THE ROLE OF RED MEAT

in Healthy & Sustainable New Zealand Diets

A navigation through the evidence exploring red meat's place in optimal healthy and sustainable dietary patterns.

Red meat as a whole food, continues to play an important role in the human diet today. It is a beneficial source of complete protein.

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History of The Role of Red Meat in a Healthy Diet report

This 2020 edition of *The Role of Red Meat in Healthy and Sustainable New Zealand Diets*, builds on the previous edition published in 2015. Content added to this current edition captures scientific publications from 2015 only, to ensure the latest evidence on the topic is captured and this report remains current. This new content was peer reviewed prior to publication of this edition.

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Contents

1. Summary

Red meat has long played a central role in the human diet. Archaeological evidence suggests early human ancestors began eating meat at least 2.6 million years ago (Pobiner, 2013). The introduction of a new calorie-dense food source rich in micronutrients is thought to have been one factor enabling the development of a larger brain. Evidence from fossil stable isotope analysis demonstrates a growing reliance on consumption of meat as humans evolved, with use of fire and cooking facilitating larger-scale meat eating.

Red meat as a whole food, continues to play an important role in the human diet today. It is an good source of complete protein and, when trimmed of visible fat, is low in total fat and saturated fatty acids. It can also be an important dietary source of monounsaturated and omega 3 fatty acids.

In terms of micronutrients, red meat is an excellent source of bioavailable iron and zinc. It also provides selenium, vitamin D, and B vitamins, with red meat being one of our major sources of vitamin B_{12}. Red meat also contains bioactive compounds such as taurine, carnitine and creatine.

Lean red meat has an important role to play in the diets of all age groups in New Zealand. It provides a unique package of nutrients that enable optimal growth and development in childhood, as well as maintenance of health and wellbeing throughout adulthood and well into old age. More often now we are seeing calls for food guidelines to move to a food systems approach, placing whole foods in context of the total diet first, rather than a focus on nutrients.

For those who exclude meat, careful consideration needs to be given to the nutritional adequacy of the diet as more restrictive diets are associated with a greater risk of deficiencies. In particular, people who follow vegan diets (i.e. exclude all animal products from their diet) need to take extra care to ensure their nutritional needs are met.

Higher red meat intakes, particularly processed meat, have been linked to increased risk of several chronic diseases, including colorectal cancer, stroke, and type 2 diabetes, in epidemiological studies. However, these associations have not been consistent across studies and have not been confirmed in clinical trials. As research in this area continues, the overall weight of evidence supports current advice within New Zealand and internationally to enjoy lean red meat in moderate amounts (300g-500g cooked weight, or approximately three portions, per week) as part of a healthy, balanced diet.

Beyond nutrition, to address the emerging pressures on human health and the environment, a food systems approach is critical to understand how the two interconnect. Inabilities to feed the future world population, deliver a healthy diet, produce equal and equitable benefits, and the system being environmentally unsustainable, have been identified as shortcomings of the food system. A fundamental challenge for those working in food systems, in both nutrition and sustainability, is getting the balance between the impacts on human health and environment, with new ways on thinking that draw upon new approaches and innovations.

To support a growing global population, sustainable and nutritious diets are of paramount importance. The attributes of a sustainable diet include long-term, low environmental impact and optimisation of natural and human resources. In addition, sustainable diets should be culturally acceptable, accessible, economically fair, affordable, safe and nutritionally adequate.

All food production has an environmental impact, including meat production. International research that examines the sustainability of sheep and beef production primarily draws on feedlot production, which have a different environmental footprint to pasture-based systems as in New Zealand sheep and beef production. When it comes to sustainability, New Zealand exports beef and lamb to 120 countries, using one of the lowest in-put and lowest impact production systems in the world.

Agriculture is an essential link in the food system, and some parts of the world are better geographically suited to livestock farming with hilly terrain and good rain fall, such as in New Zealand. Grazing livestock, such as sheep and beef, play an important role in grassland ecosystems, biodiversity and soil regeneration. In addition, pasture-fed ruminants, such as sheep and cows, are effective up-cyclers converting low-quality protein (grass) into highly-bioavailable protein in the form of meat. Lean red meat is a nutrient dense, calorie light and bioavailable way to obtain many essential nutrients therefore, it can play a valuable role in achieving the United Nation's Sustainable Development Goals relating to improving health and addressing malnutrition.

1. Introduction

The vast majority of New Zealanders eat red meat regularly as part of their diet (Parnell et al., 2003; University of Otago & Ministry of Health, 2011; Roy Morgan 2016). Preliminary results from the more recent Bayer Food Focus project showed 88% of the New Zealand adults surveyed eat red meats at least once a week with over 50% eating red meat 3-4 times a week or more often (Bayer, 2019). Therefore, consideration of red meat´s contribution to nutritional intakes, and its role in health and disease, is important.

This report provides background information on the role of red meat in the human diet and in human evolution. It reviews current scientific knowledge in terms of the nutritional content of red meat, its contribution to the diets of New Zealanders, and its role in health and disease. It also takes a broader look at food systems and the interface of human health and environmental sustainability through the lens of sustainable nutrition, and what this means for New Zealand beef and lamb producers.

The term 'red meat' in this report refers to beef, veal, lamb and mutton. For the purpose of this report, where meat is mentioned it refers to red meat flesh, which is defined as the skeletal muscle of beef, lamb, veal and mutton which includes any attached fat, connective tissue, rind, nerve, blood and blood vessels (Food Standards Code 2.2.1).

2. Human evolution and meat consumption

Meat had a central role in the diet of early man and has continued to throughout human evolution (Ruxton et al., 2013). The earliest human ancestors were herbivores, but evidence for scavenged meat goes back to the late Australopithecines. There is good evidence the human ancestral line has been consuming increasing quantities of meat for more than 2 million years (Mann, 2000). Fossil isotope ratios indicate consumption of a high-meat diet in early humans as early as 1.8 million years ago (Mann, 2000).

More recent human history, from archaeological records of around 40,000 years ago, shows the use of bone and antler tools such as spear tips and harpoons. There is also evidence to suggest animal traps and bows and arrows were used subsequent to this time (Ulijaszek, 2002). Around 12,000 years ago the settling and growth of populations and the domestication of both plants and animals began (Barker, 2009).

Not only have there been changes in cranio-dental features to enhance our ability to bite and tear animal flesh, but comparative gut morphology shows humans are truly omnivorous (Mann, 2007).

Primates in general, and humans in particular, have larger brain sizes than would be expected for their body size, a phenomenon described as encephalisation. In humans, there has been a dramatic increase in brain size over the last 2-3 million years (Aiello & Wheeler, 1995). The consumption of meat rich in fats (particularly the unsaturated fats) is one theory explaining the threefold increase in brain size compared to 4.5 million years ago (Chamberlain, 1996; Mann, 1998). Another theory - the social brain hypothesis - suggests brain size in primates is linked to the size of groups in which they live (Dunbar, 2009).

It has been estimated whenever ecologically possible, hunter-gatherers consumed 45-65% of their energy from animal foods, with protein providing 19-35% of energy at the expense of carbohydrates, which provided 22-40% of energy (Cordain et al., 2000, 2002). Yet, hunter-gatherer societies were relatively free from the signs and symptoms of cardiovascular disease (CVD). It is thought qualitative differences in fat intake, including a higher intake of monounsaturated fatty acids and polyunsaturated fatty acids, and a lower omega 6 to omega 3 ratio, would have served to inhibit the development of CVD among these populations (Cordain et al. 2002). Other dietary factors, such as a high intake of antioxidants, fibre, vitamins and phytochemicals and low intakes of salt and sugar, along with low levels of stress, higher levels of activity, and no smoking, would have further protected against the development of CVD.

There is some evidence from intervention studies that adopting a Palaeolithic-type dietary pattern can have significant health benefits, including by aiding weight loss, and improving carbohydrate and lipid metabolism, at least in the short term (O'Dea, 1984; Mellberg et al., 2014; Ghaedi et al., 2019). However, further research is needed in this area, including long-term follow-up.

While there is no consensus on what a hunger-gatherer, or Palaeolithic, diet was exactly, it is generally characterised as higher in protein, essential fatty acids, and fibre, and lower in sodium and total fat than modern diets (Turner & Thompson, 2013).

3. Key nutrients in beef and lamb

The primary components of meat are water, fat and protein. The proportions of these constituents can be highly variable, depending on the species and breed of animal, the age of the animal at slaughter, the season, and the types of grass and feed used.

The amount of trimming of fat both before and after purchase, and the cooking method used will also influence the nutritional composition of the meat as eaten (BNF, 1999).

Red meat is an excellent source of a number of valuable vitamins, minerals and trace elements. It is an excellent source of iron and zinc, which are present in highly bioavailable forms. Red meat also provides a number of B vitamins, along with vitamin D, and offal is a good source of vitamin A.

A summary of the nutrients in assorted cuts of lean beef and lamb from the forequarter and hindquarter can be found in Table 1.

Table 1: Nutrient composition of assorted cuts of cooked lean, meat (per 100g)

Nutrient	Beef* (composite cuts)	Lamb* (composite cuts)	Adult NZ RDI**
Energy (kJ)	841	792	5,600-18,600
Protein (g)	30.7	27.4	46-81
Fat (g)* **	8.6	8.8	-
Thiamine (mg)	0.04	0.08	1.1-1.4
Riboflavin (mg)	0.13	0.2	1.1-1.6
Niacin (mg)	8.8	10.7	14-18
Vitamin B6 (mg)	0.2	0.18	1.3-2.0
Vitamin B12 (µg)	1.56	1.8	2.4-2.8
Total Folate (µg)	7	0	400-600
Sodium (mg)	40	68	460-920+
Potassium (mg)	275	322	2800-3800+
Calcium (mg)	6	15	1000-1300
Iron (mg)	2.6	1.8	8-27
Zinc (mg)	5.1	4.0	8-14
Selenium (µg)	3.3	6.3	60-75
Magnesium (mg)#	21	22	310-420
Phosphorus (mg)#	237	246	1000-1250
Manganese (mg)#	0.016	0.029	5-5.5
Copper (mg)#	0.094	0.114	1.2-1.7

*** New Zealand Food Composition Database 2018, accessed March 2019**

**NHMRC nutrient reference values for Australia and NZ. Where ranges are given this reflects different values for various adult population group (i.e. male, female, pregnant, breastfeeding)
+ Adequate intake (AI) used when RDI cannot be determined
*** A breakdown of fatty acids can be seen in Table 2
# Composition values are drawn from USDA database

Detailed background information on different nutrients and their role in the prevention of deficiency, and requirements for infants, children and adolescents can be found in the National Health and Medical Research Council report *Nutrient Reference Values for Australia and New Zealand including Recommended Dietary Intakes* (NHMRC, 2006). This report also provides information on optimising diets to reduce chronic disease risk.

3.1. Fat

A small amount of fat can contribute to the palatability and flavour of meat. However, it is generally advised to remove the visible fat from meat before eating to reduce overall fat content. Red meat cuts have undoubtedly become leaner in recent years (Laugesen, 2005).

Since 1997, the red meat industry's Quality Mark has required the trimming of beef and lamb cuts to no more than 5mm external fat. This has ensured leaner cuts have become the norm for those buying meat as steaks or chops.

A study into the impact of this initiative found the trimming of fat from red meat before sale (supported by virtually all butchers) resulted in 30% less fat and 65% less saturated fat from the meat supply than the 20 years prior (Laugesen, 2005).

Data from the 2008/09 New Zealand Adult Nutrition Survey revealed intake of total fat was 33.7% and 33.8% for men and women respectively (University of Otago & Ministry of Health, 2011), down from 40% in 1977 and 35% in the 1997 survey (Russell et al., 1999).

The same survey showed beef and veal contributed 4.8% to total fat intake and lamb and mutton contributed 2%, down from the previous survey of 8% of total fat intake from beef and lamb. Sausages and processed meats contributed 4%, and pies and pasties contributed 3.5% to fat intake.

The total fat and fatty acid content of selected meats is shown in Table 2. It should be noted the saturated fat content is about 33% of total fat within the lean muscle, compared to over 50% in the fat, which is trimmed from the meat.

A considerable portion of the fat (lipids) in lean meat is phospholipids and not triglycerides. Phospholipids are higher in the unsaturated fatty acids. There is emerging evidence to show that phospholipids play a role in health, with suggestions omega-3 fatty acids in phospholipid form (rather than as free fatty acids) may have greater benefits on brain health due to their ability to cross the blood-brain barrier (Ahmmed et al., 2020) .

3.1.1. Saturated fatty acids (SFA)

Saturated fatty acids (SFA) are fully saturated with hydrogen and contain no double bond. They are the main types of fatty acids found in foods such as milk, cream, cheese, meat from most land animals, palm oil and coconut oil as well as in pies, biscuits, cakes and pastries (NHMRC, 2006).

Less than half the fat in meat is saturated (see Table 2). The rest is mainly monounsaturated fats, with small amounts of polyunsaturated fats, including some omega 3 (*n*-3) fatty acids. The main saturated fatty acids in meat are palmitic and stearic acid (Higgs, 1999); Stearic acid has almost no effect on blood cholesterol (FAO, 2010), or, when it is replacing trans fatty acids or other saturated fatty acids in the diet, stearic acid may lower LDL cholesterol (Hunter, 2010).

The density of saturated fatty acids in a 100g portion of lean meat is relatively low (see Table 2). For perspective, one tablespoon of olive oil contains 2.5g of saturated fat, and most cuts of meat contain between 1.2 and 3.2g per 100g. (New Zealand Food Composition Database, 2018). In the 2008/09 New Zealand Adult Nutrition Survey, the contribution to intake of saturated fat from beef and veal was 5% and 2.3% from lamb and mutton. (University of Otago & Ministry of Health, 2011). For more information on saturated fats and coronary heart disease, see section 6.1.

3.1.2. Monounsaturated fatty acids (MUFA)

Monounsaturated fatty acids (MUFA) have one double bond; the main MUFA is oleic acid (NHMRC, 2006).

Monounsaturates have been found to help lower the amount of LDL cholesterol in the blood. This (high amounts of MUFAs) is thought to be a factor of Mediterranean diets that makes it protective against cardiovascular disease (Michelson, 2019).

A significant proportion of the fatty acids in meat are monounsaturates (see Table 2), principally oleic acid (Higgs, 1999). In New Zealand, the contribution to intake of monounsaturated fat from beef and veal is 5.8% and 2.1% from lamb and mutton (University of Otago & Ministry of Health, 2011).

3.1.3. Polyunsaturated fatty acids (PUFA)

Polyunsaturated fatty acids (PUFA) contain two or more double bonds. There are two main types of PUFA: omega-6 and omega-3 (abbreviated as *n*-6 and *n*-3). Replacing some dietary SFAs with PUFAs can lower the level of plasma LDL cholesterol and the total cholesterol to HDL cholesterol ratio (BNF, 2019).

The ratio of omega-6 to omega-3 (*n*-6:*n*-3) in the diet is also considered to be important for health. Humans evolved on a diet that contained a ratio of 1:1 *n*-6:*n*-3, however, diets in the Western world now have a ratio of around 20:1, considered an 'imbalance' (Simopoulos, 1996).

The ratio of omega-6 to omega-3 in beef from grass fed animals in New Zealand was found to be less than 2:1 (Knight, 2003), well below the recommendation of 4:1 or less.

The ideal ratio for health is 4:1 or lower (Simopoulos, 1996). The ratio of n-6:*n*-3 in beef from grass-fed animals in New Zealand was found to be less than 2:1 (Knight, 2003), well below the recommendation of 4:1 or less. Enser (1998) also found a similar n-6:*n*-3 ratio in beef from grass-fed animals (2:1), and by comparison, found a much higher level of between 15:1 and 20:1 in beef from grain-fed animals (Enser, 1998).

Fish and seafood are the richest dietary sources of *n*-3 PUFA, with concentrations 5-15 times higher than meat (Howe et al., 2006); however meat is also likely to make a significant contribution to intakes of *n*-3 PUFA when the relative amounts eaten are considered. Australian data show meat, poultry and game contribute 43% to overall intakes of n-3 PUFA, with beef contributing 22.3% and lamb contributing 5.9% (Howe et al., 2006). Whilst this is high in percentage terms, it is still relatively low in absolute long chain n-3 amounts.

The amount of *n*-3 PUFA in meat has been shown to vary depending upon the feed type. Meat from animals raised on grass, as in New Zealand, contains higher levels of *n*-3 PUFA than meat from animals raised on grain. One study found, for example, there was 2-4 times the amount of *n*-3 PUFA in beef from grass-fed animals (including 18:3) than in meat from concentrate-fed animals, except for 20:4 *n*-3 where there was 10 times the amount in the grass group (Enser et al., 1998). The same study found similar results for lamb when the animals were grazed on grass. Enser (1995) also showed lean grass-fed beef has a much higher amount of phospholipids, which are rich in *n*-3, particularly docosapentaenoic acid (DPA) and a source of choline. DPA as a nutrient is growing in importance being a precursor of DHA.

Outside of New Zealand, studies looking at the effect different feed type has on the fatty acid composition of beef has demonstrated grass-based feeding can significantly increase *n*-3 PUFAs content, compared to grain-fed or concentrates (Ponnampalam et al., 2006; Nuernberg et al., 2005).

Another study compared the effects of consuming red meat from either grass-fed or concentrate-fed animals, and found that dietary intakes, as well as plasma and platelet concentrations of long chain *n*-3 PUFA were significantly higher in those subjects who consumed the grass-fed animals (McAfee et al., 2011). The difference in intake of long chain *n*-3 PUFA between the groups that was attributable to the red meat consumed was estimated at 18mg/day.

However, it is not only the feed type that may influence the fatty acid profile of the meat, but also variability exists between cattle breeds, age at harvest, carcass grade, and beef cut (Van Elswyk, 2014).

A significant amount of the *n*-3 PUFA in meat are from docosapentaenoic acid (DPA), which is an intermediate in the production of docosahexaenoic acid (DHA) from eicosapentaenoic acid (EPA). It has been suggested that *n*-3 DPA can improve cardiovascular and metabolic disease risk markers (for example plasma lipid parameters, platelet aggregation, insulin sensitivity and cellular plasticity) (Drouin et al., 2019). The same study also suggested that *n*-3 DPA is the second most abundant *n*-3 long chain PUFA in the brain (after DHA) and it could be specifically beneficial for elderly neuroprotection, and early-life development.

Given the evidence linking EPA, DHA and DPA to health, it would seem prudent to encourage increased consumption of these fatty acids in the diet. An intake in the region of 0.4g/day for women and 0.6g/day for men is recommended (NHMRC, 2006). Overall, red meat in New Zealand could make an important contribution to intakes of *n*-3 PUFA, particularly in those who don't eat much fish (Knowles et al., 2004).

Table 2: Fat and fatty acid content of lean cooked meat (per average 100g serving)

Meat Cut	Total fat (g)	SFA (g) (% of total fat)	MUFA (g) (% of total fat)	PUFA (g) (% of total fat)
Lean beef, cooked, composite cuts	8.6	2.9 (33.7%)	3.1 (36.0%)	0.4 (4.7%)
Beef mince, premium, simmered	3.3	1.2 (36.4%)	0.9 (27.3%)	0.25 (7.6%)
Beef silverside, lean, roasted	5.0	1.7 (34.0%)	1.8 (36.0%)	0.3 (6.0%)
Beef topside, lean, braised	7.3	2.5 (34.2%)	2.6 (35.6%)	0.4 (5.5%)
Lean lamb, cooked, composite cuts	8.8	3.2 (36.4%)	2.3 (26.1%)	0.5 (5.7%)
Lamb leg, lean, roasted,	6.4	2.1 (32.8%)	1.8 (28.1%)	0.4 (6.3%)
Lamb, rump, lean, roasted	5.3	1.8 (34.0%)	1.3 (24.5%)	0.3 (5.7%)

New Zealand Food Composition Database 2018, accessed March 2019

3.1.4. *Trans fatty acids*

Trans fatty acids (TFAs) are unsaturated fatty acids that have at least one double bond in the *trans* configuration. Most of the industrially-produced *trans* fat in the diet is found in processed margarines and baked products such as cakes, biscuits and pastries. Some *trans* fats can also occur naturally at low levels in ruminant animal foods, formed as a result of biohydrogenation by rumen bacteria. Studies have demonstrated high intakes of industrially-produced *trans*-fatty acids are strongly associated with increased risk of CHD and related mortality (Bendsen et al., 2011; Mozaffarian et al., 2010). Few studies have identified an association between intake of ruminant *trans* fatty acids and CVDs (WHO, 2018); however, most study populations have a very low ruminant *trans* fatty acid intake (Brouwer, 2013). There is an average of 0.3g *trans* fat in lean cuts of cooked beef (0.2g) and lamb (0.4g) (New Zealand Food Composition Database, 2018). The structure of ruminant *trans* fatty acids is different to those produced by industrial hydrogenation.

The World Health Organisation has released draft guidelines recommending that TFAs contribute no more than 1% of total dietary energy (WHO, 2018), and has made elimination of industrially-produced TFAs from the global food supply a priority target in its general programme of work (strategic plan) for 2019-2023 (WHO, 2019). In New Zealand, current intakes are around 0.6% of total dietary energy (FSANZ, 2014), which is due to the removal of partially hydrogenated fat from margarines by manufacturers in 2006. It is recommended saturated fatty acids and TFAs together contribute no more than 8-10% of total energy (NHMRC, 2006; Ministry of Health, 2015).

3.1.5. *Conjugated linoleic acid*

The term conjugated linoleic acid (CLA) generally refers to mixtures of positional and geometric conjugated isomers of linoleic acid. CLA has been linked to various health benefits such as being anticarcinogenic, reducing body fat deposition, reducing the development of atherosclerosis, stimulating the immune function, and lowering blood glucose (Dilzer & Park, 2012; Fuke & Nornberg, 2017). A review of the evidence concluded that while cell and animal studies show promising results, the literature on humans is limited and sometimes contradictory; the beneficial effect found in animals are not reflected in humans (Fuke & Nornberg, 2017). The authors suggested this could be due to the differences in the dose and the form of CLA. The suggested dose for a beneficial effect is 3-6g CLA/day. Estimations of current consumption varies greatly from between 52-137mg/day in the US, 600-800mg/day in England and 1500mg /day in Australia (Pariza et al., 2000).

Conjugated linoleic acids are fatty acids found naturally in foods from ruminant animals such as meat, milk, and dairy product. (Fuke & Nornberg, 2017). The method of feeding has been shown to affect the levels of CLA present in the meat, with beef from grass-fed cattle having a higher CLA content than beef from cattle fed on grain or concentrates (Daley et al., 2010, Nuernberg et al., 2005). Manipulating feed has been suggested as one way of increasing consumption of CLA (Fuke & Nornberg, 2017).

Whilst there is some evidence of the beneficial role of CLA in human nutrition, health claims will not be permitted under FSANZ as technically speaking CLA is a trans fatty acid.

CLA in meat is located in the interstitial, non-visible fat, evenly distributed along the muscle fibres, as well as in the subcutaneous deposits (Eynard & Lopez, 2003), so even when visible fat is discarded, interstitial fat, including CLA will be eaten.

In addition, a significant portion of the lipids in lean meat are in the form of phospholipids.

3.1.6. *Phospholipids*

A significant portion of the lipids in lean meat are in the form of phospholipids. These are typically part of cell membrane lipids including those surrounding muscle fibres (Bermingham et al., 2018). Phospholipids may contribute to the taste and aroma found in red meat (Huang et al., 2010) and are also a source of choline, which contributes to normal homocysteine and fat metabolism (Li et al., 2008).

