,544	692	2,106	2,798	0.09
	Heading	F	24.4	1,565,534	834	2,548	3,383	0.09
	Huntaway	M	40.0	1,287,210	1,209	2,075	3,284	0.05
	Huntaway	M	34.0	698,409	1,070	1,074	2,144	0.04
	Huntaway	F	36.3	1,305,747	1,124	2,107	3,231	0.05
	Huntaway	F	32.9	846,655	1,044	1,326	2,370	0.08
	Huntaway	M	23.4	1,025,695	809	1,631	2,439	0.11
	Huntaway	F	34.2	1,041,627	1,075	1,658	2,733	0.08
[#]LNI/Wairarapa	Heading	M	21.4	1,325,635	756	2,141	2,897	0.12
	Heading	M	17.9	629,393	661	957	1,618	0.11
	Huntaway	M	28.3	1,340,497	933	2,166	3,098	0.08
	Huntaway	M	31.2	592,780	1,003	895	1,898	0.06

Marlborough/^AT	Heading	M	25.0	533,925	850	795	1,644	0.06
	Heading	M	29.4	590,506	960	891	1,850	0.04
	Heading	M	22.8	645,993	793	985	1,778	0.09
	Heading	M	17.5	2,044,420	650	3,363	4,013	0.21
	Heading	F	25.0	657,429	850	1,005	1,854	0.07
	Heading	M	20.6	974,174	735	1,543	2,278	0.07
	Huntaway	M	28.0	1,297,924	925	2,094	3,019	0.04
	Huntaway	F	23.8	480,655	819	704	1,523	0.10
	Huntaway	M	39.2	712,303	1,191	1,098	2,289	0.08
	Huntaway	M	30.7	912,937	991	1,439	2,430	0.07
	Huntaway	M	26.0	631,350	875	960	1,835	0.06
	Huntaway	M	32.1	696,285	1,025	1,071	2,096	0.06
Canterbury	Heading	F	19.2	1,079,141	697	1,722	2,419	0.13
	Heading	F	49.9	659,906	1,427	1,009	2,436	0.05
	Heading	M	22.0	807,942	772	1,261	2,033	0.05
	Heading	M	22.7	472,883	790	691	1,481	0.08
	Huntaway	M	34.8	897,520	1,089	1,413	2,502	0.08
	Huntaway	M	35.1	826,914	1,096	1,293	2,389	0.08
	Huntaway	M	32.0	546,950	1,023	817	1,839	0.05
	Huntaway	M	36.7	809,125	1,133	1,263	2,396	0.06
Otago	Heading	F	29.0	618,973	950	939	1,889	0.09
	Heading	M	23.4	949,414	809	1,501	2,310	0.15
	Heading	M	24.0	1,880,864	824	3,085	3,909	0.10
	Huntaway	M	32.0	1,013,384	1,023	1,610	2,632	0.06
	Huntaway	M	29.9	753,292	972	1,168	2,139	0.11
	Huntaway	M	27.9	1,088,667	923	1,738	2,660	0.07

^AT = Abel Tasman, #LNI = Lower North Island, *HB = Hawke’s Bay

CHAPTER SEVEN:

Overall discussion

In New Zealand (NZ), working farm dogs are essential for the efficient running of the farm. These dogs are bred especially to perform the work they do. For years working dog nutrition and welfare have been over-looked by scientists. Recently there has been an increase in literature looking at the health and welfare of working dogs in NZ (Jerram, 2005; Worth & Bruce, 2008; Cave et al., 2009; Doyle et al., 2009; Hill et al., 2009; Jerram et al., 2009: Worth et al., 2009). Much of the published literature has focused on the health of working dogs and therefore, the feeding practices, apparent digestibility of the diets currently fed and energy requirements of working farm dogs until now have been unknown.

The work described in Chapter Two of this thesis aimed to establish background information regarding the working farm dog population in New Zealand (NZ). From a survey of a population of 2,861 working dogs we estimated that there are approximately 81,000 to 82,000 working farm dogs on sheep and beef farms in NZ (this excludes other types of farms, such as dairy, deer etc.), with at least 43,000 Heading dogs and 33,000 Huntaway dogs. This study revealed that the median age of the working dog in 2007 was 3.0 years old. A subsequent sub-sampling in 2008 and 2009 showed that the average age of a much smaller sub-population was slightly higher at 3.75 and 4.50 years old respectively. One aspect not covered in the survey was the retiring age of farm dogs. The average retirement age of farm dogs in the UK was reported as 8-9 years old (Greig, 1953: Fox, 1964), however, the authors did not state the average age of the dogs which were still working. It is recommended that any future studies surveying working farms dogs establish not only the median working age, but also the age of dogs entering and leaving the working population (retiring).