Phospholipids identified in red meat include phosphatidylinositol, phosphatidylethanolamine, phosphatidylserine, phosphatidylcholine, and sphingomyelin. In addition to red meat muscle, animal organs, such as brain and liver, contain higher amounts phospholipids (Cui et al., 2016; Bermingham et al., 2018). Red meats have greater proportions of phospholipids than white meats (Melton,1990; Wood et al., 2004).

Whereas, the positive impact on human health from dietary phospholipids in dairy and eggs is established (Kullenberg et al., 2012), to date, there is limited work published on red meat phospholipids. It is known that phospholipids have both pro- and anti-oxidant roles (Cui & Decker, 2016). Recent New Zealand research on phospholipids in different beef cuts from grass-fed Wagyu-dairy cross cattle, suggest that beef consumption could contribute significant levels of dietary phospholipids, which may have beneficial impacts of human health, in line with previous studies in humans (Bermingham et al., 2018).

3.2. Protein

Red meat is a good source of high biological value protein and is deemed one of the higher qualifing protein sources according to current testing methods (PDCASS and DIASS)*. The protein is highly digestible and provides all eight essential amino acids (lysine, threonine, methionine, phenylalanine, tryptophan, leucine, isoleucine and valine) with no limiting amino acids unlike plant foods (Williams, 2007). A 100g portion of cooked lean beef or lamb provides around 25-30g of protein.

On average, beef and veal contribute 7.8% to protein intakes in New Zealand (8.2% among males, 7.3% among females), and lamb and mutton contribute 2% (1.9% among males, 2.1% among females), according to the last National Nutrition Survey (2008/09) (University of Otago & Ministry of Health, 2011). Beef and veal make a greater contribution to protein intakes among older adults (10.1% of protein intakes among men aged 71 years and over, 9.3% among women). Lamb and mutton make a greater contribution to protein intakes among adults aged 51-70yrs (2.6% among men, 2.9% among women).

The Acceptable Macronutrient Distribution Range (AMDR) for protein to reduce chronic disease risk while ensuring adequate micronutrient status is 15-25% of total dietary energy intake (NHMRC, 2006). Diets with as little as 10% energy from protein are adequate to meet basic protein requirements. However, intakes above 15% energy from protein appear to be required for ensuring adequate intakes of micronutrients. A prudent upper limit of 25% energy from protein has been recommended until more is known about the long-term effects of a high-protein diet (NHMRC, 2006).

According to the last National Nutrition Survey (2008/09), mean percent energy intake from protein was 16.4% for males and 16.5% for females with little variation across age groups, although lower values were reported among younger females (15.2% among 15-18 year olds, 15.4% among 19-30yr olds) and 15–18-year-old Māori males (14.7%) (University of Otago & Ministry of Health, 2011). Further information on New Zealand's meat and protein intake compared to global intake, can be found in section 8.1.

Table 3 on the following page lists the Nutrient Reference Values (NRVs), including Recommended Dietary Intakes (RDIs), for protein in New Zealand and Australia (NHMRC 2006). Protein requirements for different population groups were estimated using the factorial approach, which takes into consideration the minimum amount of protein needed for maintenance of fat free (lean body) mass and growth (accretion), ongoing (obligatory) nitrogen losses from the body, and efficiency of dietary protein utilisation (WHO, 2007).

*PDCASS = Protein Digestibility Corrected Amino Acid Score.
DIASS = Digestible Indispensable Amino Acid Score. These methods to determine protein quality are currently not accounted for in New Zealand dietary guidelines, food composition tables nor nutrition information panels.

Table 3. Nutrient Reference Values for Australia and New Zealand (2006) – Protein

Age group & gender		AI[1] g/day (g/kg body weight)	
Infants	0-6m	10 (1.43)	
	7-12m	14 (1.60)	
		EAR[2] g/day (g/kg)	**RDI[3]** g/day (g/kg)
Children	1-3yr	12 (0.92)	14 (1.08)
	4-8yr	16 (0.73)	20 (0.91)
Boys	9-13yr	31 (0.78)	40 (0.94)
	14-18yr	49 (0.76)	65 (0.99)
Girls	9-13yr	24 (0.61)	35 (0.87)
	14-18yr	35 (0.62)	45 (0.77)
Men	19-70yr	52 (0.68)	64 (0.84)
	>70yr	65 (0.86)	81 (1.07)
Women	19-70yr	37 (0.60)	46 (0.75)
	>70yr	46 (0.75)	57 (0.94)
Pregnant Women	14-18yr	47 (0.82)	58 (1.02)
	19-50yr	49 (0.80)	60 (1.00)
Breastfeeding Women	14-18yr	51 (0.90)	63 (1.1)
	19-50yr	54 (0.88)	67 (1.1)

Source: NHMRC 2006
[1]Adequate Intake
[2]Estimated Average Requirement
[3]Recommended Dietary Intake

EARs for protein for older adults (over 70 years) are 25% higher than for younger adults, based on evidence that nitrogen utilisation efficiency may be lower in older adults (Rand et al., 2003). New evidence suggests optimal protein intakes for older adults may be even higher to maintain nitrogen balance and for long-term maintenance of muscle mass, strength and function, as well as improved immune status and wound healing (Wolfe et al., 2008; Nowson & O´Connell, 2015; Wham & Yaxley, 2017; Traylor et al., 2018; Richter et al., 2019). However, no recommendation currently exists specifying an ´optimal´ protein intake to enhance healthy aging beyond the minimal dietary requirement (Traylor et al., 2018).

High quality dietary protein sources are particularly important for maintaining muscle mass and function with ageing, with foods rich in the essential amino acid leucine, found predominantly in animal sourced foods, playing a particularly important role in stimulating muscle protein synthesis (Paddon-Jones et al., 2008; Nowson & O´Connell, 2015).

There is also emerging evidence that a more even protein distribution throughout the day may be beneficial for maximum stimulation of muscle protein synthesis and improved long-term maintenance of muscle mass with aging (Mamerow et al., 2014; Nowson & O´Connell 2015; Traylor et al., 2018).

In addition to maintaining muscle mass and function with ageing, a balanced diet with adequate high quality protein intake can help to aid weight management, weight loss, and weight loss maintenance, and to prevent sarcopaenic obesity (replacement of lost skeletal muscle with fat) in older adulthood (Wyness, 2016) (see also section 8.3).

3.3. Micronutrients

3.3.1. Iron

Iron is needed for the production of a number of proteins in the body, including haemoglobin, myoglobin, cytochromes and enzymes involved in redox reactions. Iron is also important for early brain development and for supporting a healthy immune system.

Iron is present in food in two forms – haem and non-haem. Haem iron is better absorbed than non-haem iron. Absorption of haem iron is influenced by the body's iron stores, the rate of absorption can vary from 15% in an individual with replete iron stores to 35% in someone with depleted iron stores. The average absorption of haem iron in meat is about 25% (Hurrell, 2010). Non-haem iron (found in meat, legumes, nuts, cereals, some fruits and dark green vegetables such as spinach) is less bioavailable and absorption is influenced by other dietary components, ranging 5-12%. For example, foods containing vitamin C can increase absorption of non-haem iron. In contrast, foods containing phytates (found in legumes and wholegrain cereals) can inhibit non-haem iron absorption. Absorption of iron from vegetarian diets has been estimated to be around 10% (Institute of Medicine Panel on Micronutrients, 2001) and it has been suggested there can be a 10-fold difference in the absorption of iron from different meals with a similar iron content (Hallberg & Hulthen, 2000). Absorption of iron is about 18% from a mixed diet, so iron requirements for vegetarians, who rely on non-haem sources, will be about 80% higher than for those who eat meat (NHMRC, 2006).

Beef and lamb are among the richest sources of bioavailable iron in the diet and, in addition, meat enhances the absorption of non-haem iron by up to two to three times from foods eaten at the same time through the action of the Meat, Fish, Poultry (MFP) factor. The nature of the enhancing effect is thought to be related primarily to the muscle proteins (Hurrell et al., 2006). In New Zealand, beef and veal have been found to contribute 7% to our total iron intake and lamb and mutton provide a further 1.5% (University of Otago & Ministry of Health, 2011). The actual contribution of meat to iron intake is much greater, however, owing to the higher proportion of iron absorbed. Further information on New Zealand's meat and protein intake compared to global intake, can be found in section 8.1.

Inadequate intakes of iron can lead to varying degrees of deficiency; from low iron stores (indicated by low serum ferritin and reduced iron-binding capacity) to iron-deficiency anaemia (low haemoglobin and haematocrit as well as reduced mean corpuscular haemoglobin and volume) (NHMRC, 2006). The recommended intake of iron in different population groups is shown in Table 4 on the following page.

Iron deficiency is the most common and widespread nutritional disorder in the world. As well as affecting a large number of children and women in developing countries, it is one of only a few nutrient deficiencies, which are also significantly prevalent in developed countries such as New Zealand. Worldwide, the number affected by anaemia is decreasing, although still high, with 29% of non-pregnant women and 43% of children reported to have anaemia in 2011 (Stevens et al., 2013). The World Health Organisation estimates that around 50% of anaemias are due to iron deficiency (WHO, 2001).

The adverse effects of iron deficiency anaemia include poor cognitive development, fatigue, reduced tolerance to work, and decreased aerobic capacity. Iron deficiency anaemia can also have an impact on behaviour. In infants, iron deficiency anaemia has been associated with maintaining closer contact with caregivers, showing less pleasure and delight, being more wary, hesitant and easily tired, being less attentive to instructions and being less playful (Lozoff et al., 1998). Severe, chronic iron deficiency anaemia in infancy has also been associated with reduced mental and motor functioning, and continued developmental and behavioural risk more than 10 years after iron treatment (Lozoff et al., 2000), and these negative effects on brain development are thought to be long lasting and potentially irreversible (Beard, 2008).

Approximately 4% (Soh et al., 2004) to 6% (Grant et al., 2007b) of infants and toddlers in New Zealand have iron deficiency anaemia. However, non-anaemic iron deficiency is considerably more common than iron deficiency anaemia in New Zealand infants and young children (Soh et al., 2004), and may be associated with subtle negative effects on cognitive function and fatigue, as well as an increased risk of developing iron deficiency anaemia if the infant is exposed to a physiological challenge such as rapid growth, infection, or injury.

A study in Auckland children aged 6-24 months found 14% were iron deficient, with the occurrence among Māori and Pacific Island children even higher at 20% and 17% respectively (Grant et al., 2007b). Iron intake was less than the estimated average requirement (EAR) for 25% of the infants.

Not meeting the EAR increased the risk of iron deficiency for children aged 6-11 months (relative risk (RR) = 18.45, 95% confidence interval [CI]: 3.24-100.00) and 12-23 months (RR = 4.95, 95% CI: 1.59-15.41). In comparison with New Zealand Europeans, Pacific children had a greater daily iron intake (p = 0.04) and obtained a larger proportion of iron from meat and meat dishes (p = 0.02). For children aged 12–23 months, the EAR was achieved by 81% and the RDI by 22% (equating to 8 out of 10 toddlers not meeting their daily iron intake requirements). (Wall et al., 2009).

Iron requirements in the first year of life are greater than at any other time due to rapid growth and blood volume expansion (Grant et al., 2007a). The depletion of iron stores accrued in utero, and increased demands for growth, mean that after six months of age infants depend on complementary foods to provide iron (Ministry of Health, 2008). Meat has been found to play an important role as a complementary food (Hallberg et al, 2003). Puréed meat can be introduced once an infant is around 6 months of age. Given the risk of iron deficiency in infants and young children, it has been suggested public health campaigns should encourage adequate meat intake to help reduce the problem (Mira et al., 1996).

The importance of both meat and fortified milk for providing iron in the diets of toddlers was demonstrated in a New Zealand trial. The trial assessed the effect of increased red meat consumption, or the use of iron-fortified milk, for improving iron status in healthy non-anaemic toddlers aged 12-20 months (Szymlek-Gay et al., 2009). In this 20 week randomised placebo-controlled trial, toddlers were assigned to either a red meat group (encouraged to consume approximately 2.6mg iron from red meat dishes daily), a fortified milk group (toddlers' regular milk was replaced with iron-fortified milk containing 1.5mg iron per 100mls) or a control group (toddlers' regular milk was replaced with a non-iron-fortified milk containing 0.01 mg iron per 100mls). While serum ferritin (iron stores) tended to decrease in the control group, it increased by 44% in the fortified milk group, and did not change in the red meat group. The authors concluded that iron-fortified milk can increase iron stores in healthy non-anaemic toddlers and red meat can prevent their decline (Szymlek-Gay, 2009).

Iron deficiency has been seen to be prevalent in Auckland high school students (Schaaf et al., 2000), particularly in girls, where iron deficiency and anaemia were each ten times more common (9.6% and 8.7% respectively) than in boys (0.8% and 0.7%). In females, iron deficiency was two to three times more common and anaemia was three to four times more common in Māori, Pacific Island and Asian adolescents compared with Europeans. Iron deficiency in this study was defined as any two or more of the following: serum ferritin less than 12 µg/L, iron saturation less than 14%, or red cell distribution width greater than 14.5%. Anaemia was defined as haemoglobin less than 120 g/L for females and less than 130 g/L for males. According to the last national nutrition survey on adults, 34.2% of females aged 15-18 years old had an inadequate intake of iron (University of Otago & Ministry of Health, 2011).

Concern has also been expressed in relation to the sub-optimal iron status of women of childbearing age in New Zealand. One study (Ferguson et al., 2001) estimated that the prevalence of sub-optimal iron status among 15-49 year old women was between 7% (serum ferritin less than 12 µg/L) and 13% (serum ferritin less than 16 µg/L). The authors stated this situation is unacceptable given the negative consequences of even mild iron deficiency.

Pregnant women in particular are vulnerable to iron deficiency, as requirements are significantly increased to meet the needs of the growing foetus as well as increased maternal blood volume. An iron-rich diet, which includes the regular consumption of red meat, chicken and fish, has been recommended (Grant et al., 2007a).

Non-haem sources of iron such as grains, cereals, legumes and eggs should also be encouraged along with foods containing vitamin C to enhance absorption.

A further study in premenopausal women in Auckland showed that, for women who had children, following a dietary pattern that was higher in meat and vegetables was associated with a 25% lower risk of sub-optimal iron status (Beck et al., 2014)

While many sub-groups of the female population (e.g., pregnant) are at increased risk of iron deficiency, a study looking at older (80-90 years) New Zealand men and women found their dietary iron intakes and iron stores (serum ferritin) were adequate. The study also found men had significantly higher iron levels compared to women. The higher intake of haem iron from beef and veal among men was suggested as a reason why their iron stores were higher (Pillay et al., 2018).

The New Zealand Adult Nutrition Survey found from 1997 to 2008/09 the prevalence of iron deficiency in females had increased from 2.9% to 7.2%, equating to 1 in 14 women being low in iron. After adjusting for age and ethnicity, there was also an increase in the prevalence of low iron stores in females (University of Otago & Ministry of Health, 2011). For certain high-risk sub-groups (for example vegetarians, athletes, pregnant women, Asians, Pacific people and Māori), the prevalence of iron deficiency and iron deficiency anaemia is often much higher (Gibson et al., 2002).

Inflammation is thought to impair iron absorption and utilisation due to its effect in up-regulating production of hepcidin – the body´s hormonal regulator of iron absorption. (Nemeth et al., 2004). High inflammation is common in periods of chronic disease (such as inflammatory bowel disease and chronic kidney disease), among people with a BMI over 30, in athletes, and potentially in certain ethnicities (Ilkovska et al., 2016).

Table 4: Recommended dietary intakes for iron in New Zealand

Population Group	RDI* (mg/day)
Infants (0-6 months)+	0.2 (AI**)
Infants (7-12 months)	11
Children (1-3 years)	9
Children (4-8 years)	10
Children (9-13 years)	8
Boys (14-18 years)	11
Girls (14-18 years)	15
Women (19-50 years)	18
Pregnant women	27
Breastfeeding women++	9-10
Women over 50 years	8
Men over 19 years	8

*RDI is the Recommended Dietary Intake (the average daily dietary intake level sufficient to meet the nutrient requirements of nearly all (97-98%) healthy individuals in a particular life stage and gender group).
**AI is the Adequate Intake, used when an RDI cannot be determined.
+ Amount normally received from breast milk.
++ Assumes menstruation does not resume until after 6 months of breastfeeding.

Source: NHMRC, 2006

In cases of iron deficiency anaemia, iron supplementation is accepted as the most appropriate method of treatment. However, a New Zealand study investigated whether dietary treatment of non-anaemic iron deficiency could improve iron status in pre-menopausal Dunedin women. The study found that dietary intervention involving increased intakes of both haem iron (from flesh food) and enhancers of iron absorption (such as vitamin C), along with a decrease in intake of inhibitors of iron absorption (such as phytic acid), may improve the iron status of pre-menopausal women with low iron stores (Heath et al., 2001).

Although the changes in iron status were less with dietary intervention than with supplements, in motivated women with low iron stores, dietary intervention may be an appropriate first-line treatment as long as they are monitored to ensure the treatment has been effective.

In regards to the cost of iron deficiency anaemia in New Zealand, it is estimated to cost District Health Boards approximately $6.7 million in 2017/18, a doubling since 2008/09 (Ministry of Health, 2018c).

Prevention and treatment of iron deficiency among vulnerable groups within New Zealand is an important public health issue. In particular, we need to ensure optimal intakes of iron among groups such as infants, children, adolescents and pregnant women.

3.3.2. Zinc

Zinc is a component of various enzymes that help maintain the structural integrity of proteins and regulate gene expression (NHMRC, 2006). It is also known to play a central role in the immune system, with zinc deprivation leading to an increased susceptibility to pathogens because of impaired immune response (Shankar & Prasad, 1998). Zinc deficiency can also lead to impaired growth and adverse pregnancy outcomes (NHMRC, 2006).

Those at increased risk of zinc deficiency include older people, vegetarians and people with renal insufficiency (Ibs & Rink, 2003). Zinc deficiency has also been found among New Zealand school children; the 2002 Children's Nutrition Survey (Parnell et al., 2003) found 16% of children had low serum zinc concentrations (21% of males and 10% of females).

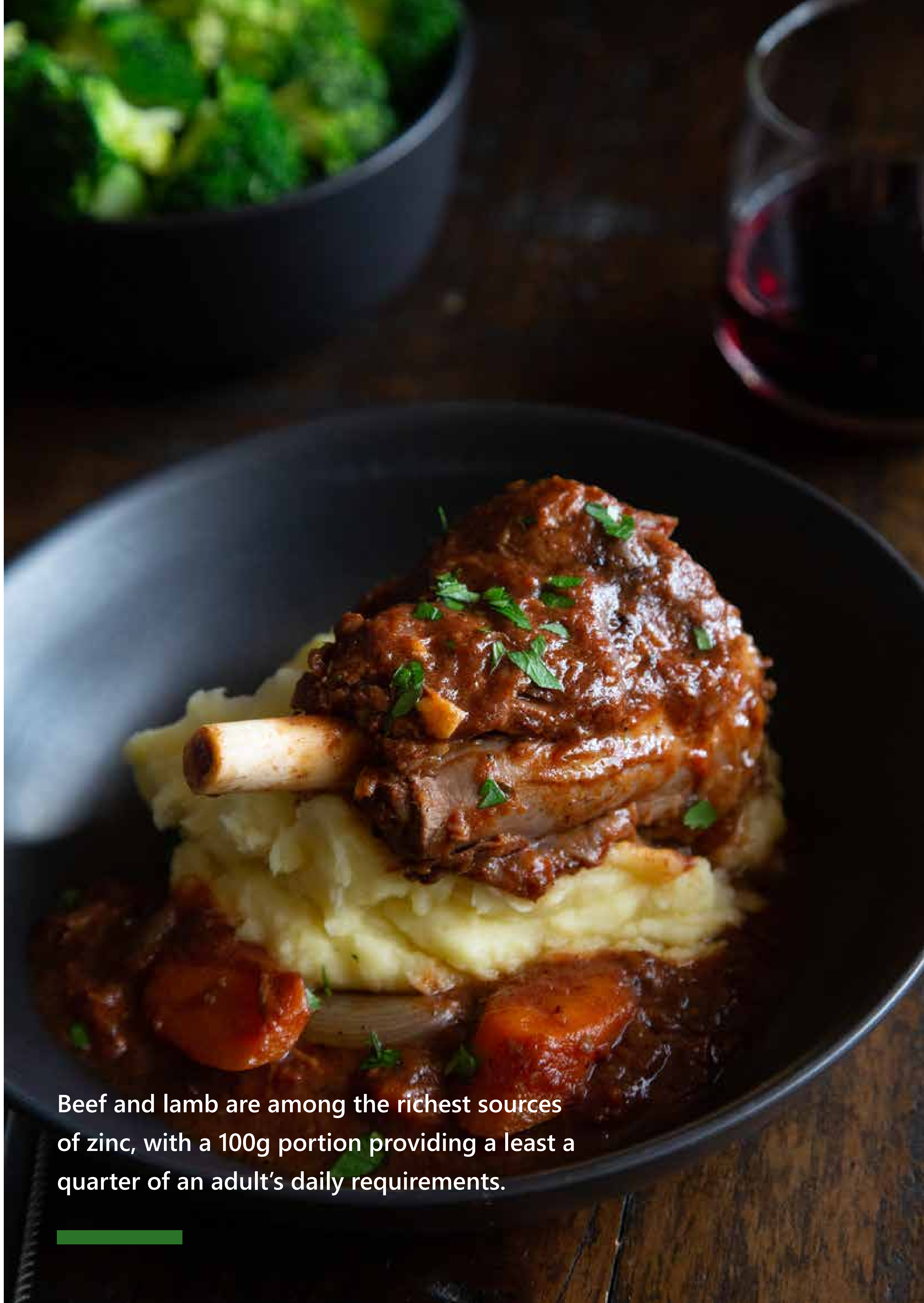
Further analysis of data from the 2002 Children's Nutrition Survey by Gibson et al (2011) found among Pacific children aged 5-15 years, the prevalence of low serum zinc concentration was 21%, compared with 16% of Māori children and 15% of European children. In this study, children derived 23% of their zinc intakes from meat, poultry and fish.

It has been suggested pre-school children may be at even higher risk of zinc deficiency. Suboptimal zinc status may increase the risk of infection (Fraker et al., 2000; Shankar & Prasad, 1998) and have detrimental effects on growth (Nissensohn et al., 2016). An intervention study found that 38% of toddlers (12-20 months of age), at baseline, had low serum zinc concentrations despite seemingly adequate zinc intakes (Morgan et al., 2010). Researchers in this study found that providing either red meat or fortified milk did not improve zinc status despite increasing zinc intakes. However, in a more recent study of New Zealand toddlers (12 months of age), red meat intake was found to be positively associated with plasma zinc concentrations (Daniels et al., 2018).

Results from the New Zealand Adult Nutrition Survey 2008/09 reported an estimated prevalence of inadequate zinc intakes of 24.7% (males 39.1%, females 11.2%). The highest prevalence of 89.7% was among older males (71+ years), although the data should be interpreted with caution as the EAR may be set too high, and biochemical zinc status was not determined (University of Otago & Ministry of Health, 2011).

An earlier study into the zinc status of older Dunedin women (70-80 years) found 12% had low serum zinc levels (de Jong et al., 2001) and the authors concluded promotion of nutrient-dense foods or trace element supplements for New Zealand seniors should be considered. Another study in pre-menopausal Dunedin women found those who ate red meat had significantly higher serum zinc concentrations than those who did not eat red meat (Gibson et al., 2001).

Although zinc is widely distributed in foods, meat, fish and poultry are major contributors, with cereals and dairy foods also providing substantial amounts (NHMRC, 2006). Beef and lamb in particular are among the richest dietary sources of zinc, with a 100 g portion providing at least a quarter of adult daily requirements (see Table 1).



3.3.3. Selenium

Selenium is an integral part of glutathione peroxidase, an enzyme that protects against oxidative damage (NHMRC, 2006). Selenium is also important for the production of other key selenoproteins such as iodothyronine deiodinase (Rayman, 2012). Dietary selenium is essential for the efficient operation of many aspects of the immune system (Arthur et al., 2003; Broome et al., 2004) and for optimal thyroid hormone metabolism (Rayman, 2012).

It has been suggested selenium may be protective against several types of cancer. However, a recent Cochrane review of the evidence (Vincetti et al., 2018) found no beneficial effect of selenium supplementation on cancer risk. It also found that while some observational longitudinal studies show an inverse association between selenium exposure and risk of some cancer types, it was not dose related and observational studies have many limitations. Overall, the Cochrane review concluded there was no evidence to suggest increasing selenium intake through diet or supplementation prevents cancer in humans (Vinceti et al., 2018).

The New Zealand Adult Nutrition Survey 2008/09 (University of Otago & Ministry of Health, 2011) found among adults, selenium is provided by fish and seafood (11.6%), bread (15.1%), poultry (9.6%) and meat and meat products (15.1%). Analysis of data from the most recent (2002) Children's Nutrition Survey showed among children aged 5-14 years, selenium was provided by bread and grains (33%), meat (14.8%), poultry (11.2%), and fish and seafood (8.6%) (Thomson et al., 2007).

There appears to be regional differences in New Zealand children´s selenium intakes (Thomson et al., 2007). According to the 2002 Children´s Nutrition Survey, children aged 5-14 years living in the upper North Island had mean serum selenium concentrations higher than those in the lower North Island and South Island. These differences have been partly attributed to the different levels of selenium found in bread, since the selenium content of bread is lower in the South Island than the North Island where higher selenium wheat from Australia is used.

High fish and poultry intakes amongst Pacific children, who make up a higher proportion of the population in the upper North Island compared with the rest of the country, may also play a role.

As a whole, New Zealanders appear to fall within the middle of the international range of serum selenium concentrations. However, the selenium status of South Island children is among the lowest values reported internationally (Thomson et al., 2007).

Pregnant and breastfeeding women may be at risk of low selenium concentrations due to the increased selenium demands of the growing foetus and the increased demands of lactation. In addition, infancy is a vulnerable time, with rapid growth and development also leading to increased selenium requirements. A New Zealand study of pregnant and breastfeeding women found 61% of pregnant and 68% breastfeeding participants had estimated selenium intakes, based on dietary data, below the EAR (55 µg/day and 65 µg/day, respectively). For pregnant women the median selenium intake based on urinary excretion was 49 µg/day, below the RDI (65 µg/day), with 59% below the EAR (Jin et al., 2019). The New Zealand Adult Nutrition Survey 2008/2009, estimated 44–72% of women aged 19–50 years had inadequate selenium intakes.

A study investigating iodine and selenium intakes in healthy, women aged 50–70 years (n=97) from three cities in the North Island of New Zealand, found the median selenium intake was 50 µg/day based on urine and 45 µg/day using dietary intake, below RDI (60 µg/day) with 49%–55% below EAR (50 µg/day) (Brough, 2017).

A study of South Island children, aged 6-24 months, and their mothers, found dietary selenium intakes were below recommended levels (McLachlan et al., 2004) with intakes of 7.9 ± 6.2 µg/d in infants; 13.7 ± 8.4 µg/d in toddlers and 38 ± 25 µg/d in mothers. The low intakes were reflected in blood selenium concentrations, which were at the lower end of international levels. The authors recommend dietary strategies to improve selenium intakes are implemented, for example, the inclusion of selenium-rich foods such as fish, meat and unrefined cereals.

The New Zealand Adult Nutrition Survey 2008/09 estimated the prevalence of inadequate selenium intake was 45% (males 32%, females 58%). Females aged 15-18 years had a consistently high prevalence of inadequate intakes (over 70%) across all ethnic groups (University of Otago & Ministry of Health, 2011).

3.3.4. Vitamin A

Vitamin A is a fat-soluble vitamin, which helps maintain normal reproduction, vision and immune function (NHMRC, 2006). The term vitamin A includes retinol from animal sources, and pro-vitamin A carotenoids, such as beta-carotene found in plant foods, which are precursors of vitamin A.

In New Zealand, 17.2% of the population have been found to have inadequate intakes of Vitamin A, with a higher prevalence among younger people aged 15-18 years; 37.5% of males and 27.4% of females (University of Otago & Ministry of Health, 2011). Lower intakes of beta-carotene among younger people contributed to their inadequate intakes.

Carcass meat contains little vitamin A, but liver is a particularly good source of this vitamin in the form of retinol. Chronic intake of large amounts of retinol over time can be toxic and pregnant women should limit their intake of liver as vitamin A can be teratogenic (ie can cause defects in the growing foetus). In some countries, pregnant women are advised to avoid liver altogether; however, in New Zealand, animal feeding practices are different and levels of vitamin A in liver are likely to be lower. The Ministry of Health in New Zealand advises up to 100g of liver may be consumed per week during pregnancy, although liver pâté is not recommended as there is a risk of food-borne illness such as listeriosis (Ministry of Health, 2006a). No more than 10g of liver or pâté per week should be offered to infants (Ministry of Health, 2008). Toddlers may have up to 3 tsp/week (15g).

It has been suggested livestock feed type can affect the level of some micronutrients. Grass-fed cattle have been found to have higher amounts of beta-carotene in muscle tissues compared to grain-fed animals (Daley et al., 2010: Van Elswyk & McNeill, 2014).

Vitamin E is another fat-soluble vitamin and it exists in different forms including a-tocopherol. Reviews have shown cattle finished on grass have higher levels of a-tocopherol in the final meat product than cattle fed high concentrate diets (Daley et al., 2010; Van Elswyk & McNeill, 2014).

3.3.5. B Vitamins

Red meat is a rich source of vitamin B_{12}, which is only found naturally in foods of animal and microbial origin. Throughout life, the dietary supply of vitamin B_{12} and other methyl donors are essential for normal growth, development and function and is an essential nutrient for one carbon metabolic pathways.

It is key for protein, fat and carbohydrate metabolism including the synthesis of fatty acids in myelin in the nervous system, and the synthesis and stability of deoxyribose nucleic acid conjunction with folate, for DNA synthesis (Stabler et al., 2013; Rush et al., 2014). Ensuring an adequate intake of vitamin B_{12} particularly in pregnancy and lactation is essential for optimising health of the offspring.

A 100g portion of cooked beef or lamb provides almost the entire daily requirement for vitamin B_{12} (see Table 1).

According to the last national nutrition survey (2008/2009), one out of five adult New Zealanders had vitamin B_{12} inadequacy (<221 pmol/L), with highest insufficiency in New Zealand Europeans (37%) and South Asians (57%). There was no difference by sex. The main dietary determinant of B_{12} sufficiency was the consumption of red meat (Devi et al., 2018). For those following vegan diets (excluding all animal products from their diet), fortified foods or supplements will be necessary to provide adequate B_{12} (see section 4).

A 100g serving of beef or lamb also provides around half the daily requirement for niacin, along with some thiamine, riboflavin and vitamin B6. These B vitamins are important for numerous metabolic functions in the body, particularly as their respective co-enzyme forms, in energy metabolism.

3.3.6. Vitamin D

The main function of vitamin D is to help maintain plasma calcium concentrations by enhancing the absorption of calcium in the small intestine and controlling urinary losses. Vitamin D deficiency is most commonly associated with musculoskeletal disease such as rickets and osteomalacia, but it has also been associated with higher risk of multiple sclerosis and poorer immune function (Harandi et al., 2014) and prevention of diabetes (Harinarayan, 2014) and some cancers (Ananthakrishnan et al., 2014).

Vitamin D status is generally maintained by the exposure of skin to sunlight. Where exposure to sunlight is inadequate, dietary sources of vitamin D become important.

A high prevalence of vitamin D insufficiency was found in an analysis of the 2002 National Children's Nutrition Survey; with 4% of New Zealand children aged 5-14 years vitamin D deficient (<17.5nmol/L) and 31% vitamin D insufficient (<37.5nmol/L) (Rockell et al., 2005). The children studied had a mean serum 25-hydroxyvitamin D concentration of 50nmol/L, with mean concentrations in sub-groups ranging from 32nmol/L in Pacific girls aged 11-14 years, to 62nmol/L in New Zealand European and other boys aged 5-6 years. Children of Māori and Pacific ethnicity may be at particular risk of low vitamin D status because of low vitamin D intakes, New Zealand's high latitude (35-47°S) and skin colour (Rockell et al., 2005).

New Zealand adolescents and adults have also been found to be at risk of vitamin D insufficiency (Rockell et al., 2006). Analysis of serum 25-hydroxyvitamin D levels using data from the 2008/09 New Zealand Adult Nutrition Survey found 4.9% were vitamin D deficient (<25nmol/L) including 0.2% with severe deficiency (<12.5nmol/L), and one in four adults (27.1%) were below the recommended level of vitamin D, but did not have vitamin D deficiency. The prevalence of vitamin D insufficiency was higher among Pacific adults who were 2.3 times as likely to have vitamin D deficiency as non-Pacific adults.

In 2013, the New Zealand Ministry of Health published a statement which advises all breastfed infants in described risk groups to be supplemented with vitamin D to prevent nutritional rickets, and suggests pregnant women could benefit from supplementation also (Ministry of Health, 2013) as the maternal vitamin D status affects the infant stores. Anecdotal information suggests most of these infants are not getting supplements (there is no published literature on how many infants are getting them), resulting in observed cases of rickets and hospital admissions for complications of hypocalcaemia (such as seizures and cardiomyopathy) (Nitert, 2018). A study of pregnant and lactating women and their infants in Dunedin, found vitamin D deficiency was common in both mothers and infants with 42% (maternal), and 57% (infant) deficiency rates (25OHD < 50 nmol/L) (Wheeler et al., 2018). Because the maternal Vitamin D deficiency is associated with an increased risk of childhood rickets, the study reiterated the need for vitamin D supplementation, further supporting the notion that supplements were not being widely used despite advice.

Red meat provides vitamin D. A study into the vitamin D content of beef and lamb found them to be a source of both vitamin D_3 and its active metabolite 25-hydroxyvitamin D_3 (Purchas et al., 2007). 25-hydroxyvitamin D_3 is suggested to have 1.5 to 5 times the activity of vitamin D_3, and the authors of this study estimate (assuming 1µg of 25-hydroxyvitamin D_3 is equivalent to 3µg of vitamin D_3) , on average, 100g of beef striploin would contain 1.2µg of total vitamin D_3 and 100g of cooked lamb leg steak would contain 2.6µg.

The New Zealand Food Composition Database shows an average of 0.17ug/100g vitamin D_3 for lean, raw beef cuts and 0.054ug/100g vitamin D_3 for lean, raw lamb cuts (New Zealand Food Composition Database 2018). Although this is a small amount compared to the amount needed (adequate intake of 5-10ug/day in adults under 70 years) to improve the vitamin D status of New Zealanders to optimal levels, there is some interest in determining whether meat has a role to play in providing vitamin D. A study by Crowe et al (2011) for example, found that plasma 25(OH) D_3 concentrations were lower among people following vegetarian and vegan diets than in meat and fish eaters. As did a Finnish study that found people following vegan diets had lower concentrations of serum 25-hydroxyvitamin D_3 (25(OH)D_3) than non vegetarians. (Elorinne, 2016) The authors did not conclude meat was the mechanism or reason for the higher level and indeed, the vitamin D content of meat may be variable and dependant on the animal feed and exposure of the animal to sunlight (Glossmann, 2011).

3.4. Bioactive substances

A bioactive compound is one that has beneficial effect on the health and wellbeing of a person over and above any effects it may have as a nutrient. Meat contains various compounds with bioactivity, but it is difficult to show with certainty that the amount in meat will have a bioactive effect, because this would require a trial with humans that compared meats with and without the compound or with contrasting concentrations of the compound, but otherwise the same. A difficult task, especially when the effects are not likely to be large and may only be apparent over a long term period.

This means that most of the available evidence is based on information on the concentration of compounds in meat and on effects of administering them to humans or animals. Some examples of compounds with bioactive properties found in meat are outlined in Table 5.

Table 5: Examples of compounds present in meat that have been reported to have bioactive properties

Compound(s) with possible bioactive properties or activity in humans	Role in the body	Effects when administered to humans or animals	Concentrations reported in meat and factors shown to affect these concentrations
L-Carnitine: a compound derived from lysine.	Required to assist in the transport of fatty acids into mitochondria where they can be catabolised to release energy. Deficiency may lead to fatty acids being stored rather than used for energy.	Results have been inconsistent, but some suggestion of a decrease in fatness in some trials. May have a role in reducing the likelihood of atherosclerosis. Effective for those with a deficiency in carnitine synthesis.	Concentrations in meat are generally lower than those used in supplementation trials. They differ significantly between meat from different meat-producing species, and are higher in redder muscles.
Taurine: A free amino acid that is not found within proteins.	Taurine is an antioxidant with many biological actions and is particularly important for infants and the elderly. It is important for sight and has a protective role in muscle injury.	Taurine is widely used as a supplement with a range of claimed benefits.	The amount of taurine in a typical 100g serving of meat is less than common daily supplements. Concentrations vary widely between muscles, with higher levels in red versus white muscles.
Carnosine & Anserine: Closely related dipeptides.	These compounds are important in the control of pH (acidity) in muscle eliciting a buffering effect. Carnosine dominates in mammalian muscle, and anserine in non-mammalian muscle (eg: birds).	Readily available as supplements with suggestions of a range of benefits, many of which are still being researched.	Because of the important buffering effect, concentrations are significantly higher in white rather than redder muscle types. Amounts in a 100g serving of certain muscle meats may be similar to the amounts used as supplements.
Creatine: An amino-acid like compound.	Involved in energy metabolism where, in the form of creatine phosphate, it acts as an important energy source when the phosphate is removed.	Widely available as a supplement that has been reported to enhance muscle stamina and muscle growth under certain conditions.	The amount of creatine in a 100g serving of meat is several times lower than that commonly taken as supplements, but is greater in the whiter-type muscles.
Coenzyme Q10 (ubiquinone).	A key component in the electron transfer chain within mitochondria of every cell. As such, it is potentially critical to the production of energy in a usable form as ATP (adenosine triphosphate). Usually the body synthesises adequate coenzyme Q10. It is a strong antioxidant.	Considerable research into the value of coenzyme Q10 supplements for healthy or unwell humans have yielded mixed results.	Although present, the amount of this compound in a 100g serving of meat is low compared with the amount used in trial work. Levels are higher in redder muscles.
Alpha-Lipoic acid: A sulphur-containing short-chain fatty acid.	Important in cells as an antioxidant, but also has other important roles.	Trial work has been mainly with chickens where variable results have been obtained.	Information on levels in various types of meat is sparse.
Bioactive peptides: Peptides with up to 30 amino acids that are produced from large meat proteins during processing and/or digestion.	A wide range of effects because of many possible peptides. Generally not active in the living muscle because they are part of larger proteins.	An active area of research with a range of effects give the variable nature of peptides involved (Mora et al., 2014).	This will depend on the processing steps involved and on the stage of digestion. Considerable research interest.

The compounds listed in Table 5, which is not an exhaustive list (Kulezynski et al., 2019), are normally synthesised within the human body, so the question is whether or not the extra amount obtained by consuming meat is beneficial to an individual. Some information is available on the extent to which these compounds are affected by cooking, processing or digestion, but there is limited information on the extent to which they are affected (positively or negatively) by interactions with other meat components (including other bioactive compounds). Although more information is required, it is worth knowing these potentially beneficial compounds are present in meat, albeit at low concentrations in some cases, adding to the already well-known highly desirable palatability and nutritional features of meat.

Summary: Key Nutrients in Beef and Lamb

- Beef and lamb are excellent sources of protein, containing roughly 27-30g per 100g. The protein found in red is highly bioavailable, easily digested, and contains all eight essential amino acids.
- Lean red meat (trimmed of all visible fat) is low in fat. The fat content of beef and lamb is made up of approximately equal amounts of saturated and monounsaturated fatty acids, along with small amounts of polyunsaturated fat, including some omega-3 fatty acids.
- Meat from grass-fed animals, as in New Zealand, contains higher levels of omega-3 fatty acids than meat from animals finished on grain with a favourable omega-3:omega-6 balance.
- Beef and lamb contribute to the intake of selenium and fat soluble vitamins, D and E, with liver providing a rich source of vitamin A.
- Red meat is an good source of many essential vitamins, minerals and trace elements, including bioavailable iron and zinc, along with several B vitamins (particularly B_{12}), magnesium, phosphorus, potassium, manganese, copper as well as a number of bioactive substances (including taurine, creatine and carnitine).

Meat is a rich source of key nutrients including iron, zinc, and vitamin B_{12}, and can be essential in the diets of population groups with higher nutrient needs.

4. Food and Nutrition Guidelines in New Zealand

National food-based dietary guidelines (FBDGs) provide guidance on which foods and eating patterns will provide the required nutrients to the general population to promote overall health and prevent chronic disease (FAO, 2020). They are adapted by each country to reflect their nutrition situation, food availability, cuisine, and eating habits, including the foods that people enjoy eating and are culturally important to that population. New and updated FBDGs are increasingly incorporating environmentally sustainable diet considerations.

The New Zealand Ministry of Health Eating and Activity Guidelines recommend eating 1-2 portions of meat or meat alternatives per day. This implies individual foods within this group are interchangeable. Legumes, nuts and seeds certainly provide valuable nutrients and should be included in a balanced diet. However, these foods are not direct substitutes for animal-source foods in terms of the nutrients they provide.

Meat is an good source of key nutrients including iron, zinc, and vitamin B_{12}, and can be essential in the diets of population groups with higher nutrient needs. New Zealand research has shown red meat to be excellent protein value for money (Rush et al., 2007). The Ministry of Health recommends including at least 1-2 servings a day of iron-containing foods in our diet. For recommended serving sizes, see Table 6 on the following page.

4.1. Infants and toddlers

Complementary foods are recommended for infants at around 6 months of age (Ministry of Health, 2008). At this age, puréed meat can be added to an infant's diet with finely chopped, tender meat being introduced as swallowing develops (Ministry of Health, 2008). Lean meat can make an important contribution to the diets of infants and toddlers, providing protein, vitamins and minerals, in particular iron and zinc, which are present in a highly bioavailable form (see sections 3.3.1 and 3.3.2). Iron-fortified infant cereals can be introduced from around 6 months and foods containing vitamin C (e.g. fruits and vegetables) should be offered with meals and snacks, to assist in non-haem iron absorption. If an infant is not breast-fed, it is important to use an iron-fortified infant formula until 12 months of age. Beverages containing iron inhibitors such as tea and coffee should be avoided by young children. Overall, it is important to offer a wide variety of foods from the different food groups to ensure nutritional needs are met during this period of rapid growth and development.

4.2. Children and young people (2-18 years old)

Nutritional needs are highest during rapid growth, for example during early childhood and during the adolescent growth spurt; iron needs are particularly high in menstruating girls (Ministry of Health, 2012).

Ensuring optimal iron and zinc intake remains important among children and young people. New Zealand adolescent girls, especially those of Māori or Pacific ethnicity are at greatest risk of iron deficiency anaemia; young children may also be at risk.

To ensure adequate iron intakes, it is recommended animal foods should be included in the diet, for example meat, poultry, fish and seafood along with plant foods such as breads, cereals vegetables, legumes, nuts and fruit which provide non-haem iron. Eating foods rich in vitamin C will help to enhance absorption of non-haem iron; children and young people should also avoid drinking tea with meals. At least 1-2 servings a day of iron-containing foods should be provided in the diets of children and young people. Lean meat, poultry, fish and shellfish are also good bioavailable sources of zinc (Ministry of Health, 2012).

4.3. Healthy adults

The Ministry of Health's *Eating and Activity Guidelines for Healthy Adults* states making good choices about what and how much you eat and drink and being physically active are important for good health. Recommendations include eating a variety of nutritious foods, including vegetables and fruit, grain foods (mostly wholegrains), (low fat) milk and products, and some legumes, nuts, and seafood, poultry and red meat with the fat removed. It is advised to choose unsaturated fat, low salt, little sugar and less processed foods, with water being the drink of choice. (Ministry of Health, 2015). It is recommended to have up to 500g of cooked red meat per week (which is 700-750g of uncooked meat).

The Ministry of Health recommends New Zealand adults eat at least two servings of legumes, nuts or seeds a day or at least one serving of fish and other seafood, eggs, poultry or red meat a day – as red meat is an excellent source of key nutrients such as iron (in an easily absorbed form) as well as zinc. Low iron levels are a problem for some New Zealanders, particularly young women.

4.4. Pregnant and breastfeeding women

Iron requirements increase significantly during pregnancy (see Table 4 in section 3.1.1). However, routine iron supplements are not recommended in New Zealand as the proportion of iron absorbed from food increases in response to the increased need. They should only be given after diagnosis of iron deficiency anaemia. Iron requirements during breastfeeding are substantially lower than in pregnancy while women are not menstruating.

To ensure adequate iron intake among pregnant and breastfeeding women, dietary strategies should include consumption of at least two servings of iron-containing foods a day (Ministry of Health, 2006a). Beef and lamb can make a particularly useful contribution to intakes of iron as they are rich sources of bioavailable iron. Other sources of iron are poultry, seafood, eggs, nuts and seeds, and legumes. Monitoring of iron status throughout pregnancy is important to identify current or potential iron deficiency and all women should receive advice on dietary sources of iron and factors affecting iron absorption, in order to avoid iron deficiency.

Pregnant women following vegetarian and vegan diets may find it difficult to meet iron requirements and should be encouraged to consume plenty of iron-containing plant-based foods along with foods rich in vitamin C, while avoiding iron inhibitors at meal times, such as tea and coffee, and to have blood levels of iron checked regularly.

Pregnant and breastfeeding women should be advised to consume a variety of nutritious foods from the main food groups to ensure adequate nutritional status.

4.5. Older adults

Older adults (aged 65 years and older) have specific nutritional needs to maintain physical and mental wellbeing, including for the prevention and management of chronic diseases (Wham & Yaxley 2017).

Older adults are advised to include a variety of foods in the diet from the main food groups and to drink plenty of fluids each day. In addition, at least 30 minutes of physical activity is recommended on most days of the week (Ministry of Health, 2013a). It is recommended older people have at least one serving a day of iron-containing foods, such as lean meat, skinless chicken, seafood, eggs and legumes. It is also recommended that older adults eat adequate intakes of high-quality protein sources across the day to maintain muscle mass and function.

Older adults tend to eat less food, and less variety of food, than younger people, and are more prone to nutritional deficiencies (Fávaro-Moreira et al., 2016; Wham & Yaxley, 2017). Age-related loss of muscle mass and strength is associated with chewing and swallowing difficulties (dysphagia) which can have a detrimental impact on food intakes and therefore nutritional status (Cichero, 2018). There is a growing area of New Zealand research to address the issue of the difficulty of chewing meat in older adults, and subsequent reduced energy intake.