The survey data described in Chapter Two also established that the majority of farmers (97%) fed their dogs once a day, on a diet composed of homekill combined with dry dog food. The feeding regime of farmers around the country was remarkably similar and the composition of the diet (i.e. 50% homekill and 50% TUX Energy) did not change during peak and off-peak periods, however the total amount fed changed, and dogs were fed more during peak periods.

Hence the average diet of a farm dog consists of 50% homekill and 50% dry biscuits, and Chapter Two showed that 82% of farmers in NZ fed TUX Energy as the main brand of dry dog food. Therefore, in order to have diets closely resemble the diet that is commonly fed, we tested the apparent digestibility of a diet comprised of 50% homekill and 50% TUX Energy (50% diet) on a ME basis (called the 50% diet) (Chapter Three). The aim of Chapter Three was to establish the apparent digestibility of diets commonly fed to working farm dogs in NZ.

The nutritional benefits and apparent digestibility of 50% homekill and 50% TUX Energy was previously unknown, this study has established the apparent digestibility of this diet. Adding TUX Energy to homekill significantly decreased the apparent digestibility of all nutrients except calcium and phosphorus. There were significant ($p<0.05$) differences in apparent digestibility of homekill versus 50% diet on dry matter, fat, crude protein and all amino acids tested. However, calcium apparent digestibility increased by adding TUX Energy to homekill and this is advantageous because calcium apparent digestibility was extremely low in homekill alone. As mentioned in Chapter three, one of the dogs on diet two, period one, produced negative apparent digestibility results for calcium and phosphorus, this may have been a result of bone fragments in the faeces which was subsequently analysed. Calcium and phosphorus apparent digestibility found in chapter three are extremely low, at 21.49 and 29.89 % (50% diet) and 22.54 and 32.85% % respectively, other studies in dogs have also shown negative and low calcium and phosphorus digestibility (Lewis *et al.,* 1994). A study by Lewis *et al*. (1994) found low calcium apparent digestibility (ranging from -2.0 to 10.7%) and phosphorus digestibility (ranging from 26.6 – 60.8%). Murray *et al.* (1999) found that phosphorus digestibility was lowest in a diet where the calcium intake was the highest, but found the result difficult to explain. However, they also reported low calcium and phosphorus digestibility in all test diets (16 - 22.6% for calcium and 48.2 – 65.8% respectively). Kastenmayer *et al.* (2002) also concluded that the apparent digestibility of calcium in dogs is low, but did not investigate phosphorus. These studies all report low calcium and phosphorus digestibility in a range of experimental diets, therefore the low calcium and phosphorus digestibility found in this study are not just indicative of a raw meat and bone diet, but perhaps may represent the low apparent digestibility of calcium and phosphorus in the dog.

Adding TUX Energy to homekill also had the benefit of increasing the amount of carbohydrate in the diet. Although researchers have shown that sled dogs perform better on a low or a carbohydrate-free diet (Kronfeld, 1973; Kronfeld and Hammel, 1975), this may not be true for farm dogs, because farm dogs work differently to a sled dog. Sled dogs are endurance athletes, and while farm dogs also require endurance, they may also need to sprint to bring in stock that has broken off from the herd. Therefore, although farms dogs may benefit from an energy dense diet (i.e. high fat) for sustained energy, they may also require carbohydrates to replenish glycogen stores in muscles for sprinting and for short bursts of energy.

A major limitation of assessing energy requirements of free-living creatures has been the methods available. Until the validation of doubly-labelled water (DLW) in the dog (Speakman *et al.*, 2001), the only means of estimating energy expenditure required the subject studied to be in a laboratory setting. Doubly-labelled water is the gold standard for measuring energy expenditure in free living subjects, however using DLW on over 100 dogs would be extremely expensive, and therefore Chapter Four used doubly labelled water to calibrate activity monitors, which were then used to estimate activity-associated energy expenditure. Previous studies with humans and monkeys (Puyau *et al.,* 2002; Pfeiffer *et al*., 2006; Sullivan *et al.,* 2006) showed that Actical® activity monitors could be used to estimate energy expenditure when calibrated using standardised methods for measuring energy expenditure. This study used five working farm dogs to calibrate the Actical® activity monitors to estimate activity associated energy expenditure. A constraint of this study was the limited weight range of dogs used, therefore the equation derived from this study may only be suitable for dogs between 18 and 26 kg of body weight. This being said, the average weight of Heading dogs in both chapter Five and Six were both within this range, so it could be possible that the energy requirements for Heading dogs were measured accurately in this set of trials.