Table 6: Recommended serving sizes for meat and alternatives for adults

Serving size for lean meat, chicken, seafood, eggs, legumes
¾ of a cup of cooked dried beans, split peas or lentils
30g of nuts or seeds
2 slices (100g) cooked meat
¾ cup mince or casserole
1 egg (50g)
1 medium fillet of cooked fish (100g)
2 drumsticks or 1 chicken leg

Source: Ministry of Health, 2003b

5. Eating patterns of New Zealanders

5.1. Majority of New Zealanders choose to include red meat in a healthy diet

National nutrition surveys, the last of which was conducted in 2008/09, provide the most comprehensive picture of New Zealanders' eating patterns. The 2008/09 New Zealand Adult Nutrition Survey *A Focus on Nutrition* (University of Otago & Ministry of Health, 2011) studied New Zealanders aged 15 years and older, and updated the 1997 survey *NZ Food: NZ People* (Russell et al., 1999). In 2008/09, most adult New Zealanders (94.5%) reported eating red meat in the previous four weeks, with red meat eaten 1-2 times per week by 30.1% of the population and 3-4 times per week by 45.4%. More than half the population reported that they regularly or always trimmed the excess fat from meat (University of Otago & Ministry of Health, 2011).

A 2019 project between Bayer, the New Zealand Nutrition Foundation and the Auckland University of Technology (AUT) called 'The Bayer Food Focus Project' surveyed 1,346 New Zealand adults on their dietary habits. 88% of respondents reported eating red meat at least once a week, with over 50% eating eating red meat 3-4 times each week or more (Bayer, 2019).

According to the 2002 national child nutrition survey (*NZ Food NZ Children*), 95% of New Zealand children aged 5 to 14 years reportedly consumed an omnivorous diet, with just 3.6% avoiding red meat and 0.7% avoiding all meat (Parnell et al., 2003).

These surveys indicate that meat makes a valuable contribution to the intake of a range of nutrients for many New Zealanders (see section 3).

At the time of the last national nutrition survey in 2008/9, average beef and lamb intakes in New Zealand were reportedly 400g/week. Data from the 2020 OECD-FAO Agricultural Outlook shows the average New Zealander eats 3.4kg sheep meat per capita, and 11.5kg beef per capita (OECD, 2020), equating to about 63g/week and 221g/week of sheep meat and beef respectively.

There is also a trend in food-based dietary guidelines towards recommending upper limits on red meat intakes (e.g. up to 500g cooked unprocessed red meat per week), on chronic disease risk and/or sustainability grounds. Based on available consumption data, many New Zealanders are already eating red meat at a level below this recommendation.

Red meat is a nutrient-dense food and is a particularly rich source of bioavailable iron and zinc. Therefore, population-level guidelines that recommend limiting red meat intake should be combined with careful advice on planning a healthy diet to ensure nutrient needs are met first, particularly in specific population groups at elevated risk of iron deficiency.

5.2. New Zealanders choosing not to include red meat in their diet

The dietary patterns of New Zealanders have undoubtedly shifted over the last decade, and there is evidence to suggest that New Zealanders are choosing to eat less meat, less regularly as availability of non-meat meal options and foods has increased, and meat prices increase. A 2015 Roy Morgan poll found that 10.3% of respondents reported eating all or mostly vegetarian, compared with 8.1% in 2011 (an increase of 27%) (Roy Morgan, 2016). The Bayer project found 20% of respondents had experimented with a vegetarian dietary pattern within the previous 12 months, and 10% had tried a vegan eating pattern. (Bayer, 2019).

It is possible for a diet that excludes meat to be nutritionally adequate. However, if an increasing number of foods are excluded, it becomes important to plan the diet carefully to ensure nutrient needs are met. Intakes of iron, zinc and vitamin B_{12} need careful consideration – especially for people following a vegan diet.

Vitamin B_{12} is of notable concern as it is only found naturally in foods of animal origin (see section 3.3.5). Vegetarian and vegan diets have been linked to low serum B_{12} status and asymptomatic B_{12} deficiency in New Zealand-based research (Rush et al., 2009; Gammon et al., 2012). People following a vegan diet, in which all animal foods are excluded from the diet, are at particular risk of vitamin B_{12} deficiency (Mann et al., 1999).

Among adults, an inadequate vitamin B_{12} intake may not lead to symptoms of deficiency for many years, as most of us have significant body stores.

In contrast, newborn infants have only small body stores and breastfed infants of unsupplemented mothers following a vegan diet may be at particular risk. Breastfeeding mothers who choose to follow a vegan diet are advised to supplement their diet with vitamin B_{12} to the recommended level during pregnancy and lactation (NHMRC, 2006). An appropriate soy-based infant formula should be used for non-breastfed infants being fed a vegan diet and, once an infant has started to eat complementary foods, it is important to ensure a daily intake of vitamin B_{12} with fortified foods or a supplement (Ministry of Health, 2008).

Diets that exclude animal foods also have the potential to have low iron and zinc bioavailability. Eliminating meat, along with increasing intake of phytate-containing legumes and wholegrains, reduces the absorption of both iron and zinc (Hunt, 2003) and a higher intake of these nutrients will be required to meet nutritional requirements.

Vegetarians need iron intakes about 80% higher than non-vegetarians (NHMRC, 2006), and zinc intakes about 50% higher – particularly vegans (Hunt, 2003; NHMRC, 2006).

The environmental sustainability of New Zealand grass-fed beef and lamb production is considered in section 9.

Summary: Red Meat in a Healthy New Zealand Diet

- As a nutrient-dense food, lean red meat has an important role to play in the diets of all age groups in New Zealand. It can be essential in the diets of population groups with higher nutrient needs, including children, pregnant and breastfeeding women, and older adults.
- New Zealand´s Ministry of Health Eating and Activity Guidelines recommend eating 1-2 portions of meat or meat alternatives per day to ensure a healthy, balanced diet.
- It is estimated the average New Zealander eats approximately 284g/week of beef and lamb (comprising 63g/week lamb and 221g/week beef), down from a 400g/week a decade ago.
- For healthy adults, current advice is to eat up to 500g of cooked red meat per week (equivalent to 700-750g of uncooked meat) as part of a healthy, balanced diet and lifestyle.
- It is possible for a diet excluding meat to be nutritionally adequate. However, given the unique package of nutrients meat provides, careful consideration needs to be given to the nutritional adequacy of diets that exclude meat. People who follow vegan diets (i.e. exclude all animal products from their diet) need to take extra care to ensure their nutritional needs are met, and may need to take supplements (or consume fortified foods) to avoid deficiencies, particularly of vitamin B_{12}.

6. Red meat consumption and risk of chronic disease

Dietary habits play an important role in increasing or decreasing risk of a number of chronic diseases, including heart disease, stroke, type 2 diabetes, and certain cancers. These diseases account for a substantial proportion of New Zealand´s total disease burden. Dietary risks are the leading cause of health loss among specific risk factors in New Zealand, accounting for 9.4% of total disability-adjusted life years (DALYs) (Ministry of Health, 2016a).

Globally, the leading dietary risk factors for deaths and DALYs in 2017 were: high intake of sodium (accounting for 3 million deaths and 70 million DALYs globally), low intake of wholegrains (accounting for 3 million deaths and 82 million DALYs), and low intake of fruits (2 million deaths and 65 million DALYs) (GBD 2017 Diet Collaborators, 2019). High consumption of red meat was ranked the lowest of 15 dietary risks for deaths and DALYs.

Dietary guidelines in New Zealand, and around the world, focus on individual dietary components such as food groups or nutrients. However, people do not eat food groups, foods, or nutrients in isolation but rather in combination, to form an overall eating and lifestyle pattern. Different patterns of diet act in combination with other behaviours linked to health, including physical activity, smoking, and alcohol consumption, as well as genetic and other environmental factors, to shape individual disease risk. This makes identifying a causal link between specific foods or nutrients and disease risk very challenging. At the same time, certain foods are thought to be more beneficial or harmful than others when it comes to specific diseases.

Latest evidence for the role of red meat in chronic disease causation is summarised in sections 8.1-8.5 below. While there is debate over the strength and quality of this evidence (Johnston et al., 2019), the overall weight of evidence supports current guidance within New Zealand and internationally to enjoy unprocessed red meat in moderate amounts (350-500g of cooked red meat per week, or around three portions). Red meat should be enjoyed as part of a healthy, balanced diet high in vegetables, fruits, wholegrains, seafood, legumes, and nuts. 500g cooked meat is equivalent to around 700-750g when raw.

Experimental studies, particularly randomised controlled trials (RCTs), provide the strongest evidence for drawing causal inferences on the role of dietary exposures in health and disease outcomes. However, it is often not practical or ethical to conduct RCTs on diet-disease links. In the absence of RCT data, the best available evidence tends to come from epidemiological studies, particularly prospective cohort studies. Although observational in nature, prospective cohort studies can track dietary patterns and disease outcomes in large numbers of subjects over long periods of time. Epidemiological evidence is also available from case control studies, although the retrospective design of case control studies is more susceptible to recall bias (when cases with a disease recall certain exposures more clearly than controls).

Epidemiological studies provide critically important information on diet-disease relationships. However, their findings need to be interpreted with caution. Observational studies cannot establish causation; they can only provide evidence of associations, or correlations, between dietary exposures and disease outcomes. It is possible to infer causation when a) association between an exposure and an outcome is observed consistently across many high-quality population-based studies, and b) a biologically plausible mechanism between cause and effect can be established. The case for inferring causation is further strengthened when observed differences in risk are large, and a dose-response relationship is observed.

High quality nutritional epidemiology studies account for potential confounding factors (e.g. genetic factors, other diet and lifestyle behaviours) in study design and/ or during data analysis. They also seek to minimise errors in measurement of dietary intakes – a notorious challenge for nutrition epidemiology studies which typically rely on indirect estimates of dietary intakes using self-reported instruments (such as diet records, diet recalls, or food frequency questionnaires).

6.1. Cardiovascular diseases (CVD)

Cardiovascular diseases (CVDs), including coronary heart disease (CHD) and stroke, are a leading cause of health loss and death in New Zealand (Ministry of Health, 2016a, 2016b). Diet is one of the most important modifiable risk factors in CVD. A healthy diet low in saturated and trans fats, salt, and sugar, and high in wholegrains, fibre, antioxidants and unsaturated fats can substantially reduce CVD risk.

Red meat has been linked to increased CVD risk due to the potential of its saturated fatty acid (SFA) content to raise LDL cholesterol. However, evidence from epidemiological and clinical studies is inconsistent. Epidemiologial evidence suggests that high red meat intakes (more than 100g per day) may be associated with moderately increased risk of hypertension (Zhang & Zhang, 2018), all-cause and ischaemic stroke (Chen et al., 2013; Yang et al., 2016; Kim et al., 2017), and CVD-related mortality (Abete et al., 2014). More moderate levels of red meat intake (0.5 servings/ day) have also been associated with moderately higher CVD-mortality risk among Seventh Day Adventists in the US (Alshahrani et al., 2019).

However, red meat intake does not appear to be associated with CHD or haemorrhagic stroke risk, particularly evidenced in more recent studies (Ndanuko et al., 2018). In fact, a recent analysis of data from a large UK-based prospective cohort study – the EPIC-Oxford study - found higher rates of haemorrhagic and total stroke among vegetarians than meat eaters (Tong et al., 2019).

Available evidence from clinical trials indicates low-to-moderate red meat intake has no significant effect on CVD risk factors (Ndanuko et al 2018). A meta-analysis of 24 RCTs assessing the effects of red meat intake on CVD risk factors found that eating more than half a serve (roughly 50g) of red meat per day did not significantly influence blood lipids, lipoproteins or blood pressure compared to eating less than half a serve per day (O´Connor et al., 2017). An updated meta-analysis of 36 RCTs assessing the effects of red meat intake on CVD risk factors, which stratified the results by type of comparison diet found that red meat intake yielded no significant differential effects on total, LDL, or HDL cholesterol, apolipoproteins A1 and B, or blood pressure, while resulting in slightly lesser decreases in triglycerides, relative to all comparison diets combined (Guasch-Ferré et al., 2019). In comparison with carbohydrates, red meat yielded greater decreases in triglycerides. Dose-response analysis showed that increasing red meat intake (evaluated as continuous in g/d) had no significant effects on blood lipids or apolipoproteins within the studied intake range of 0 to 500 g/d. Preliminary evidence from research conducted in New Zealand suggests that red meat consumption, within the WHO guidelines does not negatively impact markers of CVD in hypocholesterimc men compared to soy-based diets (Milan et al., 2019).

Internationally, experts recommend replacing SFAs in the diet with unsaturated fats, particularly polyunsaturated fatty acids (PUFAs), to reduce CVD risk (Hooper et al., 2012; Li e al 2015; de Souza et al 2015; Sacks et al 2017; Clifton and Keogh, 2017; SACN 2018). The New Zealand Heart Foundation and Dietitians New Zealand support this recommendation (Heart Foundation, 2018; Dietitians New Zealand, 2014). Lean red meat is low in total fat and SFAs, and can be included in modest amounts in a heart-healthy diet made up of mostly minimally processed foods (including plenty of vegetables and fruit; plus legumes, nuts, wholegrains, plant oils, and fish) (Heart Foundation 2013; Bechthold et al., 2017). All visible fat should be trimmed from meat before consumption, and consumption of fatty meat and meat products (e.g. meat pies, sausage rolls, tinned corned beef and salamis) should be limited (Heart Foundation, 2018).

Recent research from New Zealand assessing the atherogenic index of long-chain, omega-3 fatty acids and phospholipid content of grain-finished and pasture-fed Wagyu, Angus and Wagyu/Dairy cross cattle, found the phospholipid concentrations were higher (in certain cuts) in pasture-fed compared to grain-finished beef. Additionally, concentrations of long-chain omega-3 fatty acids were two-fold from pasture-fed Wagyu/Dairy cross beef compared to grain-fed beef, suggesting that beef from non-traditional breeds such as Wagyu/Dairy cross cattle may significantly contribute to the recommended dietary intake of long-chain, omega-3 fatty acids (Bermingham et al., 2020).

There is emerging evidence that a high carbohydrate diet may be more harmful to cardiovascular health than high fat or protein intakes. A recent analysis of data from the Prospective Urban Rural Epidemiology (PURE) study - a large prospective cohort study involving 135,335 people from 15 countries, with a median follow-up of 7.4 years, found diets in which a higher percentage of total energy was obtained from fat, saturated fat, and protein were associated with lower risks of total mortality and non-CVD mortality (Dehghan et al., 2017). Higher animal protein intake was also associated with lower total mortality risk. No significant associations were found between total fat and saturated fat intake, and major cardiovascular disease, myocardial infarction, or CVD mortality. Eating a high carbohydrate diet (more than approximately 60% of total energy intake), on the other hand, was associated with higher risk of total mortality and non-CVD mortality.

The National Heart Foundation of New Zealand recently updated its position on red meat within a heart-healthy diet, indicating New Zealanders can enjoy up to three meals of unprocessed lean red meat per week (totaling 350g or less of cooked weight) as part of a healthy dietary pattern (National Heart Foundation of New Zealand, 2020). The review completed by the Heart Foundation to inform the updated position, was informed in part, from a 2017 systematic review that looked at the relationship between the highest and lowest red meat intake on coronary heart disease (intake range: 9-205g/d) and stroke (intake range: 0-175g/d), and the dose-response relationship of each additional 100g of red meat (Bechthold et al., 2017). The highest intakes of red meat showed a 16% relative risk of heart disease and stroke compared to the lowest intakes. This new recommendation is in line with the majority of nutrition guidelines worldwide of 350-500g cooked red meat weight per week.

6.2. Cancer

A link between red meat consumption and cancer risk, particularly colorectal cancer risk, has been heavily researched. However, while there are plausible mechanisms for the role of red meat in carcinogenesis (see section 8.2.3), epidemiological evidence is largely inconclusive.

Expert working groups for the World Health Organisation´s International Agency for Research on Cancer (IARC) and the World Cancer Research Fund (WCRF)/American Institute for Cancer Research (AICR) have recently reviewed the latest evidence on red meat consumption and cancer risks (IARC, 2018; WCRF/AICR, 2018a). The IARC Monograph Working Group, which assess hazard analysis, not risk assessment, classified red meat as "probably" carcinogenic to humans, based on limited epidemiological evidence and strong mechanistic evidence supporting a carcinogenic effect (Group 2A). The 2018 WCRF/AICR Continous Update Project (CUP) report determined there is evidence of a ´probable´

link between red meat consumption and colorectal cancer, and ´limited´ evidence of a link with other cancers, including nasopharynx, lung, and pancreas. Red meat has been downgraded from convincing for colorectal cancer, since the 2007 WCRF/AICR report, demonstrating the association is weakening over time.

As research in this area continues, it appears practical to enjoy moderate amounts of lean red meat as an important source of essential nutrients, limit very-high-temperature cooking methods (see 8.2.3.1), and limit processed meats (which the IARC has classified as Group 1 carcinogenic to humans based on a hazard analysis).

6.2.1. Colorectal cancer

New Zealand has one of the highest colorectal cancer rates in the world (Bray et al., 2018). In 2013, 3,075 New Zealanders were diagnosed with bowel cancer, and 1,252 New Zealanders died from the disease (Ministry of Health, 2013). Colorectal cancer is the second most common cause of death from cancer in New Zealand, accounting for 14% of all deaths from cancer (Ministry of Health, 2013).

Dietary factors are considered to be a major risk factor for colorectal cancer. Healthy dietary patterns characterised by high intakes of fibre-rich wholegrains, fruits, and vegetables, as well as dairy products, are considered to be protective against the disease, while processed meat is considered to be a ´convincing´ cause of colorectal cancer (IARC 2018; WCRF/AICR 2018b). Evidence for the role of unprocessed red meat is considerably less conclusive.

The WCRF/AICR CUP downgraded its classification of the strength of the evidence of an association between unprocessed red meat consumption and colorectal cancer risk from ´convincing´ in 2007 and 2011 (WCRF, 2007; WCRF/AICR, 2011) to ´probable´ in 2018 (WCRF/AICR, 2018c). The 2018 CUP review found generally consistent evidence from a large number of cohort studies showing a dose-response relationship. However, the association in the dose-response meta-analysis was significant for colon cancer, but not for colorectal and rectal cancers. Three published pooled analyses reported no significant association, but were consistent in the direction of effect.

The International Agency for Research on Cancer has also acknowledged the epidemiological evidence linking red meat to colorectal cancer remains limited and inconsistent (IARC, 2018). Half of the studies reviewed by the IARC Working Group showed a positive association, but half showed no association, including several larger studies. A positive association between red meat consumption and risk of colorectal cancer was found in half (7 of 14) of the cohort studies analysed, and approximately half of case-control studies.

A meta-analysis including data from 10 cohort studies reported a weak, but statistically significant dose–response association between consumption of red meat and cancer of the colorectum (RR 1.17 (95% CI, 1.05–1.31) for an increase in consumption of red meat of 100 g/day) (IARC, 2018). In other words, eating 100g more red meat a day increases an individual´s relative risk by 17%, equivalent to an absolute risk of about 1%.

Subsequent meta-analyses, which have included studies published since the IARC and WCRF/AICR reviews, generally support these findings. A recent meta-analysis by Schwingshakl et al (2018) showed a dietary pattern characterised by high intake of wholegrains, vegetables, fruit and dairy products and low amounts of red meat and processed meat was associated with lower risk of CRC. Each additional 100g/day of red meat was positively associated with colorectal cancer relative risk (RR 100g/d: 1.12, 95% CI 1.06, 1.19; n=21). Another meta-analysis observed positive associations for colorectal cancer, but not distal colon cancer risk, while evidence for rectal cancer was inconclusive with positive results in case control but not cohort studies) (Zhao et al., 2017a).

A pooled analysis of data from the Nurses Health and Health Professionals Follow-Up Studies found little evidence that higher intake of unprocessed red meat substantially increased risk of CRC (Bernstein et al., 2015). Higher unprocessed red meat intake was associated with a lower risk of distal colon cancer, after adjusting for calcium, folate, and fibre intake. A weak non-significant positive association between unprocessed red meat and proximal cancer was observed (Hazard ratio = 1.14, 95% CI: 0.92–1.40; *P* for trend 0.22).

A meta-analysis of prospective studies examined the association between intakes of meat subtypes (beef, pork lamb, veal, and poultry) and colorectal cancer (Carr et al., 2016). Comparing highest versus lowest intake, beef consumption was associated with an increased risk of CRC (RR = 1.11, 95% CI: 1.01-1.22) and colon cancer (RR = 1.24, 95% CI: 1.07-1.44), but no association was found with rectal cancer (RR = 0.95, 95% CI: 0.78-1.16). Higher consumption of lamb was also associated with increased risk of CRC (RR=1.24, 95% CI: 1.08-1.44).

A recent analysis of data from the UK Biobank – a large prospective cohort study of approximately 500,000 men and women aged 40-69 years recruited from across the UK between 2006-2010, found those who reported consuming an average of 54 g of red meat per day had a 15% greater relative risk of incident colorectal cancer (hazard ratio (HR): 1.15, 95% CI: 0.98–1.36) compared with those who reported consuming an average of 8 g/day (Bradbury et al., 2019). Each 50g/day increment in red meat intake was associated with an 18% increased relative risk (HR: 1.18, 95% CI: 1–1.39, *P*trend = 0.049). The association was stronger among men but a null association was observed in women. There was also heterogeneity by sub-site of the colon - a positive association was observed for distal colon cancer and no association for proximal colon cancer.

Overall, where positive associations have been observed between red meat consumption and colorectal cancer, they have tended to be weak in magnitude, with most relative risks being below 1.5. In practice, increases in risk observed tend to be small at an individual level. Most studies adjusted for major known confounders, including smoking and alcohol consumption, however most did not adjust for consumption of other foods/food groups – therefore, it is possible the apparent effects of red meat could be due in part to low consumption of other foods such as fibre, fish and vegetables.

According to one recent New Zealand study, the most important modifiable lifestyle risk factors for colorectal cancer in New Zealand are obesity and alcohol consumption (Richardson et al., 2016). This study estimated population attributable fractions (PAFs) for six known modifiable risk factors associated with colorectal cancer. The PAF is the burden of disease that could be avoided if exposure to these risk factors were reduced. The overall PAF for red meat consumption was found to be 4.8% (95% CI: 2.6-7.0), compared to 9% for obesity (95% CI: 6.7-11.2) and 6.6% for alcohol (95% CI: 3.6-9.6). In calculating the PAF for red meat, the study team assumed a high RR (for the highest quartile of red meat consumption compared with the lowest) of 1.35 (95% CI: 1.21-1.51) and high red meat consumption of 5 or more times per week.

6.2.2. Other cancers

Although red meat consumption has been linked to other cancers, including pancreatic, prostate, nasopharyngeal, breast, and lung cancer, the overarching evidence is limited to weak according to the World Cancer Research Fund (WCRF/IARC, 2018).

Lippi et al (2016) reviewed published meta-analyses of the links between different types of meat consumption and cancer risk, and found red meat consumption increased risk of colorectal, lung, esophageal, and gastric cancers, but not hepatoceullular carcinoma, pancreatic, ovarian and prostrate cancers.

Latino-Martel et al (2016) determined that evidence of a positive association between red meat consumption and colorectal cancer is ´convincing', while there is ´suggestive´ evidence of positive associations with pancreatic, stomach, breast, and bladder cancers. The evidence on esophageal, lung, prostate, and kidney, endometrial and ovarian cancers was deemed ´not conclusive´. Others have also found inconclusive evidence of a link between red meat consumption and prostate cancer (Bylsma & Alexander 2015; Wu et al., 2016).

A meta-analysis of evidence from case-control and cohort studies by Zhao et al (2017b) observed a statistically significant association between red meat consumption and pancreatic cancer in case control, but not cohort studies when comparing highest versus lowest consumption. In dose-response analysis, pancreatic cancer relative risk increased by 11% for each 100 g/day increase in red meat consumption.