The disadvantage of using activity monitors are that these devices only measure activity associated energy and therefore basal metabolic rate (BMR) still needs to be estimated. The National Research Council has reviewed the literature on BMR research conducted in dogs and recommended the equation $BMR = 76 \times BW^{0.75}$.

Results described in Chapter Five suggest that there may be significant differences in the energy requirements between the two main breeds of working farm dogs in NZ, with Heading dogs requiring more energy ($p<0.05$) than Huntaway dogs during peak periods of work, however further research needs to be conducted to scientifically prove this. Chapter Six showed that there were no significant breed differences in energy requirements between the two breeds of working dogs during peak or off peak periods of work. The reason why the two years showed differences is unknown, and further research is required to understand the effect on annual variations in workload. However, it is possible that different farmers, even within the same region, have different farming practices, or that the two different years had different weather patterns. Further studies are required to establish whether the differences are due to natural elements, or due to differences between farms by collecting data over a few years, or even a lifetime of a dog, on the same farm. This would eliminate all but seasonal differences between different years, and weather conditions. Regional information between the two seasons showed variation within regions, for example Gisborne peak/off peak comparison in chapter six are the opposite of the findings in Chapter 5. The dogs used between studies were different, as well as the farms and there were only 2 farms at each season, therefore it could be reasonably expected that workload between regions, as well as gender and breed differences would differ between Chapter 5 and 6.

The results from the combination of data from both seasons show that there are breed differences in the energy requirements for both peak and off-peak periods, and regional differences in energy requirements during off-peak periods. The data suggests that there is differences in energy requirement between the two breeds and although was not proven in this study due to the limitations of the equation derived in chapter Four. The data from this set of trials strongly suggests that differences in energy expenditure and energy requirements exists and further research needs to be conducted to explore this hypothesis. Although there is no published data on the working behaviour of the two main breeds of working dogs in NZ: the Heading and Huntaway, the results from chapter six and the GPS data, (figure 6.6c) strongly suggest that these dogs may have different working behaviour. The Heading dogs' movements vary more than the Huntaway, i.e. the Huntaway follows the direct path from A to B, whereas the Heading dog movement is more erratic. Further studies need to be conducted to explore the difference in working behaviours in the two breeds.

The final study established the energy requirements of working Heading and Huntaway dogs during peak and off-peak periods. This study (Chapter Six) used activity monitors that had been calibrated with DLW and geographical positioning system (GPS) monitors. These relatively new devices are useful for tracking and measuring activity in free living subjects. Although GPS monitors have their relative errors, these can be minimised by selecting data with obtained from at least four satellites, this technology allowed us to track farm dogs and establish the terrain and distance that the dogs cover. This study found that during peak periods of work over an 8 hour day, a working farm dog covers 20 ± 1.3 km/d, at an average speed of 2.14 ± 0.12 km/h. During off-peak periods over an 8 hour day a farm dog would cover 10 ± 0.7 km/d, at a speed of 1.18 ± 0.09 km/h. The peak period distances covered by working farm dogs correspond to the distances covered by Australian cattle dogs (Hampson and McGowan, 2007) who showed that farm dogs in Australia covered distances between 13.3 and 30.2 km during a mustering session (ranging from 1 h 59 min to 4 h 24 min), with an average distance covered of 20.1 ± 5.6 km.

The GPS and activity count data show that the proportions of energy expended between peak and off-peak periods corresponded to the proportion of distance that the dogs covered, between the two periods. The GPS data showed that Heading and Huntaway dogs cover the same distance, whether it is during peak or off peak periods of work. Even though the same distance was covered by both breeds, these dogs may have different working behaviours. The Huntaway was bred to bark, whereas Heading dogs work by moving stock with its body position, in relation to the stock, and the farmer (I. Singh, pers. Obs). These theories are based on personal observations, and data from Chapter six suggests that GPS monitors could be used to monitor and/or establish the working behaviour, of both Heading and Huntaway dogs. This information can then be used to substantiate why the two breeds have different energy requirements. Once the working behaviour of farms dogs is established, it will help researchers understand what type of nutrition is important for the dog, whether it be carbohydrates for sprinting, or fat for sustained energy. From this information, the optimal diet for farm dogs in NZ can be established.