A single published meta-analysis of case-control studies investigating the association between red meat consumption and risk of nasopharyngeal cancer observed a statistically significant dose response relationship (Li et al., 2016). The summary RRs were 1.35 (95% CI = 1.21-1.51), 1.54 (95% CI = 1.35-1.76), and 1.71 (95% CI = 1.14-2.55) for <100, 100-300, >300 g/week compared with no consumption, respectively (P trend = 0.003). However, there was significant heterogeneity between study outcomes and the definition of red meat used was not clear.

A meta-analysis of 6 cohort studies and 28 case-control studies identified a pooled RR of increased risk of lung cancer associated with red meat consumption of 1.44 (95% CI, 1.29-1.61). Dose-response analysis revealed for every increment of 120 grams of red meat per day, the relative risk of lung cancer increases 35% and for every increment of 50 grams red meat per day the relative risk of lung cancer increases 20% (Xue et al., 2014). A more recent meta-analysis by Gnagnarella et al (2018) looked at the association of lung cancer, among never smokers, with consumption of various types of meat, fish, heterocyclic amines and polycyclic aromatic hydrocarbons. They found a statistically significant 24% increased relative risk of lung cancer for high consumption of red meat (summary relative risk 1.24, 95% CI 1.01-1.51), based on 11 estimates, with low heterogeneity (I2 = 31%).

A number of recent meta-analyses have identified positive associations between red meat consumption and breast cancer (Guo et al., 2015; Wu et al, 2016; Dandamudi et al., 2018; Farvid et al., 2018). However, again, increases in risk tend to be small. In a meta-analysis of prospective studies that investigated the association between red meat and processed meat consumption with incident breast cancer by Farvid et al (2018), for example, high consumption of red meat was associated with a 6% higher breast cancer relative risk than those with the lowest consumption (pooled RR:1.06; 95%CI :0.99-1.14). Another meta-analysis found a small increase in risk relating to processed meat consumption, but no association for red meat (Anderson et al., 2018).

6.2.3. Possible mechanisms linking red meat consumption with cancer

Several possible mechanisms linking red meat consumption and certain cancers have been hypothesised. These include: the promotion of carcinogenesis by high-fat diets; the formation of carcinogenic heterocyclic amines (HCAs) and polycyclic aromatic hydrocarbons (PAHs) during cooking at high temperatures; the promotion of carcinogenesis by haem iron; and the formation of carcinogenic N-nitroso compounds (NOCs) both within meat and endogenously (WCRF, 2007; Baghurst, 2007; Santarelli et al., 2008; IARC 2018). These mechanisms have been explored in animal, in vitro, and clinical studies.

Despite concluding that ´strong´ mechanistic evidence exists for the carcinogenicity of red meat, the 2018 IARC Monograph Working Group report cautioned the carcinogenic mechanisms associated with the consumption of red meat and processed meat cannot be attributed to a particular meat component, and that meat consumption is not the only context of exposure to some of these components (IARC, 2018).

6.2.3.1. Formation of mutagenic compounds at high temperatures

The formation of mutagenic compounds such as HCAs and PAHs during cooking of meat at high temperatures may play a role in red meat´s carcinogenicity (Chiavarini et al., 2017; IARC, 2018). HCAs are produced during high-temperature cooking of meat, such as frying and when using a barbecue. Such high cooking temperatures cause amino acids and creatine to react together to form HCAs (WCRF, 2007). PAHs are produced from the incomplete combustion of organic compounds; the main sources are cooked and smoked meat and fish (notably barbecued meat) and tobacco smoke (Santarelli et al., 2008).

However, evidence to support the hypothesis that human cancer risk is specifically due to the intake of HCAs in the diet is mixed and inconclusive (Le et al., 2016). Data on PAHs in overcooked meat suggest these may be a risk factor, but there is insufficient evidence to draw firm conclusions (Santarelli et al., 2008). In addition, HCAs and PAHs are also present in chicken and fish that have been cooked at high temperatures, neither of which have been associated with cancer risk (Alisson-Silva et al., 2016). In practical terms, when barbecuing, it is suggested to cook meat on a solid hot plate without exposure to a naked flame.

6.2.3.2. Haem iron carcinogenicity

Haem iron may catalyse the formation of NOCs from natural precursors in the gut. Red meats are a richer source of haem iron than white meats, so such an effect may theoretically explain a stronger association between red meat and colorectal cancer, than between white meat and colorectal cancer. It would not explain, however, why white meat and fish (which also contain haem iron) appear to be protective against colorectal cancer (Baghurst, 2007).

NOCs are alkylating agents that can react with DNA and are produced by the reaction of nitrates and nitrites in processed meats with secondary amines and N-alkylamides (Santarelli et al., 2008). Endogenous formation of NOCs can also be catalysed by red meat-derived haem iron (Alisson-Silva et al., 2016). Although some research has linked red meat consumption to faecal NOC levels, it is not yet clear whether red meat-catalysed NOCs are carcinogens (Alisson-Silva et al., 2016). Further research is needed in this area.

6.2.3.3. Fat

Although fat intake from meat has been suggested to explain a link between colorectal cancer and meat intake, experimental studies show inconsistent results and epidemiological studies have failed to confirm a link (Santarelli et al., 2008). There is now little support for the notion that fat in meat promotes carcinogenesis (Baghurst, 2007). The 2011 WCRF/AICR Continuous Update Project (CUP) found limited evidence that consumption of foods containing animal fats is a cause of colorectal cancer (WCRF/AICR, 2011).

6.3. Obesity

Obesity is a significant concern in New Zealand and is a form of malnutrition. One in three (32.2%) adults and one in eight (12.4%) children are now obese (BMI ≥30 kg/m^2) (Ministry of Health, 2018). Maintaining a healthy body weight lowers risk of developing a number of chronic diseases, including type 2 diabetes and heart disease.

Internationally, recommendations for maintaining a healthy body weight and reducing risk of obesity include eating a healthy, balanced diet high in vegetables, fruits, wholegrains, seafood, nuts, and legumes; moderate in dairy products; lower in red and processed meats; and low in sugar-sweetened foods and beverages and highly processed foods, and refined grains (CDC, 2016; VicHealth, 2016; Ministry of Health, 2018a).

There is some evidence that higher red meat intakes may be associated with moderately increased risk of weight gain and obesity (Rouhani et al., 2014; Smith et al., 2015; Schlesinger et al., 2019). However, this assocation is likely to be strongly mediated by the types of red meat eaten (e.g. fatty versus lean) and the overall quality of the diet. Lean red meat is widely acknowledged as a rich source of essential micronutrients, particularly zinc, iron, and vitamin B_{12} (see section 3.3) and an excellent source of quality protein (see section 3.2). Good sources of protein may aid weight management, weight loss, and weight loss maintenance by promoting satiety and appetite control; reducing fat, carbohydrate, and total energy intakes; and improving body composition (Anderson and Moore, 2004; Larson et al., 2010; Santesso et al., 2012; Wycherley et al., 2012; Aller et al., 2014; Gosby et al., 2014).

With the aging of the population there is an increasing concern of sarcopenic obesity where there is high fat mass and low muscle mass. Improved quality and quantity of dietary protein intake helps improve muscle strength and preserve muscle mass alongside increased exercise and physical activity. The replacement of refined carbohydrate intake with low-fat protein sources such as lean meat and fat reduced dairy as part of a balanced diet helps maintain a healthy weight (Zamboni et al., 2019).

6.4. Type 2 Diabetes

Type 2 diabetes and its complications, including CVD and kidney disease, are a major cause of morbidity and mortality in New Zealand and exert considerable costs. Key risk factors include age, ethnicity, family history, smoking, obesity, and physical inactivity. A healthy dietary pattern high in vegetables, legumes, and fish, and low in sugar and refined starches, is important in maintaining a healthy weight and reducing type 2 diabetes risk (Jannasch et al., 2017).

In individuals without diabetes, high-protein, low-carbohydrate diets can have positive effects on glycaemic regulation, including: reductions in fasting blood glucose; reductions in early post-prandial glucose response; reductions in insulin responses; and a reduced percentage of glycated haemoglobin (Layman et al., 2008).

In individuals with type 1 diabetes, dietary fat and protein appear to increase postprandial glycaemic response, with implications for insulin management (Paterson et al., 2015).

There is epidemiological evidence to suggest high red meat intakes may be associated with increased type 2 diabetes risk, but it is inconsistent (Pan et al., 2011; Feskens et al., 2013; Tian et al., 2017; Schwinghakl et al., 2017; Neuenschwander et al., 2019). Many studies have not adjusted for the influence of other dietary factors, including fibre, lipids, and carbohydrates, on diabetes risk, which may have confounded the results.

There is some emerging evidence high protein diets may increase type 2 diabetes risk by raising blood glucose levels and promoting hyperinsulinaemia (a risk factor for insulin resistance (Zhao et al., 2018). Certain essential amino acids present in red meat and other animal foods, including leucine, tyrosine, and phenylalinine, may also play a role (Zhao et al., 2018).

As research in this area continues, the evidence supports current advice to enjoy lean red meat in moderate amounts as part of a healthy, balanced diet high in vegetables, fruits, wholegrains, seafood, legumes, and nuts.

Good sources of protein may aid weight management by promoting satiety and appetite control and improving body composition.

6.5. Mental Health

Mental health is an integral part of health and well-being, as reflected in the definition of health in the Constitution of the World Health Organisation: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." (WHO, 2013).

According to the latest (2017) Global Burden of Disease Study findings, depression is the third leading cause of disability worldwide, after low back pain and headache disorders (James et al., 2018). In New Zealand, rates of diagnosed mental health conditions are on the rise with rates of psychological distress, depression, and mood and/or anxiety disorders highest among Māori adults, and adults living in the most socioeconomically deprived areas (Ministry of Health, 2019). In the latest (2017/18) update of results from the New Zealand Health Survey, 8.6% of adults reported experiencing psychological distress in the past four weeks, and 16.6% reported that they had been diagnosed with depression (Ministry of Health, 2019).

The relationship between diet quality and mental health is an emerging area of research. Epidemiological evidence suggests healthy dietary patterns (high in vegetables, fruits, legumes, wholegrains, and lean protein sources) are associated with a reduced risk for depression and anxiety disorders, while unhealthy dietary patterns (high in processed foods, refined carbohydrates, and saturated fat) are associated with poorer mental health outcomes (Jacka et al., 2010, 2011a; Psaltopoulou et al., 2013; Lai et al., 2013; O´Neil et al., 2014). The hypothesis of reverse causality is not supported by the available data; that is, reported associations do not appear to reflect poorer eating habits as a consequence of mental health problems (Jacka et al., 2011b).

There is some, limited intervention evidence suggesting improvements in diet quality can improve mental health outcomes (Opie et al., 2015; Jacka et al., 2017). A recent RCT to investigate the efficacy of dietary improvements in the treatment of major depression among adults, for example, found that provision of dietary counselling and support resulted in a significantly greater reduction in self-reported depressive symptoms (measured using the Montgomery–Åsberg Depression Rating Scale) over a 12-week period compared to the provision of general social support ($t(60.7) = 4.38$, $p < .001$) (Jacka et al., 2017). Dietary advice provided to participants in the intervention group was based on Australian and Greek Dietary Guidelines and included a recommendation to eat lean red meat 3-4 times per week.

Another Australian study which examined the relationship between red meat consumption and depressive and anxiety disorders among adult women (n=1,046) found that women consuming less than the recommended intake of red meat per week (3-4 serves of 65-100g per week) were more likely to have a diagnosed depressive or anxiety disorder than those consuming the recommended amount (Jacka et al., 2012).

A more recent review of research published between 2007-2018 found that reported vegetarians were more likely to be depressed than meat-eaters in eight of 11 cohort studies, while the remaining three studies reported no differences in depression between meat-eaters and vegetarians (Rosenfeld, 2018). One study reported that 34% of people with depression started on a vegetarian diet prior to the onset of illness. It is important to note that this evidence is associative rather than causal.

These findings suggest red meat consumption may play a beneficial role in mental health independently of overall dietary quality. However, more research is needed to fully understand what effects diet quality overall, and red meat consumption specifically, may have on mental health. It is likely overall dietary patterns are more important than any single food component. It has been suggested, for example, that the synergistic combination of omega-*3* fatty acids together with other unsaturated fatty acids and antioxidants from olive oil and nuts, flavanoids and other phytochemicals from fruit and other plant foods, and large amounts of natural folates and other B vitamins exert a fair degree of protection against depression (Sánchez-Villegas et al., 2009).

The relationship between diet quality and mental health is an emerging area of research. Epidemiological evidence suggests healthy dietary patterns (high in vegetables, fruits, legumes, wholegrains, and lean protein sources) are associated with a reduced risk for depression and anxiety disorders.

Summary: Red Meat and Chronic Diseases

- High intakes of red meat, particularly processed meat, have been linked to increased risk of several chronic diseases, including colorectal cancer, stroke, and type 2 diabetes, in epidemiological studies. However, the evidence is inconsistent and inconclusive.
- While evidence for the carcinogenicity of processed meats is considered ´convincing´, there is inconclusive evidence of a link between unprocessed red meat and cancer risk from epidemiological, mechanistic, and clinical studies.
- High red meat intakes have been associated with moderately increased risk of weight gain and obesity. However, this association is likely to be strongly mediated by the types of red meat eaten (e.g. fatty versus lean) and the overall quality of the diet.
- Eating high quality, lean sources of protein as part of a healthy, balanced diet can aid weight management, and help to improve muscle strength and preserve muscle mass as people age.
- There is emerging evidence to suggest red meat consumption may play a beneficial role in mental health independently of overall dietary quality; however, more research is needed to fully understand this relationship.
- Overall, the weight of evidence supports current guidance within New Zealand and internationally to enjoy unprocessed red meat in moderate amounts (between 350g-500g of cooked red meat per week, or around three portions) as part of a healthy, balanced diet high in vegetables, fruits, whole grains, seafood, legumes, and nuts.

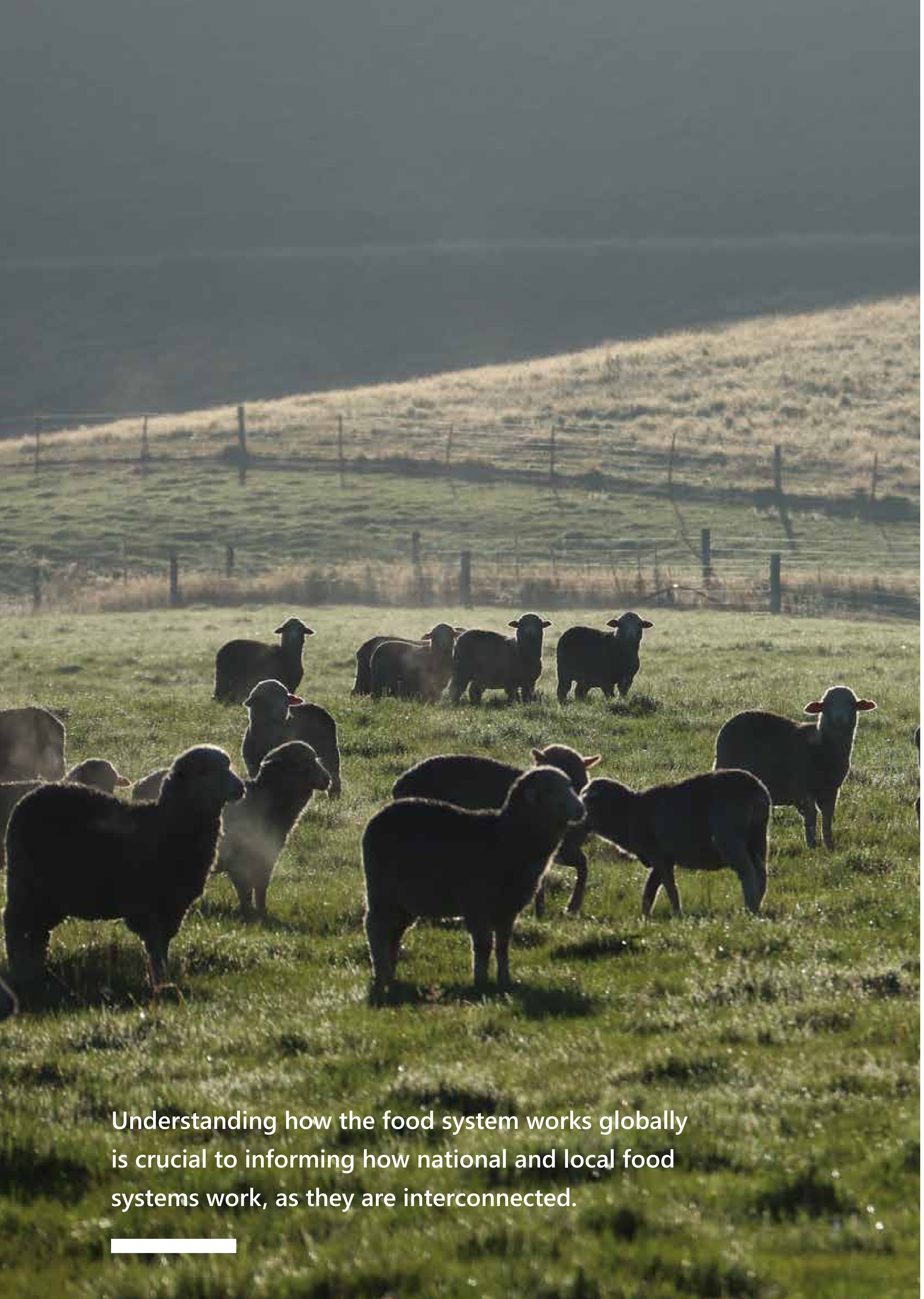
Conclusions: Health and Nutrition

Meat has been an important part of the human diet throughout our evolutionary history and today most New Zealanders include meat in their diet. Lean New Zealand beef and lamb are nutrient-dense foods that play a pivotal role throughout the life cycle – from young infants and children, through to adults and older people.

In particular, red meat is a rich source of bioavailable iron, which is important for vulnerable groups such as infants and toddlers, adolescents and women of childbearing age. Meat also provides zinc, selenium, B vitamins (particularly vitamin B_{12}), vitamin D, copper, potassium, manganese, magnesium, omega-3 fatty acids and omega-3 fatty acids, and liver is an excellent source of vitamin A. Red meat is also an excellent source of quality protein, and when fully trimmed, is low in total and saturated fatty acids.

The unique combination of nutrients found in meat can play an important role in the health issues facing many New Zealanders today.

For example, lean meat can be a helpful part of a heart-healthy diet for those at risk of cardiovascular disease; it can form a part of a weight-reducing diet for obese and overweight people. In terms of cancer prevention, the key focus should be to avoid smoking, limit sun exposure, maintain a healthy weight, and be physically active. In relation to diet, the emphasis should be on fruits, vegetables and unprocessed cereals and pulses, as well as limiting alcohol intake. A reduction in moderate red meat intakes in New Zealand is unnecessary based on current scientific evidence. However, it may be prudent to avoid very high intakes, particularly of processed meats, and to limit very-high-temperature cooking methods.



7. Food systems and the role of sustainability and nutrition

7.1. A food systems approach

A food system encompasses all activities and people involved in the production, manufacturing, distribution, consumption and disposal of food, originating from agriculture, forestry, and fisheries. This includes the economic, social and environmental aspects (Nguyen, 2018).

Understanding how the food system works globally is crucial to informing how national and local food systems work, as they are interconnected. National and local food systems are however nuanced, with cultural and community differences that need to be understood and considered (Béné et al., 2019; Nguyen, 2018).

A food systems approach is often advocated for to understand how the value chain of food works together (for one or more products), to see where and how changes can be made that better improve impacts upon the environment and people involved along the way (Nguyen, 2018; FAO 2017). The value chain of the food system is not linear but complex (Béné et al., 2019). Multi-disciplinary tactics for solving issues that the food system faces are therefore required, given the sheer number of stakeholders and systems involved (Nguyen, 2018).

7.2. Shortcomings of food systems

There are four predominant narratives about why the food system is failing: the inability of it to feed the future world population; inability to deliver a healthy diet; inability to produce equal and equitable benefits; and the unsustainability of the system and its impact on the environment (Béné et al., 2019). While there is consensus in food systems research that there is a failure of food systems and something needs to be done about it, what those failures are and how they can be addressed stems from different sectors (agriculture, nutrition, agro-ecology, socio-ecology, value chain nutrition) with different priorities on what should be 'fixed' first (Béné et al., 2019).

Solving the shortcomings of the food system is challenging with political, economic, marketing, and societal factors influencing consumer behaviours and food business priorities. The more local and the simpler the system, the easier it is to address these issues, but with a global and complex food system it becomes significantly more complicated.

7.3. Global approaches to address issues facing the food system

The UN's Sustainable Development Goals, 2015 (SDGs) are a set of 17 goals that are a universal call to act to end hunger and poverty, protect the environment, while ensuring peace, inclusion and prosperity for all (UN, 2019). The 2030 Agenda for Sustainable Development comprise the SDGs.

While many of the SDGs are connected to addressing issues facing the food system (FAO, 2016; FAO, 2018), SDG 2 directly aspires "*to end hunger, achieve food security and improved nutrition and promote sustainable agriculture*." It recognises the interconnectedness of supporting sustainable agriculture, empowering small farmers, promoting gender equality, ending rural poverty and ensuring healthy lifestyles, and addressing climate change (UN, 2019; FAO, 2016).

The 2030 Agenda for Sustainable Development recognises that food, livelihoods and the management of natural resources can no longer be addressed separately (FAO, 2016; FAO, 2018). To achieve all SDGs related to food, hunger and nutrition, a food system transformation is needed that is well considered, involves all stakeholders in the food system, and will require new ways of thinking (Caron et al., 2018).

7.4. Sustainable food systems: society and environment

The definition of what constitutes a sustainable food system varies depending on the community of practice discussing it and can be broader including social, economic, environmental aspects, or narrower focusing solely on environmental impacts of the food system (Béné et al., 2019). Here a broader definition is used:

'Sustainable food systems are those which deliver food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for our future generations is not compromised.' (Nguyen, 2018).

A food system needs to generate positive value economically, for people involved, and for the environment, in order to be sustainable (Nguyen, 2018). In practice, what constitutes a sustainable food system relies on many factors and varies depending on location, what is grown or made, and how much of it is consumed or wasted.

7.4.1. Food systems and society

Sustainable food systems have people at their core, with farmers, growers, and their employees and families producing food. See section 9 for examples in the New Zealand beef and sheep sector. Social issues such as worker's employment rights, fair salaries, and safety at work, along with rights for women, social protection for small-holder farmers and secure land tenure, are challenges for people working in the food system worldwide (FAO, 2018). Impacts on human health such as obesity and under-nutrition are also social impacts of the food system (Willet et al., 2019).

7.4.2. Food system impacts on the environment

All food production depends on natural resources. Our food system is reliant on healthy soil, water, and air. Where and when those elements are compromised, it affects food production and the ability to continue to produce food for future generations.

The food system itself also has an impact on the environment across all aspects of the value chain, not just in the growing/production stage. Manufacturing and processing food uses energy (often from fossil fuels such as coal), water, chemicals, and plastic for packaging food products. Transportation also has an impact, with shipping, air freight, rail and road all used to move food items across the value chain and expending energy and fossil fuels along the way. Consumers also impact on the system, with over-buying and poor meal planning leading to food going to waste post-purchase. Poor refrigeration and storage leads to energy and heat waste in some stores and warehouses. (See section 8.4.4).

All parts of the food system have an environmental impact. Understanding where the biggest impacts are, and helping to change them, is a core part of food systems work.

7.4.3. Climate change

Food systems are affected by climate change impacts and also contribute to climate change through emissions. Extreme weather events that destroy crops, such as floods, droughts or storms, have become more common (OECD, 2019). Pests, diseases and viruses also move to different areas and affect crops, livestock and fisheries. Farmers rely on predictable weather and a sufficient growing season for crop and livestock production, which is not guaranteed with climate change scenarios (OECD, 2019).

Globally, greenhouse gas emissions attributed to the food system from agriculture production is 14% and if emissions related to land use changes are accounted for, this rises to 24% (IPCC, 2014). Small-scale farmers and food processors produce around 80% of the food consumed in the world and they also represent 80% of the 570 million households living from agriculture (Caron et al., 2018; FAO, 2018). See section 9.3 for information on New Zealand beef and sheep sector emissions.

Farmers' and workers' livelihoods around the world are not only reliant on the current food system, but are directly affected by the impacts of climate change (Caron et al., 2018; FAO, 2018). Transforming the food system through farming practices that mitigate climate change and allow farmers to adapt will be key to meet climate change reduction targets and to take necessary climate action (Caron et al., 2018). Agro-ecology, regenerative agriculture, and innovative climate-smart farming practices can help the resilience of land use practices (FAO, 2018; Caron et al., 2018). Every level of the food system value chain, not only farming, will be affected in some way by the extreme events associated with climate change and the slow onset impacts (FAO, 2017). Storage, processing, transportation, ports and other food facilities are not yet adequately designed to be climate resilient.

A food systems approach can help to identify hotspots and what measures and interventions are needed to have the greatest impact (FAO, 2017). While mitigation, namely reducing greenhouse gas emissions, is needed, most of the pressing work required for the food system value chain to withstand the impacts of climate change, is in the need for it to adapt and be resilient (FAO, 2017).

Growing different crops (e.g. drought tolerant) in an area prone to be drier may be an example of adaptation for a farmer, who may also, by changing that crop type or land-use practice also reduce their emissions. Across the food value chain, this intervention is only valuable for the farmer if there is a secure supply to market, which means infrastructure such as roads or ports may in fact be the most important part of that food system to adapt to localised extreme events, such as storms or flooding. Seeing the system as a whole is therefore critical for food system resilience and planning for climate change impacts.

7.4.4. Water, food waste, and land development affect food systems

Water quality and its accessibility for food production and processing is another critical issue facing food systems (FAO, 2018). This is also compounded by climate change impacts in some areas (OECD, 2019). Access to fresh water is crucial for all aspects of the food system from production through to processing, which are reliant on hygienic and safe water (FAO, 2018). Crops and livestock account for 70% of global water withdrawals and that is set to increase (FAO, 2018). Ridoutt et al., (2019) have looked at water scarcity footprints in relation to diet quality from Australian diets as one of numerous factors to consider in sustainable food systems. See section 9.5 on water usage in the New Zealand beef and lamb sector.

Food loss and waste squanders resources used in production and also contributes to global greenhouse gas emissions, estimated to be 8% of all global emissions, with most food waste creating methane (HLPE, 2014). It's estimated that food loss and waste is equivalent to one third of food produced for human consumption in mass, which is 1.3 billion tonnes per year (HLPE, 2014). Depending on the region, that is either in production and post harvest (often lower income countries) or distribution and consumption (often in middle to higher income countries) (HLPE, 2014). Understanding where waste occurs in the food system and how to reduce or eliminate it (through new ways of processing or technology upgrades) is an important part of improving the food systems' sustainability.

In some areas, pressures from urban land use development also impact on food production, with soil paved for housing and urban sprawl at the expense of growers and farmers in those areas (OECD, 2019). Protecting soil and working with urban planning is crucial to reducing this loss to the food system's productivity. Clearing of forests, wetlands and land use changes, for food production continues to be a challenge for biodiversity, which is currently in extreme decline (FAO, 2018). Currently more than 75% of global food crop types rely on animal pollination and the annual value of global crop output at risk due to pollinator loss is estimated to be between US$235 to US $577 billion (IPBES, 2019). Cropland scarcity footprints in relation to Australian dietary choices and planetary boundaries, have been investigated by Ridoutt et al (2020). Also see section 10.4 on land use and deforestation and section 10.7 on biodiversity in the New Zealand beef and sheep sector.

Taking a food systems approach can help to understand where water issues, food wastage, biodiversity loss, and land use changes are occurring to help make better decisions for natural resources.

7.5. Food systems and nutrition

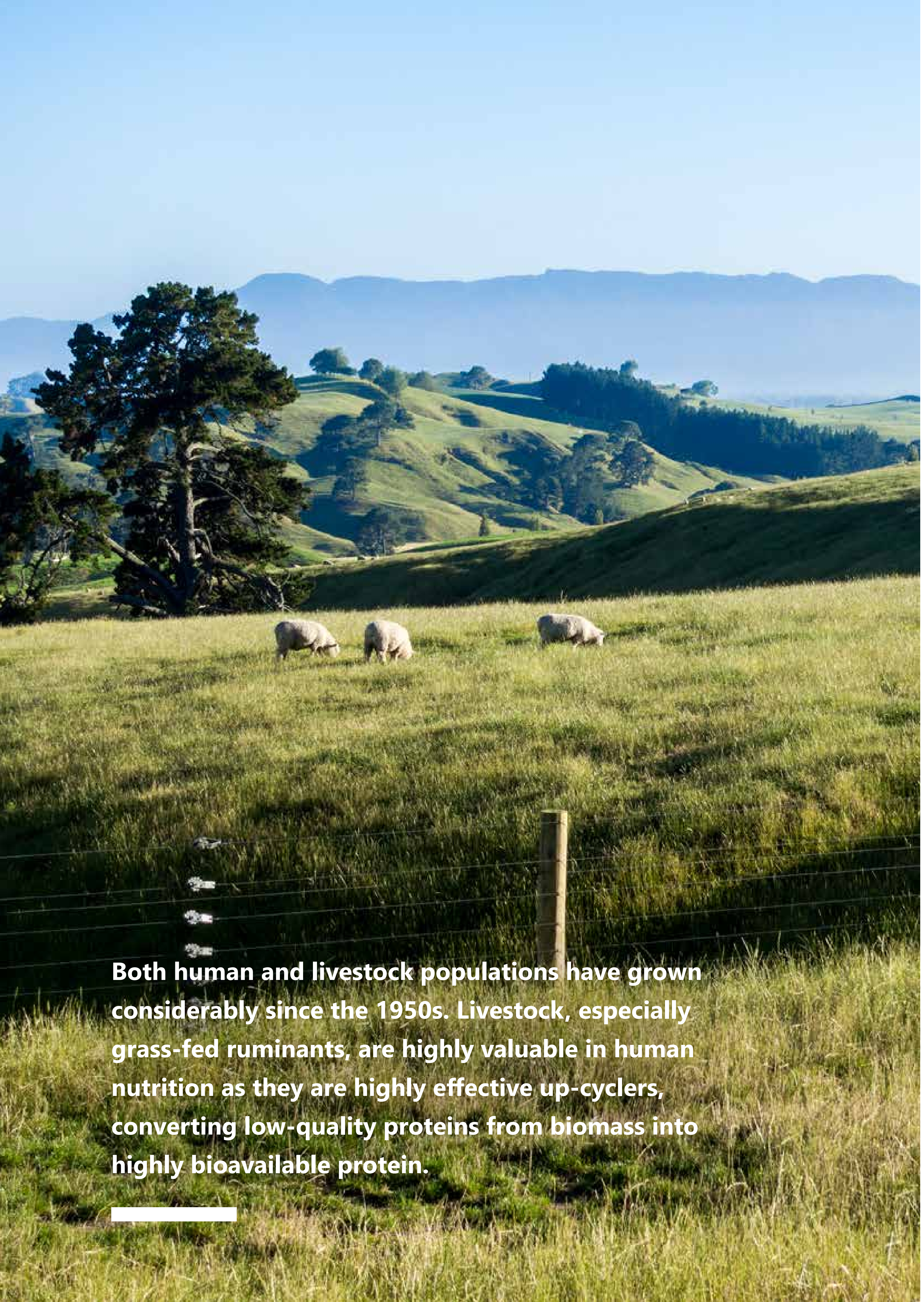
Historically, work and studies by nutritionists, and those in public health, have not been designed to consider the impact of the wider food system, including effects on the environment and food businesses (Dangour, Mace, & Shankar, 2017). Now with an ever more complex set of problems being faced by the food system, there is a push to combine approaches of finding 'healthy' and 'sustainable' food.

Work on food systems has shifted in the past decades from a focus on increasing production (i.e. feeding people) to helping people to nourish themselves in a sustainable way (Caron et al., 2018). For example, in multi-lateral agreements like the 2030 Agenda for Sustainable Development; global food forums (e.g. EAT's Stockholm Food Forum; ICLEI's Resilient Cities); reports such as those by the EAT-Lancet Commission (Willet et al., 2019); and numerous organisations now including that approach in work objectives (e.g. CGIAR; FAO).

This approach recognises that the social and health impacts of the current food system (obesity and under-nutrition) are directly linked to a failure in the food system itself, and therefore forms a core part of the food system. Recent reports have directly linked food, health, and sustainability at a global scale. The EAT-Lancet Commission (Willet et al., 2019) called for a significant change to the way people eat globally to try and address simultaneously the environmental and health impacts of food production and consumption (only looking at those two parts of the food system). The Lancet Commission report (Swinburn et al., 2019) described obesity, under-nutrition and climate change as pandemics, that together form 'The Global Syndemic', a synergy of pandemics occurring in time and place and affecting each other. This represents a paramount challenge for people, the environment and our health with the food system an underlying driver of these problems (Swinburn et al., 2019).

At the same time, broad and all encompassing approaches that simultaneously link together nutrition, culture, environment, and society to solve food system challenges have been critiqued for espousing win-win solutions that are yet to be truly applied and tested technically, particularly where there is often a lack of political will to change (Béné et al., 2019).

Therefore, a fundamental challenge for those working in food systems (both in nutrition and sustainability) is how to get the balance between impacts on human health and the environment right. This means new approaches and innovations are required to find solutions to these pressing issues; many of the solutions needed, we have not yet found.



8. Sustainable Nutrition

Meat has an important place in the human diet. Animal source foods (ASF) are nutrient-dense, and a source of highly bioavailable essential amino acids, together with key vitamins and minerals including vitamin A, B12, B6, riboflavin, pantothenic acid, niacin, iron, zinc, phosphorus, selenium, and essential omega-3 polyunsaturated fats. 100g of lean red meat can provide up to 10-25% of the recommended allowance of these micronutrients and protein (Williams, 2007).

At present, the world population can be split broadly into two major dietary scenarios, with over 2 billion people relying on a diet rich in animal source foods (ASF), and the rest of the world's population living on diets rich in plant sourced foods, particularly of cereal origin (Pimentel et al., 2003). Historically, ASF can form a substantial portion of the diets consumed in regions with geographical conditions more suited to livestock farming. In regions where arable farming is predominant, ASFs are important (nutritionally) complementary foods for the population requirements for certain critical nutrients that may be low/lacking in plant foods (FAO, 2017b; Neumann et al., 2014; Reynolds et al., 2015). Further, grazing livestock are an integral part of the grassland ecosystems that cover up to 25% of the earth's total land surface (Reynolds et al., 2015) and an important source of livelihood for millions of people including farmers, in particular small-holder farmers worldwide (Godde et al., 2019) with pastoral farming contributing up to 40% of the global income from agriculture (Nabarro & Wannous, 2014).

Both human and livestock populations have grown considerably since the 1950s. Livestock, especially grass-fed ruminants, are highly valuable in human nutrition as they are highly effective up-cyclers (Mottet et al., 2017). Ruminants convert low-quality proteins from plant biomass into highly bioavailable protein (Broderick, 2018). Globally, today, ASF provides > 40% of the dietary protein with meat (18%), dairy (10%), fish and shell fish (6%) and other animal products (9%) being the major subtypes (FAO, 2010; FAO, 2019). According to estimates by the UNFAO, livestock protein consumption is estimated to be 27.9% globally, however, developed countries can derive up to 47.8% of their protein from ASF (FAO, 2011).

8.1. Red meat consumption and health

International agencies such as the WHO, World Cancer Research Fund (WCRF) and International Agency for Research on Cancer (IARC) have deemed there exists an association between (higher (> 200g/d)) consumption of red and processed meat and colon and rectal cancer (WCRF/AICR, 2018; Godfray et al., 2018; Le Leu et al., 2015; Lewin et al., 2006; Chan et al., 2011; English et al., 2004) and other major non-communicable diseases including cardiovascular disease (Karageorgou et al., 2019; Kontogianni et al., 2007; Key et al., 2019), diabetes mellitus (Karageorgou et al., 2019; Kontogiani et al., 2007; Key et al., 2019; van Dam et al., 2002) and obesity (Appleby, 1998). In 2015, an IARC working group on the Evaluation of Carcinogenic Risks to Humans reviewed over 800 epidemiological studies that evaluated links to over 15 types of cancer, and classified processed meat (meat that has undergone salting, curing, fermentation, smoking or other processes, such as ham, salami, bacon, and certain sausages) as "carcinogenic to humans" while unprocessed red meat (muscle meat including beef, veal, pork, lamb, mutton, horse and goat) was classified as "probably carcinogenic to humans" (Domingo et al., 2017; IARC Monographs, 2015). For more information on the role of red meat in health and disease, see section 6.

The global average consumption of meat is believed to be 122g (carcass weight or ready to cook equivalent)/d (33% pork, 33% poultry, 20% beef, and the remainder 14% being lamb, goat and other animal meats) (Food and Agriculture Organisation of the United Nations Statistics Division, 2019; Godfray et al., 2018). The global average intake of red meat in populations that consume it regularly is 50-100g/person/d, with over consumption recorded at a high of 200g/person/d (Bouvard et al., 2015; Food and Agriculture Organisation of the United Nations Statistics Division, 2019). In comparison, overall meat consumption in New Zealand has reduced from 277.82g/person/d in 2013 to 205.4g/person/day in 2019. However, these estimates may be higher than the actual individual intake of red meat, since the above studies are based on the data extracted from the Food and Agricultural Organisation (FAO)'s Food Balance Sheets (FBS) and Commodity Balance Sheets, which do not directly measure individual consumption and also do not make adjustments for different types of wastes (Del Gobbo et al., 2015; Godfray et al., 2018;). In a study that compared the FAO's FBS estimates to nationally representative, individual-based dietary surveys from the Global Dietary Database (GDD), it was found that the FBS overestimated the national dietary intake for a majority of the food groups including that of red and processed meat by up to 120% (Del Gobbo et al., 2015), and at the same time potentially underestimated the intake of discretionary convenience foods (Williamson et al., 2005).

The most recent (2015) comprehensive estimates of the GDD that carried out 1137 survey-years of global data with participants from 185 countries, reported that the global unprocessed red meat intake was 57.9g/d (40.1–89.2g/day) (Miller et al., 2019).

According to Beef + Lamb New Zealand's Economic Service, working estimates of consumption to the year ending 2018/19 indicate New Zealanders eat about 47.2kg per annum comprising 23.9kg pork, 17.4kg beef, 5.1kg lamb and 0.8kg mutton. Since the data was first collected year ending 1990/91, consumption of beef has decreased 44%, lamb has decreased 62%, mutton decreased by 95%, and pork has increased 81%. Poultry consumption has increased 184% from 16.8kg to 47.8kg in the same period (BLNZ Economic Service, 2019).

In terms of protein intake, the global total protein intake is 78.2g/d (61.0-92.5g/d), and mean national total protein intake of all 185 countries is > 46g/d. The global animal protein intake was 33.3g/d (38.3-42.8 g/d), while the global plant protein intake is 29.1g/d (Reedy et al., 2019). It is of note that in terms of mean intake, New Zealand does not appear to consume more than the recommended amounts of unprocessed red meat as a subtype (the consumption trends are in line with the quantities recommended by New Zealand's food-based dietary guidelines (FBDGs)) (Miller et al., 2019). Overall, at the population level, New Zealand appears to consume sufficient quantities of protein as a macronutrient (Reedy et al., 2019), however, there is a lack of recent data on whether the population is getting sufficient high quality protein with bioavailable essential amino acids.

Moreover, while there is an overall increase in global meat consumption (Henchion et al., 2014), there appears to be a decline in the consumption of beef in most high-income countries since the early 2000s (European Environment Agency, 2017; Godfray et al., 2018), while the consumption appears to have drastically increased in several middle-income countries (Godfray et al., 2018), with a worldwide noticeable shift to poultry Environment Agency, 2017; Mottet et al., 2017). Globally, rising population and urbanisation, especially in the developing world, will result in an increased total meat consumption in future, most likely through a rise in pork and poultry consumption, with poultry expected to become the highest consumed meat by 2022 (OECD/FAO, 2016).

The reduction in red meat consumption may partly be driven by its perceived link with several chronic diseases. However, the scientific evidence for this association remains contentious (Campbell, 2019; Stanton et al., 2018).

The current section is restricted to reviewing some of the latest investigations into red meat consumption and their associated health risks (Table T1). The three major approaches to understanding the effect of red meat consumption on long-term health of individuals are: (a) epidemiological cohort studies (observational studies that have a large number of participants whose health is followed over a number of years), (b) randomised controlled trials (RCTs) in humans (experimental studies wherein participants are allocated to treatment/intervention or control/placebo groups at random), and (c) Meta-analysis (a type of statistical analysis that combines the results from select, different studies to arrive at an accurate assessment of an effect). RCTs are considered as the gold standard of evidence-based medicine and nutrition, as they can enable the investigation of cause–effect relationships with the least bias and confounding factors. All of the above mentioned methods have their drawbacks, and therefore, results from any cause–effect relationship study must be interpreted with caution.

Red meat has been implicated in various chronic diseases owing to certain intrinsic compounds such as myglobin and haem-iron, its saturated fat content, and the heterocyclic aromatic amines and polycyclic aromatic hydrocarbons generated during high-temperature cooking. Processed meat intake is considered a dietary risk as it contains carcinogenic chemicals (N-nitroso compounds and polycyclic aromatic hydrocarbons) that are produced during the processing steps of curing and smoking. For several decades, saturated fat was thought to be a major risk factor due to its supposed effect on LDL cholesterol levels that were implicated in the development of coronary artery disease, and cancer, but recent studies have shown that there is insufficient evidence for the link between intake of dietary fat and progression of atherosclerosis (Malhotra et al., 2017; Shih et al., 2019; Temple, 2018).

Up to 40 % and 48 % of total fatty acids in the lean component of red meat and fat components of red meat are comprised of saturated fatty acids, respectively (Williams, 2007). The major saturated fatty acids in beef are myristic acid (C14:0), palmitic acid (C16:0) and stearic acid (C18:0). Beef and lamb contain relatively lower levels of arachidonic acid (C20:4) in both the visible fat and lean portion (Li et al., 1998; McAfee et al., 2010). Further, most trimmed lean red meats are relatively low in fat (<7%) and contain moderate amounts of cholesterol, except for mince meats (Williams, 2007). Ruminant meats are a natural source of conjugated linoleic acid (CLA; C18:2) - fatty acids that are believed to have several health benefits including immunomodulatory, antioxidant and antidiabetic properties among others (Mulvihill, 2001). Furthermore, red meat is a source of endogenous antioxidants such as carnosine and glutathione (Williams, 2007), and the gastrointestinal digestion of red meat protein is also known to generate health-beneficial bioactive peptides (Escudero et al., 2010; Mora et al., 2017).

In addition, regardless of their genetic makeup, gender, age, species or geographic origin (Daley et al., 2010), grass-fed red meat has the potential to be nutritionally superior to grain-fed cattle (Daley et al., 2010). Apart from having an overall lower fat content (Daley et al., 2010), grass-fed beef and lamb have naturally high levels of α-linolenic acid (C18:3) and long-chain (C20–C22) n-3 polyunsaturated fatty acids (Wood et al., 2004), and higher tissue-levels of pro-vitamin A, vitamin E and antioxidant content (Daley et al., 2010).

Several recent studies (summarised in Table 7) have investigated and/or re-examined the numerous health risks associated with red and processed meat intake, including cardiovascular disease, colorectal cancer, breast cancer, central nervous system demyelination, and all-cause mortality. Briefly, the following key inferences can be drawn from these studies: (a) Much of the evidence suggests that unprocessed red meat as a food group, when consumed within the recommended levels, may result in marginally negative health outcomes; however, in-depth mechanistic studies are required to ascertain causality. Within this context, given that the role of saturated fatty acids in cardiovascular disease is disputed, other meat compounds such as haem iron and sodium content may be involved in the health risks attributed to monotonous dietary patterns involving (over) consumption of red meat and consequent suboptimal intake of other nutritious foods, notably low fibre intake (Mozaffarian, 2016; Reynolds et al., 2019) alongside lifestyle-related factors including activity levels; (b) Processed meat may pose certain health risks; (c) The focus of dietary advise must be on holistic "dietary patterns" (Moughan, 2018) , wherein the intake of beef, veal, pork, lamb, mutton, horse and goat is recommended to be limited to the range of 350-500 g of cooked weight/week depending on regional food preferences and nutrient requirements; (d) It is inferred for overall health, processed meats should be completely eliminated from all diets.

The above conclusions are in agreement with the current worldwide recommendations about red meat consumption including those issued by consensus-based or national, and international organisations (Herforth et al., 2019; IARC Monographs, 2015; WHO, 2019).

Based on a recent global review of food-based dietary guidelines (FBDG) of over the 90 countries (7 from Africa, 17 from Asia-Pacific, 4 from the Near East, 33 from Europe, 27 from Latin America and Caribbean, and 2 from North America), following are the major guidelines for red meat consumption (Herforth et al., 2019):

1. Consume lean meat or separate fat from meat (34% of countries with FBDGs)
2. Limit *or* moderate consumption of meat (23% of countries with FBDGs)
3. Eat less red and processed meat (≈ 500 g/week, refers to cooked weight that would correspond to 700-750g of raw meat)

Further, the recently released IPCC report encourages the adoption of a global average diet that is flexitarian in approach with a limited red meat intake of one portion/week, while also approving of grass-fed meat production systems such as those in New Zealand.

New Zealand does not appear to consume more than the recommended amounts of red meat, in line with food-based dietary guidelines (Miller et al., 2019).

Table 7: A synopsis of recent studies that examined the relationship between processed and unprocessed red meat intake, and the occurrence of various nutrition-related non-communicable diseases.