There were no gender differences in the energy requirements of farm dogs in the season 2009-10 (p>0.05). However, there were significant gender and breed differences during the peak period in season 2007-2008, where female dogs had higher energy requirements than males (p<0.05), and Heading dogs had higher requirements than Huntaway (p<0.05). These two different seasons used relatively low numbers of different dogs, owned by different farmers, on different farms, and this may have contributed to anomalous results. When further statistical analysis was conducted, it was established that these two different seasons (i.e. the data set from Chapter five and the dataset from Chapter six) could be combined into a larger dataset. When the energy requirements from both years were combined, there were no differences in gender and no gender and breed interactions for both the peak and off-peak periods (p>0.05).

If we assume that the equation derived from chapter four is correct for dogs for the weight range in this set of trials, then when the data from Chapter Five and Six are combined, the average weight of a Heading dog during off-peak and peak periods over both seasons (2007-2008 and 2009-2010) was 20.8 kg and 21.6 kg respectively. This indicates that it requires 1373 kcal/d during off-peak 2096 kcal/d during peak periods. Similarly a Huntaway weighing 31.6 kg requires 1709 kcal/d during off-peak periods and a 31.7 kg dog requires 2472 kcal/d during peak periods. If we consider the most commonly fed 50% homekill and 50% biscuit diet, the average Huntaway would require 207 g of

TUX Energy biscuits and 620 g of homekill to sustain them during peak periods and 136 g of TUX Energy biscuits and 409 g of homekill to sustain them during off-peak periods. Similarly, a Heading dog would require 185g of TUX Energy biscuits and 554 g of homekill to sustain them during peak periods and 121g of TUX Energy biscuits and 363 g of homekill to sustain them during off-peak periods. The major problem with diets containing homekill is the nutrient composition of homekill may vary from that used in this study. Although all precautions were made to simulate the normal diet of the working farm dog, it is well known that the quality of meat by products varies between batches (Murray *et al.,* 1997; Johnson *et al.*, 1998), or in this case between carcasses.

Studies in Greyhounds have shown that restricted feeding (85% *vs.* 100% of maintenance requirements) resulted in increased speed performance and a BCS of 3.5 (Hill *et al.,* 2005). Restrictive feeding has also been shown to increase longevity in Labradors (Kealy *et al*., 2002). Kealy *et al.* (2002) recommended that dogs should be fed to maintain a BCS of less than five for good health and longevity. To the authors' knowledge, this type of research has not been conducted in other types of working dogs. The ideal BCS has not been established for working farm dogs in NZ and needs validation, but it maybe that working dogs may benefit from being less than a BCS of 5.

Currently there are no guidelines to assist nutritionists in formulating a diet that will meet the requirements of working farm dogs in NZ. This study has estimated the energy requirements of working dogs, and future studies should concentrate on other macro and micronutrient requirements of working farm dogs in NZ.

This body of work has outlined the large amounts of work these dogs carry out during peak periods of work, but this study has also outlined many gaps in the literature that still need to be investigated. Filling these gaps will enable researchers to understand the working behaviour, and the affect that altitude and climatic conditions have on the working farm dog of NZ. It may be that dogs working in different environments and climates might benefit from different diets, and therefore in the future there could be specialised diets for farm dogs working under different environmental conditions. Future research may potentially answer these questions.

Although this research has answered the most basic questions on the energy requirements of the working farm dog during both peak and off-peak periods, there are still many unanswered questions that need to be investigated. Although some extrapolation can be conducted from studies carried out in Greyhounds and Sled dogs, working farm dogs are unique in the work that they conduct, which is a combination of that carried out by Greyhounds and Sled dogs, a mixture of sprint and endurance. It seems imperative that working dogs have a more prominent place in future literature, as there is a large gap in understanding of not only their minimum nutrient requirements (including amino acids, vitamins and minerals), but also working behaviour. We still need to understand what level of protein needs to be included in the diet and if a certain level will minimise injuries, and at which concentration of carbohydrate, and fat optimises performance, and also if antioxidants have beneficial properties for the working dog. Regardless of the many unanswered questions, this thesis provides unique information which can be built on. Future research can build on this work and help to optimise the performance of working farm dogs in NZ.

7.1 References

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