Author and year	Study name and country	Design of the study	Total no. of participants/articles reviewed/Data type	Year(s) of study	Age and Sex	Consumption scenario tested	Health event/ outcome studied	Adjustments made/ considerations	Key findings
De Oliveira Mota et al., 2019	Dietary survey - INCA 2; Metropolitan France	Probabilistic risk assessment model quantifying the risk, deaths and disability adjusted life years (DALY) of selected outcomes	Incidence of outcome per 100000 people	2005-2007	3-79 years old; M and F	Unprocessed beef, pork, lamb and veal; mean consumption for each age class and gender and the probability density of consumption for red meat eaters	Colorectal cancer and cardiovascular disease	Age, sex, smoking status, and body mass index, intake of fruits, vegetables, energy, and alcohol	Red meat consumption associated with a total of 19 [95% CI = 8–33] DALY per 100,000 people/y for colorectal cancer and 21 [95% CI = 12–32] disability-adjusted life year (DALY) per 100,000 people/y for cardiovascular disease. Consumption of < 65 g/d can limit the risk of the studied health outcomes. (The total cardiovascular disease mortality associated with red meat intake in France was 1%)
Zheng et al., 2019	Nurses' Health Study and the Health Professionals Follow-up Study; United States	Prospective cohort studies (# 2)	53553 women and 27916 men	Baseline set as 1994; End of follow up in 2010	30-55; M and F	Processed and unprocessed red meat consumption	Total and cause specific mortality in women and men	Age, race, family history of myocardial infarction, diabetes or cancer, weight, smoking status, aspirin use, multivitamin use, menopausal status and postmenopausal hormone therapy use for women, physical activity, and physician diagnosed hypertension, diabetes, or hypercholesterolemia and alcohol consumption	Increase in processed red meat consumption by a minimum of half a serving/d associated with 13% increased mortality risk (1.13, 1.04 to 1.23). For processed meat, there was a 9% higher mortality risk (1.09, 1.02 to 1.17).
Thomsen et al., 2019	Based on data from the Danish National Survey of Diet and Physical Activity (DANSDA); Denmark	Probabilistic substitution model (risk-benefit assessment)	2811 participants	Dietary intake data spanning over 19677 individual days	4–75; M and F	Substitution of red and processed meat with both vertebrate and invertebrate seafood	Fetal neurodevelopment associated with maternal fish consumption and methylmercury (MeHg) exposure; coronary heart disease (CHD) mortality risk associated with intake of the fatty acids docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA); hypothyroidism and male infertility risk associated with exposure to dioxin and dioxin-like (dl-) polychlorinated biphenyls (PCBs); colorectal cancer (CRC) risk associated with red and processed meat consumption; and non-cardia stomach cancer (NCSC) risk associated with processed meat consumption		A total of 5,786 (4,390; 7,299) DALYs/y in Denmark could be averted if red and processed meat was substituted with seafood in the population group of 15-75 years, however, significant variations were observed across age and gender groups, with a potentially negative impact of the studied dietary substitution scenario for women of childbearing age.
Kaluza et al., 2019	Swedish Mammography Cohort; Sweden	Population-based prospective Cohort (with Cox proportional hazard models)	34053 participants	2002-2014	53-88; F	Processed and unprocessed red meat consumption	Chronic obstructive pulmonary disease	National identification number, cancer history	Increased risk of COPD only among women consuming ≥ 50 g/d of processed meat [confined to ex-smokers (P for interaction = 0.30)]. No statistically significant association observed between long-term unprocessed red meat consumption and COPD incidence (HR = 0.87; 95% CI 0.74–1.02)
Argyridou et al., 2019	Based on data from the UK Biobank; UK	Observational cohort study (with Cox model)	419075 participants	2018	40–69; M and F	Red meat assessed through three variables: beef, lamb/mutton,and pork intake. Processed meat defined through a single variable (any intake of bacon, ham, sausages, meat pies, kebabs, burgers, and nuggets)	All-cause mortality, cardiovascular disease death and cancer mortality in relation to physical function assessed using handgrip strength and self-reported walking pace	Cancer and/or cardiovascular disease history, demographic characteristics, physical activity and dietary factors	Each additional serving/week of unprocessed and processed red meat was linearly proportional to an observed increase in all-cause- (3.3%), cardiovascular disease- (2.4%), and cancer (2.6%) mortality. Observed risks of all-cause- and cancer mortality mitigated in participants with a brisk walking pace.

A note on risk: When risk is reported in outcomes, it is relative risk, not absolute risk. Relative risk is the likelihood of the condition occurring in a group of people with different behaviours, physical conditions or environments.

Absolute risk is the likelihood of an event or health condition occurring under specific conditions.

For example a relative risk increase of 18% reported to develop bowel cancer if you eat 50g/day of processed meat equates 1% absolute risk (an increase from 5.6% lifetime risk to 6.6% estimated lifetime risk).

Salari-Moghaddam et al., 2019	Studies from the US and Sweden	Systematic review and dose-response meta-analysis of prospective cohort studies	289952 participants	Papers published until April, 2018	≥ 27; M and F	Search key words included: ("Red meat" OR (Meat AND Red) OR Pork OR Beef OR "Cured meat" OR "Processed meat" OR Diet OR Lifestyle OR Food OR Meat OR "Risk factor" OR N-nitroso OR "Nitroso compounds" OR Nitrates OR Nitrosamines)	Search key words included: (("Pulmonary Disease" AND "Chronic Obstructive") OR COPD OR "Chronic Obstructive Pulmonary Disease" OR COAD OR COBD OR AECB OR "Chronic Obstructive Airway Disease" OR "Chronic Obstructive Lung Disease" OR "chronic obstructive respiratory disease" OR "chronic obstructive airflow disease" OR "chronic obstructive bronchitis disease" OR "acute exacerbation of chronic bronchitis" OR ("Airflow Obstruction" AND Chronic) OR "Chronic Airflow Obstruction" OR emphysema OR "lung disease" OR "chronic bronchitis")	Eligibility/Study selection criteria: all prospective cohort studies that considered processed red meat as the exposure variable and chronic obstructive pulmonary disease as the main or one of the outcomes. Two publications in which hazard ratios were reported as effect size	Linear dose-response meta-analysis revealed that each 50g/week increase in processed red meat intake increased the risk of chronic obstructive pulmonary disease by 8%
Cui et al., 2019	Sweden, US, Germany	Meta-regression analysis	321 articles reviewed; final analysis included 6 articles; 134863 participants	Papers published until August, 2017	M and F	Processed and unprocessed red meat consumption	Risk of heart failure	Most studies adjusted for energy intake, demographics: age, sex, race, education level lifestyle factors: physical activity level, smoking, and drinking status, disease history: cardiovascular disease, diabetes, and hypertension	No significant association between red meat intake and heart failure in American or European populations
Ruan et al., 2019	ComPARe project; Canada	Alternative population attributable risk estimation method based on average exposure to relative risks	Simulation of 10000 samples	Most current literature syntheses (IARC monographs, WCRF reports)	M and F	Processed and unprocessed red meat consumption	Risk of cancer	Dietary and lifestyle behaviours	Current burden of cancer attributable to red meat consumption found to be 5.9% for all associated cancers (5.3% for colorectal cancer, 12.8% for male pancreatic cancer and 5.4% for stomach cancer), translating to 0.6% and 0.9% of all incident cancers ≥ 30 y for probable cancers (colorectum) and all associated cancers (colorectum, pancreas, stomach), respectively. It was also found that a mean decrease of 0.5 servings/week of red meat or processed meat may prevent ≈ 8700 or 16,600 cancer cases, (between 2015 and 2042)
Alshahrami et al., 2019	Adventist Health Study 2; US and Canada	Prospective cohort study	96000 participants	2002-2007	M and F	Unprocessed (cooked) red meat and processed red meat, and poultry consumption	Cardiovascular diseases death	Adjusted for age, sex, diet and lifestyle factors	Found a higher all-cause and CVD mortality with relatively low intake of red and processed meat; the effects of unprocessed red meat were more evident

van der Brandt et al., 2019	The Netherlands Cohort Study	Multivariable case-cohort analysis	58279 men and 62573 women; Present findings based on 8823 deaths and 3202 subcohort members	1986-1996	M and F	Unprocessed red meat, poultry, processed meat; and fish, eggs, dairy, pulses and nuts		History of cancer (excluding skin cancer) or CVD (myocardial infarction, angina pectoris, stroke) and other confounders	Higher red meat and processed meat consumption were found to be associated with higher alcohol intake and BMI in men and women; Red meat linked to lower fruit and low-fat dairy intake; Red meat intake directly proportional to intake of vegetables, eggs and nuts in men; Red meat correlated with the incidence of diabetes, but inversely proportional to poultry intake in women; Unprocessed red meat intake not related to increased mortality, processed meat consumption is related to an hightened risk of overall, CVD and respiratory mortality; substitution of processed meat with other proteins could lower the studied health risks
Cobaic & Scarborough, 2019	UK, France, Finland, Italy and Sweden	Life table model to study the health impact of achieving sustainable dietary scenarios	Country-specific nutrition surveys-based study	Data from before 2019	M and F	Various diets that meet nutrition recommendations but have different degrees of impact on greenhouse gas emissions (fruits, vegetables, fibre, red meats and processed meats intake extracted from surveys)	Dietary risk factors included based on meta-analyses of studies that have quantified diet–disease associations. Diseases included in the study were coronary heart disease, stroke, type 2 diabetes, breast cancer, colorectal cancer, lung cancer and stomach cancer	-	The optimisation model used in the study for evaluating dietary scenarios in the UK, France, Italy, Sweden and Finland, showed that reducing greenhouse gas emissions of the diet while maintaining its nutritional quality, deviating as little as possible from the current consumed diet will lead to considerable reductions in red meat and processed meat consumption.
Black et al., 2019	Data from the Ausimmune Study; Australia	Case-control study	282 cases and 558 controls	2003–2006	18–59; M and F	Alternate Mediterranean diet score (aMED)	Risk of a first clinical diagnosis of central nervous system demyelination	Models run, both, unadjusted and adjusted for history of infectious mononucleosis, serum 25-hydroxyvitamin D concentration, total years of smoking, education, total energy intake, and dietary misreporting	
Farvid et al., 2018		Systematic review and meta-analysis of prospective studies (Databases MEDLINE and EMBASE)	13 cohort, 3 nested case–control, 2 clinical trial studies (Participant nos. ranging from 493 to 319,826)	Until January, 2018 (study duration/ follow-up = anywhere from 1.9 to 20 y	40-76; F	Red meat, processed meat, and total red meat (red meat + processed meat) consumption	Breast cancer	Adjustment for energy intake, smoking, benign breast disease, family history of breast cancer, and alcohol intake	Unprocessed red meat consumption not associated with an increased risk of overall breast cancer; processed meat consumption associated with a greater risk of breast cancer; significant risk association between processed meat intake and breast cancer risk after menopause

Wang et al., 2019	Dietary Protein Sources and Atherogenic Dyslipidemia', Clinical Trials	Randomised 2-arm crossover design study	113 volunteers (44 males and 69 females)	2016	21-65; M and F	Red meat, white meat, or non-meat protein sources (relating to either high- or low-saturated fat intake)	Effect on lipoprotein particles and trimethylamine N-oxide (TMAO) metabolism	-	Significant increases in fasting plasma and urine TMAO levels in case of red meat diet, in comparison to white meat or non-meat isocaloric diets (some subjects showed over a 10X increase); Mechanism behind increased systemic TMAO levels: (i) enhanced nutrient density of the dietary metabolite's precursors; (ii) increased microbial TMAO production from carnitine, and (iii) reduced renal excretion of TMAO; discontinuation of dietary red meat can lower plasma TMAO levels within a month
Karageorgou et al., 2019	Sub-analysis from the Global Dietary Database (P10-073-19); global study	Comparative risk assessment model (data obtained from from meta-analyses of prospective cohorts)	266 surveys; 1,630,069 individuals; 113/187 countries; 82% of the world's population	Data from 2010	25-85; M and F	Suboptimal unprocessed red and processed meat consumption	Coronary heart disease and type 2 diabetes mortality	Details not available (Nutrition 2019 Abstracts)	Suboptimal intake of processed red meat resulted in significant cardiometabolic disease associated mortality. The above burden far exceeded that of the burden resulting from unprocessed red meat consumption.
O'Connor et al., 2019	OR22-08-19; multiple countries	Meta-analysis and meta-regression of randomised controlled trials	1171 articles (PubMed, Cochrane, and CINHAL)	Up to August 2018	≥ 19; M and F	≥ vs <0.5 servings/d of total red meat (generally recommended intake levels by most FBDGs)	Effect of defined dietary parameters on the markers of glycemic control and inflammation	No diagnosed cardiometabolic disease	In adults without any diagnosed cardiometabolic disease, consumption of 0.5 servings of total red meat/d (≈ 250 g/week) does not have a negative impact on the markers of glycaemic control or inflammation
Khuu et al., 2019	Women's Healthy Eating and Living (WHEL) Study (P05-038-19); United States	Cross-sectional design	3088 breast cancer survivors	Details not available (Nutrition 2019 Abstracts)	F	Processed and unprocessed red meat consumption	Association of the said meat intake to serum C-reactive protein (CRP) and haemoblobin A1c (HbA1c) in breast cancer survivors	Details not available (Nutrition 2019 Abstracts)	Study found significant positive correlation for both unprocessed and processed red meat with plasma CRP and HbA1c (predictors of breast cancer prognosis and development of comorbidities such as diabetes). This association does not appear to be fully mediated by BMI among the subjects
Bradbury et al., 2019	UK Biobank study; UK	Cox-regression models	475581 participants	2006-2010	40-69; M and F	Meat, poultry, beef, lamb, pork, oily fish, non-oily fish, fresh fruit, dried fruit, raw vegetables, cooked vegetables, cheese, tea and coffee, and alcohol intake (questionnaires)	First diagnosis of colorectal cancer or primary underlying cause of death by colorectal cancer	Adjusted for education, and 18 variables (known/suspected confounders) + further adjusted red and processed meat for milk, cheese and fibre from bread and breakfast cereals	A 25g/d increase in processed meat intake and a 50g/d increase in red meat intake resulted in a 19% and 18% greater risk of incident colorectal cancer, respectively. Highest intake of 76g/d of red and processed meat that corresponds to the recommended amounts of red meat as per most dietary guidelines also had a 20% greater risk of colorectal cancer in comparison to an intake level of ≈ 21g/d

See page 48 for explanation on relative vs absolute risk.

Randomised control trials are considered the gold standard of evidence-based nutrition, enabling the investigation of cause-effect relationships with least bias and confounding factors. Other research methods have drawbacks, and must be interpreted with caution.

8.2. Red meat and sustainable diets

Present global food systems are one of the major causes of environmental degradation. Every food consumption pattern has a measurable environmental impact.

In particular, higher consumption of animal sourced foods (ASF), and red meat in particular, is believed to exert relatively greater stress on the environment (Lindgren et al., 2018; Walker et al., 2019). Livestock farming has a significant requirement for natural resources (Gerber et al., 2013) and can alter the biogeochemical cycles, thereby impacting soil, water, air, crops, climate and biodiversity (Billen et al., 2014; Bouwman et al., 2013; Leip et al., 2015).

In terms of greenhouse gas (GHG) emissions, wholegrains, nuts, legumes, fruits and vegetables are considered to have the lowest emissions/g food produced. Within plant foods, rice production has significantly high emissions. Dairy production has marginally higher emissions than wholegrains, followed by egg production that can emit 3-5 times the GHG of plant foods. Fish production emits greater GHG than poultry, and one gram of red meat can emit up to 5 times more GHG than poultry (Clark, 2019).

In other global estimates based on a review of recent life cycle assessment (LCA) meta-analyses on the environmental impact of different foods by Clark et al. (2018), it was found that per kilocalorie (kcal) of food produced, dairy, eggs, poultry and low-impact fish production systems emit 100-2500% more GHG in comparison to plant foods. Ruminant meats including beef, sheep and goat were found to emit 2000-10000% higher amounts of GHG compared to per kcal plant food produced. In terms of land requirements (on a per kcal food produced basis), the review found that pork and poultry require 100-400% more land than dairy and eggs, and red meat requires 2000-10000% more land than plant foods. Dairy, eggs, poultry and pork were found to cause intermediate levels (1000-5000% higher than plant foods) of nutrient pollution per kcal of food, but red meat production was deemed to cause the greatest extent of nutrition pollution per unit of food at around 10000% higher than plant foods (Clark et al., 2018). But the environmental stresses of different animal production systems are likely to vary greatly, with managed grazing being known to have the ability to moderate climate change by playing a role in improving the health of soil, plants, wild and domestic animals, and humans (Provenza et al., 2019). See section 9 for the New Zealand beef and sheep sector's work in on-farm environment management.

Variations in environmental impact will occur when calories, bioavailabilty of micronutrient, and the true digestibility of dietary proteins measured in terms of the digestible indispensable amino acid score or DIAAS (Report of an FAO Expert Consultation on dietary protein quality evaluation in human nutrition, 2013) of different foods are taken into account (Barré et al., 2018).

The FAO defines sustainable diets as follows:
"Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimising natural and human resources."

From a consumer perspective, the four main determinants of sustainable diets are:

(1) the amount of plant to animal source foods in the diet,
(2) the proportion of (ultra-) processed to whole foods,
(3) the proportion of imported to local foods and
(4) the extent of food wastage.

Dietary patterns that are founded on whole plant foods, containing low amounts of ultra-processed foods and more local produce with low levels of food waste are considered to be environment-friendly (Sabaté et al., 2019).

Given that agricultural emissions are projected to become approximately 70% of the total allowable emissions for all sectors by 2050 (Searchinger et al., 2018), moderating meat intake in populations consuming more than the recommended allowance would form a key strategy for closing the climate mitigation gap. It has been estimated that limiting ruminant meat intake to <200g/week (i.e. ≈ 52 kcal/person/day) in all regions by mid-century would reduce the GHG mitigation gap by half (Searchinger et al., 2018). The right dietary choices have the ability to improve diet-related environmental outcomes, but individual health outcomes of a particular dietary pattern may not always be linearly or inversely proportional to associated environmental impacts (Walker et al., 2019). In other words, depending on individual nutrient requirements, and regional food availability and traditional eating patterns, a healthy dietary choice may not necessarily translate into a relatively low environmental impact. In a diet modelling study of 16 diets to meet the New Zealand nutrient recommendations for men (only), it was found that although low-cost and low-GHG emissions diets are complementary, there may be a trade-off between reductions in higher GHG emitting foods like ASF to resultant selection of expensive alternative plant foods to fulfill the requirements of certain essential micronutrients (Wilson et al., 2013).

Further, emissions are a very complex component of climate change. All of the major greenhouse gases (water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) have different warming potentials. CO_2 is the most important anthropogenic long-lived GHG, and can impact climate from centuries to millennia. Methane, on the other hand has an atmospheric lifetime of approximately 12 years but its impact can be around 34 times that of CO_2 over the period of a century. Thus, if the emissions of CH_4 remain constant, its concentration and resultant global warming can also remain constant. Like CO_2, N_2O is long-lived with an atmospheric lifetime of approximately 120 years, and tonne for tonne, N_2O has approximately 298 times greater warming effect than CO_2. In addition, N_2O is also the most dominant anthropogenic ozone-depleting chemical (IPCC, 2013; Ravishankara et al., 2009). Consequently, the two major approaches suggested for mitigation are (i) Comprehensive multi-gas approach and (ii) Specific focus on reduction in long-lived gases (Hollis et al., 2016). Given the distinct attributes of different GHGs, and the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement goal to stabilise GHGs to prevent further climate change, it has been proposed that policies should aim for zero emissions from CO_2, and an eventual decline in CH_4 emissions (NZ Government Bill, 2019; Allen, 2015). See 9.3 for information on New Zealand's beef and sheep sector's emissions.

In the case of livestock, direct emissions, resulting mainly from animal numbers and animal performance, are CH_4 from enteric fermentation and manure management, N_2O from urine seeping into the soil, and N deposition or application on pastures.

As a country, New Zealand's emission profile is unique with nearly half of its GHG emissions coming from agriculture, exporting enough red meat to feed 19 million people one 100g serving/day (Rush et al., 2020). This is because, unlike the rest of the world, New Zealand's emissions from the energy sector are relatively low. Biogenic CH_4 from ruminants is the largest (>30%) contributor to the total New Zealand GHG emissions and is believed to be New Zealands's largest single contributor to global warming (Reisinger & Leahy, 2019). As CH_4 doesn't accumulate in the atmosphere, the extent to which New Zealand would need to reduce its own CH_4 emissions would depend on the collective actions that the rest of the world undertakes (Reisinger et al., 2019). For e.g., globally, and particularly in China and India (Zhange et al., 2016), rice cultivation contributes to around 20% of agricultural CH_4 emissions, although they only occupy approximately 10% of total arable land (Cavicchioli et al., 2019).

New Zealand meat has a significantly low carbon footprint product (Clune et al., 2017; Morris et al., 2014; Opio et al., 2013; Zonderland-Thomassen et al.,2014), with work underway to improve the present-day production system in order to foster sustainable biodiversity and promote ecosystem multi-fuctionality.

Hence, both phased reduction in biogenic CH_4 (NZ Ministry for Environment, 2019) and incentivising the provision of ecosystem services to move away from damaging agricultural monocultures (Anderson et al., 2019; Norton et al., 2018), would be equally important in achieving New Zealand's 2050 climate goals (Government Bill New Zealand, 2019; Norton et al., 2018). Norton, et al. (2018) have outlined the best course of action in the form of eight key recommendations that can help achieve significant reversal of biodiversity decline and tackle GHG emissions in New Zealand. At present, 17% of New Zealand's native forest and 24% of New Zealand's native vegetation is estimated to be on the country's sheep and beef farms (Norton & Pannell, 2018), highlighting the farming community's ongoing efforts towards restoration of native biodiversity, and Sustainable Development Goal 13 on climate action.

In summary, the larger issues of climate change may also be better resolved by making productivity improvements, restoring carbon sequestering potential of pastures, integration of agroecology, greater integration of animal production in the circular economy, and cutting-edge research such as the development of methane vaccines (FAO, 2017; Kristensen et al., 2014; Morris et al., 2014; PGgRc, 2019). Finally, ecological nutrition should be viewed in the context of agriculture, food systems, nutrient requirements, dietary and global biodiversity, cost, social and cultural aspects of food and trade (Auestad et al., 2015; Mann, 2000; Wilson et al., 2013). Further information of on-farm advances and innovation in the New Zealand beef and sheep sector can be found in section 9.

8.3. Cellular agriculture

There has been a growing interest and investment in the development of plant-based meat substitutes, in vitro cellular and acellular meat products, and insect protein to address the environmental stresses associated with livestock farming and the predicted future demand for meat (van der Weele et al., 2019). Cellular meat is cultured in vitro meat, also referred to as "clean" meat, while acellular products are specific proteins or compounds developed using microbial synthesis techniques (Tuomisto, 2019).

However, the study of the environmental impact, digestibility and nutritional value of vat-grown meats is a nascent area, and there are limited studies that investigate these aspects in detail. Preliminary evaluations based on assumptions about bioreactor design, composition and amount of nutrition medium required, have shown the production of cultured meat using cyanobacterial hydrolysate in a stirred tank bioreactor with a 60 day production cycle would have significantly lower GHG emissions, land requirements, water and (primary) energy use. These resource requirements were estimated to be up to 46 % lower than (Alexander et al., 2017) European beef that was produced conventionally (Tuomisto, 2019). Cultured meat can also free up land for extensive cattle grazing that maintains several habitats and species and aids in biodiversity conservation (Tuomisto, 2019). Information on land use and biodiversity in the New Zealand beef and sheep sector can be found in sections 9.4 and 9.7, respectively.

But there are numerous drawbacks in the above analyses: (i) a majority of these estimates assume short cultivation times that can only generate loose cell mass for use in processed meat products, while growing muscular tissue would naturally result in greater resource requirements and would therefore also come at a higher environmental impact; (ii) The estimation of environmental strain exerted by in vitro meats often excludes the wide range of co-products provided through livestock farming, replacing a significant measure of livestock with cellular- and/or plant-based meat would require a massive investment in alternative production of livestock co-products; and (iii) Cultured meat is, at present, an energy-intense production system (Tuomisto, 2019), that can have considerably high direct energy requirements for housing and unit operations of raw biomass conversion into cells and final product that would then have to be sterilised and hydrolysed (Alexander et al., 2017; Tuomisto et al., 2011).

8.4. Alternative Proteins

In the case of insect-derived proteins, initial estimates have shown while the global warming potential (expressed as CO_2-equivalents (CO_2-eq) and the summation of CO_2, CH_4, and N_2O emissions, with the conversion factor to CO_2-eq being 1 for CO_2, 25 for CH_4 and 298 for N_2O) of mealworms per kg of edible protein, was 6-12 fold lower than beef. The energy use of mealworm production per kg of edible protein is comparable to pork and only marginally lower than that of beef (1.02–1.58x as high) (Oonincx & de Boer, 2012; van Huis et al., 2013).

From a nutritional perspective, alternative proteins are marketed as products that can confer improved nutrition through tailor-made production systems, yet little is known about the true digestibility nutritive value and toxicity/health risks of these products, particularly in case of plant-based meat analogues, the formulation of which makes use of various refined ingredients and food additives, that would classify these foods as "Ultra-Processed", as per the NOVA food classification system (Monteiro et al., 2019).

It is known that excess consumption of ultra-processed foods can lead to dysbiosis (an imbalance in microflora, particularly of the gut), that can result in inflammation and chronic diseases (Aguayo-Patrón et al., 2017; Logan et al., 2017; Miclotte et al., 2019; Valdes et al., 2018).

Furthermore, the potential rise in demand of such niche, highly processed plant materials may lead to promotion of monocultures that are known to have serious environmental (Sabaté, 2019) and health consequences (Toldeo et al., 2006). Moreover, the life cycle assessment of plant-based substitutes (e.g. soy/wheat/gluten-based meat substitutes) has demonstrated that these food materials themselves have a major climate footprint (Mejia et al., 2019; Smentana et al., 2015) including having a water footprint (both on mass and edible protein) similar to that of unprocessed meat like pork and chicken (Fresán et al., 2019).

In another comparative study based on the cradle-to-plate meal life cycle assessment of various meat substitutes (including plant-based, mycoprotein-based, dairy-based, insect protein and lab grown meat against chicken meat), workers utilised a functional unit of 300g of digested proteins (based on Protein Digestibility Corrected Amino Acid Score) and found that lab-grown meat had the highest impact on a range of endpoint and midpoint categories including human health, resource availability, and ecosystem quality (Smetana et al., 2015).

While the promise of animal-free alternative proteins appears to have its advantages, at this stage, the potential sustainability gains of meat alternatives such as existing plant-based meat alternatives, and whole insects is moderate to uncertain.

In addition, the technological innovation required ranges from moderate (meat analogues and insect proteins) to high for cultured meat (van der Weele et al., 2019), indicating much work is required to ascertain their climatic sustainability (Thorrez & Vandenburgh, 2019; Lynch & Pierrehumbert, 2019), as well as their social acceptance (Hocquette, 2016) including willingness-to-eat, neophobic reactions (particularly in the case of edible insects) (Rumpold et al., 2020), and their ontological and ethical status (Mouat et al., 2018; Stephens et al., 2018), especially given the rising demand for natural foods.

Conclusions: Sustainable Nutrition

Fulfilling the nutritional requirements of 10 billion people by mid-century through a balanced and sustainable diet will require in-depth re-evaluation and re-orientation of the current food systems.

Unprocessed red meat is an authentic food that has an important role in the contemporary and future nutrition landscape owing to its social, cultural and traditional associations. Red meat, in particular lean red meat, can be an important food group for achieving the United Nations Sustainable Development Goals relating to health and prevention of malnutrition in certain regions.

It is currently recommended that moderate consumption (i.e. up to 500g of cooked red meat per week), be followed for health reasons, and in order for global pastoral farming to contribute positively to the Paris Agreement climate change targets, and closer to home, to the recently introduced Zero Carbon Bill in New Zealand. Giving up meat alone will not save the planet, but, the weight of the scientific evidence indicates that modest reductions in red meat consumption or the flexitarian dietary approach (Hagmann et al., 2019) among populations that typically consume high amounts of these foods can help promote dietary diversity that can impart several health benefits (WCRF/AICR, 2018; Arimond & Ruel, 2004; Lachet et al., 2018), with the co-benefits of reducing the environmental impact and biodiversity loss stemming from large-scale farming of domesticated terrestrial animals (HLPE, 2019). In addition, encouraging the consumption of animal proteins from diverse species would also help address some of the sustainability challenges of the Anthropocene (Hocquette, 2016).

Apart from the reported inefficient use of resources per unit protein consumed and GHG emissions from certain red meat production systems (Tilman & Clark, 2014), the inherent drawbacks of antibiotic use, animal welfare concerns, zoonosis, the purported increased risk associated with red meat consumption warrant further research. Information on New Zealand's beef and sheep sector's production systems can be found in section 9.

Finally, policies and regulations must be devised based on comprehensive metrics for food systems taking into consideration the various environmental, nutritional, social, economic and biological advantages and risks (HLPE, 2019; van der Weele et al., 2019).

9. Farming Practices and the Production of Red Meat in New Zealand

Summary

Most international research is based on feedlot production which is very different to New Zealand's grass-fed system. New Zealand has one of the lowest input and efficient livestock farming systems in the world. Farmers are working to improve their environmental footprint by further reducing greenhouse gas emissions, continuing to improve biodiversity on farms, supporting soil regeneration and water quality.

Greenhouse Emissions

- New Zealand is one of the most efficient whole life-cycle producers of beef and lamb and aspires and aims to work towards the goal to be carbon neutral by 2050.
- New Zealand's carbon emissions per kilogram of beef or lamb produced are around 25% of the global average due to our low input, low intensity and low energy free range grass-fed systems.
- Emissions from the beef and sheep sector have decreased by over 32% since 1990 through decreasing stock numbers and improved eco-efficiency per animal.
- New Zealand's sheep and beef sector has reduced methane emissions year-on-year since 1990.
- The emissions intensity (i.e. emissions per unit of production) has improved (i.e. reduced) at an average rate of about 1% per year since 1990.
- Research has determined that the majority of the remaining on-farm emissions are offset by the sequestration of woody vegetation hosted on beef and sheep farms.
- The sector is investing in a range of major projects to further reduce emissions produced by sheep and cows.

Land Use and Deforestation

- Sheep and beef production uses 34% of New Zealand's total land mass, but only 7% is suitable for cropping and much of this land is already in some form of cropping.
- Considerable forest regeneration has occurred since the 1950s - 24% of New Zealand's total native vegetation is on sheep and beef farms.

Water Usage

- Global average water usage for a kilogram of beef is 1,001 litres, excluding natural rainfall, and including irrigated water to grow grain. Global averages for fruit production are 236 litres/kilogram, and pulses 875 litres/kilogram.
- New Zealand's average is 210 litres/kilogram of beef, and sheepmeat is 46 litres/kilogram, due to limited use of irrigation as the overwhelming majority is from natural rainfall.

Water Quality

- The New Zealand sheep and beef sector is actively working on improving its impact on water quality:
    - Sediment loss is being improved through planting erosion-prone areas and retiring areas from production.
    - Phosphorus fertiliser use has decreased significantly over the last decade.
    - Nitrogen leaching on sheep and beef farms is generally significantly lower than dairy farming or vegetable production due to lower stocking rates and low use of nitrogen fertiliser.
    - E-coli is being managed by excluding stock from waterways and controlling intensive grazing.

Antibiotics, Hormonal Growth Promotants, Genetically Modified Organisms

- New Zealand has strict controls around the usage of antibiotics and has among the lowest usage globally of antibiotics in cattle and sheep production.
- Our extensive outdoor farm systems mean animals are less likely to catch infections requiring antibiotics, which can be transmitted more when kept in close proximity to one another.
- Hormonal growth promotants are virtually never used in New Zealand, only approximately 0.001% of livestock.
- New Zealand has one of the most comprehensive and rigorous genetic modified organisms (GMO) approval regimes in the world.
- No genetically modified commercial crops, fresh produce or meat are grown in New Zealand.

Animal Welfare

- New Zealand has a high standard of animal welfare set through regulation and a progressive approach from industry, adopting new technologies and meeting public expectations. Development of assurance programmes aim to capitalise on the farmers exceeding minimum legal standards.

Food Safety

- New Zealand has an international reputation for excellence in food safety and quality.
- Processors supplying markets overseas must also comply with the standards of the destination country.
- Meat is regularly tested for a wide range of contaminants and residues by independent authorities.
- The National Animal Identification and Tracing (NAIT) scheme identifies and traces animal movements enabling a quick response to a biosecurity incursion.

Halal Processing

- Halal processing has been present in New Zealand for 40 years and over 90% of animals are processed as halal.
- Halal processing must meet both halal and all other regulatory requirements, including animal welfare and food safety.
- All animals must be stunned before commercial slaughter, ensuring immediate loss of consciousness to prevent pain during the process. Unlike in some other countries, there are no exceptions to this requirement.

Our climate and landscape mean our sheep and cattle can be outside, eating pasture year-round. These factors have set a global benchmark for pastoral farm production, to sustain this, supporting policies and programmes are in place to ensure the industry is economically profitable and environmentally sustainable into the future.

Animal welfare and the environmental impact of livestock and red meat production have long been fundamental to the sector, and public interest about how their food is produced has grown.

9.1. Sustainability

Research indicates a meat-based diet requires more energy, land and water resources than a lacto-ovo-vegetarian diet (Pimentel & Pimentel, 2003; Poore & Nemecek 2018), implying the lacto-ovo-vegetarian diet is more environmentally sustainable.

Red meat production undoubtedly has an impact on the environment, as does any human activity. However, it is important to note that international research primarily draws on feedlot production, which has a very different footprint to a pasture-based system – how beef cattle and sheep are raised in New Zealand. Much of the environmental impact from a feedlot system comes from the land, water, fertilisers and cropping required to provide the feed and manage waste.

Appropriateness and sustainability of agricultural production is also relative to the climate and natural capability of the land. A production system suited to an environment can require fewer inputs to maintain production and minimise the environmental impacts in a simpler manner compared to a system that is an ill-fit. The environment also influences the appropriate production intensity of the system.

New Zealand has one of the lowest input and most efficient livestock farming systems in the world over the full life cycle. New Zealand's sheep and beef cattle utilise land that other production systems cannot practically use due to factors such as terrain, climate or impracticality of infrastructure like irrigation. For example, only 7% of the land used for sheep and beef cattle production is suitable for crops (Beef + Lamb New Zealand (B+LNZ) Economic Service, 2019), most of which is already used for cropping activities.

However, the sector recognises there is still more to be done to improve its environmental footprint and has laid out a strategy to do this (B+LNZ, 2018). Trees currently play a significant role in supporting biodiverse ecosystems. Twenty-four percent (2.8m ha) of all native vegetation is on sheep and beef farms (Norton & Pannell, 2018).

Between 1990 and 2018, New Zealand sheep and beef farmers have reduced their absolute greenhouse gas emissions by 32% (Ministry for Environment (MfE), 2017). There are 1.4 million hectares of native forests and 180,000 hectares of pine forests on sheep and beef farms that plays a significant role in sequestering carbon from the atmosphere. (Norton & Pannell, 2018). This contributes to New Zealand sheep and beef farm systems sustainability.

New Zealand's red meat processing industry has committed to improving water quality. For example, processing plant waste product treatment systems have and are being upgraded to improve waste use as soil nutrients, instead of going to wastewater treatment. Approximately 760,000 tonnes of inedible animal material per year is produced via processing practices (Statistics New Zealand, 2019). Rendering processes convert these materials into more valuable fats, oils, and protein products, providing secondary products such as biofuels, and pet and livestock feed.

9.2. Eco-Efficiency Gains

Over the last 30 years, the New Zealand sheep and beef sector has produced more from fewer animals and reduced the environmental footprint of red meat production.

B+LNZ uses 1990 as a base year because the affects of agricultural subsidies, which were removed in 1984, were deemed to have dissipated. Between 1990 and 2019, sheep numbers fell by over 50% – from 58 million to 27 million, while lamb production was only slightly lower (between -5% and -10%) and the value of exports doubled (Statistics New Zealand, 2019). Stocking rates of livestock per hectare have not increased.

The eco-efficiency gains have been built through a combination of technologies, management and infrastructure. For example, the sustained lamb production from fewer sheep has been the result of continuous improvements in many aspects of production:
Lambing rates and weaning weights: Adoption of research in ewe management for improved condition through pastures and pasture management, sheep genetics increasing lambing rates per ewe and improved lambs at weaning.

- **Lamb finishing weights:** The improvements in genetics and pasture management carry over to bigger and faster-growing lambs. Through better communications and infrastructure, lambs are able to be finished at heavier weights as they can be transported to where adequate pasture is available – whereas in the past they may have been processed at lighter carcass weights if local summer feed supply was not available. This has still occurred despite high-value sheep and beef finishing land becoming incorporated into the dairy sector from 2006 to 2016.
- **Consumer-driven and value-added:** Larger and more consistent carcasses are more efficient for further processing with potential for further value to be added to the product. Eco-efficiency gains have improved the consistency of product and size. However, optimal carcass weights are governed by consumer demand, without agricultural subsidies or trade protections, production is driven by market signals.

9.3. Greenhouse Gas Emissions

Globally, livestock are one of the significant contributors towards emissions, and the sector can also deliver a significant share of the necessary mitigation efforts (Gerber et al., 2013). The Intergovernmental Panel on Climate Change report (Pachauri et al., 2014) on Climate and Land highlighted how resilient, sustainable and low-GHG emission systems, similar to New Zealand's pastoral systems, can play a role in minimising the impacts of warming and help adjust to changing climates.

The global contribution of livestock to global warming

The Food and Agriculture Organisation of the United Nations (FAO) has undertaken a lifecycle analysis of livestock production, estimating that livestock globally contributes 14.5% of total greenhouse gas emissions (Gerber et al., 2013). This includes beef cattle, dairy cows, sheep and deer, incorporates direct animal emissions (6% of global emissions), plus the impact of cutting down trees for pasture and to grow feed and use of fertilisers.

It is often cited that livestock contribute more greenhouse gas emissions than transport, which the FAO - who published the original report - has admitted is flawed. In its 2006 report titled "Livestock's Long Shadow" (Steinfeld et. al., 2006), the FAO claimed that livestock was responsible for 18% of global greenhouse gas emissions, more than transport at around 14%. This was shown to be inaccurate and FAO retracted its original figure, and reduced it to 14% (Gerber et al., 2013).

However livestock were considered in a full life cycle analysis but transport's 14% only included emissions from fuel usage. If the same analysis was applied to the transport sector, emissions associated with production and assembly of cars and building of roads should have been included. The errors were identified in a white paper by Professor Frank Mitloehner of University of California, Davis (Mitloehner, 2015). The direct emissions for livestock and transport respectively are 6% and 14%.

It is also important to note around 63% of the estimated 1.4 billion livestock globally are in India, Brazil and China where many households rely on inefficient subsistence farming (Cook, 2020), World Cattle Inventory: Ranking of Countries, 2018). There are over 300 million cattle in India alone (31% of all cattle globally), many of which are considered sacred and not farmed for food directly.

Livestock numbers in the developing world are increasing, while livestock numbers in many developed countries (including New Zealand, Australia, UK and the US) have been falling, reducing the livestock contribution to warming from these countries.

Greenhouse gas emissions comparison between grain-fed and grass-fed beef

Many international life cycle analyses (LCA) of livestock carbon footprint (i.e. kg CO2 – equivalent per kg of product) are based on global averages whereas New Zealand's pasture-based systems have been consistently shown to be considerably lower. Some studies show grain-fed beef systems as having a lower carbon footprint, primarily because the animal has a shorter lifespan, .but these do not take into account emissions in the full life cycle, such as: grain production, or sequestration by the soil in pasture-based systems or sequestration from native vegetation on grass-based systems.

A lifecycle analysis study by AgResearch (Table 8) found that New Zealand's footprint was around one-quarter of global averages, even before sequestration by native forests on sheep and beef farms are taken into account.

Saunders et al (2019) compared the carbon footprint of New Zealand lamb exported to the UK with lamb that was produced in the UK. The study found that New Zealand lamb had a smaller footprint, despite being exported across the world, because of New Zealand's very low input/energy production systems (Saunders et al., 2019).

Table 8: Estimates of total greenhouse gas emissions (kg CO2-equivalent/kg functional unit (FU)) for the cradle to farm-gate using LCA for different animal products applied using a common methodology in each study

Region/country	FU	Sheep/lambs	Beef	Pigs	Poultry	References
Global	1 kg CW	23.4	46.2	6.1	5.4	Gerber et al. (2013)
Europe (27 countries)	1 kg meat	19-28	21-28	7-10	5-7	Weiss and leip (2012)
The Netherlands	1 kg CW	11.3	15.9	5.6		Head et al. (2011)
Australia (Eastern states)	1 kg edible meat	14.4	21.6-25.5			Wiedemann et al. (2015a)
Canada	1 kg LW	13.9	11.6			Dyer et al. (2014)
New Zealand	1 kg LW	8.6	10.5 (9.2*)			Ledgard et al. (2011b and unpubl.)
United Kingdom	1 kg CW	13.5	23.8			Webb et al. (2013)
United Kingdom	1 kg CW (or LW)	25.2 (11.9)	22.5 (12.2)			EBLEX (2012)

CW = carcass weight and LW = liveweight

*Including dairy-derived beef cattle.

New Zealand sheep and beef contribution to global warming is reducing

In New Zealand, agriculture contributes about 48% of total emissions on a global warming potential over 100 years (GWP100) basis (MfE, 2019a). The main contributors to agricultural emissions are dairy (22.5%), sheep (12.7%) and beef (8.1%).

In 2018, the New Zealand sheep and beef sector set a goal of being carbon neutral by 2050 (B+LNZ, 2018). Significant progress has been made towards this goal.

Emission levels from the beef and sheep sector have decreased rapidly. Between 1990 to 2018, absolute emissions from sheep and beef livestock have decreased by 32%, largely due to decreasing livestock numbers (52.5% for sheep, 21.4% for non-dairy cattle), while improving eco-efficiency and production (MfE, 2019a). The emissions intensity (i.e. emissions per unit of production) has improved (i.e. reduced) at an average rate of about one percent per year between 1990 to 2018.

Further processing of inedible animal material (rendering) reduces greenhouse gases, avoiding emissions from natural decomposition like carbon dioxide and methane. Estimates put this reduction in emissions from rendering alone as similar to removing 360,000 cars from the roads.

New Zealand sheep and beef farms also host native or pine forests which sequester carbon. 1.4 million hectares of native forest have been identified on sheep and beef farms, and 180,000 hectares of pine forests were estimated in joint research by University of Canterbury and Auckland University of Technology (Norton & Pannell, 2018). Research by the Auckland University of Technology has determined the sequestration taking place on sheep and beef farms by woody vegetation, is offsetting between 63% and 118% of on-farm emissions (Case & Ryan, 2020). This is equivalent to between -10,394 kt CO_2e and -19,665 kt CO_2e. Additionally, a significant proportion of the 3.3 million hectares lost from the sheep and beef sector since the 1990s was to the forestry sector.

The sector is also investing heavily in research aimed at reducing emissions produced by sheep and cattle through the Pastoral Greenhouse Gas Research Consortium (PGgRc). Over $81 million has been invested into research by the agricultural sector through the PGgRc for GHG mitigations since its inception in 2003. In particular, the sector has launched a programme into sheep that produce less methane, and research is well advanced to develop a methane inhibitor. To find out more about this research, visit pggrc.co.nz

New research about methane

The science around methane's contribution to warming is evolving rapidly. Recent research found if methane is reduced by 0.3% per year then it is no longer contributing to additional warming because methane is a short-lived gas. Any reduction of more than 0.3% per year effectively has a 'cooling' impact, like the effect of a tree (Allen et al., 2018).

New Zealand's sheep and beef sector per year between 1990 and 2018 reduced methane emissions by 1% per year since 1990, indicating no methane-related additional warming for three decades.

The existing metric for measuring the warming impacts of greenhouse gases, GWP100, masks the true effects of short-lived gases like methane. GWP100 calculates the global warming potential (GWP) of a gas over 100 years. The latest value for methane under this metric is 28, meaning methane is considered – in existing frameworks that use GWP100 – has 28 times the "global warming potential" as carbon dioxide.

However, the way methane actually behaves in the atmosphere is quite different. While methane has a very strong warming impact when it's first emitted, it diminishes rapidly over a few decades, and after a century is no longer causing strong warming because almost all of it has broken down. However, the GWP100 metric treats methane as if it will last in the atmosphere contributing to warming for centuries, or longer, which doesn't match reality. If methane is reducing, then the GWP100 metric significantly overstates the warming impact of methane. If methane is increasing, GWP100 also understates the additional warming that is being created.

The newer GWP* metric recognises the lifecycle of methane, attributing much more global warming potential to it when its emitted and if it is increasing, then reducing this in line with how the gas breaks down in the atmosphere.

What this means is GWP* provides a more accurate measure for determining how much global warming potential increases or decreases in methane has over a given timeframe. For example, where methane is increasing, it will have a much greater global warming potential under GWP*, and conversely when it is reducing, this global warming potential effect is negative (ie it is "cooling").

This means that traditional carbon footprinting methodologies based on GWP100, overstate the warming impact of New Zealand sheep and beef production compared to other products, because methane emissions from sheep and beef production in New Zealand have been steadily declining for the last 30 years.

9.4. Land Use & Deforestation

Sheep and beef production occurs on a significant proportion of land in New Zealand – 34% of total land mass (Statistics New Zealand, 2019). Nearly all production is pasture-based on land unsuitable for producing other agricultural products, with only 7% of sheep and beef land suitable for cropping (B+LNZ Economic Service). New Zealand farmers run diverse operations, so 6% of sheep and beef land is already in some form of cropping for either stock feed or food for human consumption.

In developing countries, deforestation is often linked to the clearing of land for either direct livestock grazing or growing crops to feed livestock (Hosonuma et al., 2012).

Deforestation was significant in New Zealand between 1850 and the 1950s, but since then considerable reforestation has occurred. The University of Canterbury and Auckland University of Technology estimate there are 2.8 million hectares of native vegetation on sheep and beef farms in New Zealand, 1.4 million of which is native forests (Norton & Pannell, 2018). This represents 24% of New Zealand's total native vegetation, making it the largest collection of indigenous biodiversity outside of the public conservation estate, and nearly 13% of the land covered sheep and beef farms themselves (Norton & Pannell, 2018).

The removal of agricultural subsidies in the mid-1980s made lower value pastoral land uneconomical. Since 1990, the land under sheep and beef production has decreased from 12.5 million ha to 8.2 million ha (including the 2.8 million hectares of native vegetation identified by Norton et al., 2018). Of that 4.3 million ha, approximately 1 million ha went into dairy operations while 3.3 million ha went into forestry, native regeneration, into the conservation estate through land tenure review (South Island high country), some into urban development, viticulture and horticulture, and permanent conservation under QEII Trust covenants (B+LNZ Economic Service).

9.5. Water Usage

Water used in all industries can be categorised into three types: green (rainfall), blue (extracted water from natural water bodies or bores from irrigation), and grey water (water used in processing).

The water footprint of New Zealand beef and lamb production by Zonderland-Thomassen et al (2014) shows the majority of water used is from natural rainfall, which is often not reflected in sustainability comparisons.

To produce beef, the most widely cited figure internationally for water usage is 15,400 litres/kilogram (Mekonnen & Hoekstra, 2010). This figure includes all forms of water, including rainwater, and the water used to produce grain for feedlot animals.

Mekonnen & Hoekstra (2010) highlighted that the focus should be on the use of blue and grey water as green water occurs regardless of land use type and cannot be attributed to an industry. Their research estimates the global average for blue and grey water usage in industrial beef production is 1001 litres per kilogram of beef produced, including irrigated water to grow grain.

Research from AgResearch estimates to produce one kilogram of New Zealand beef requires between 210 litres of blue and grey water, and 40-90 litres/kilogram for sheepmeat only 46 litres/kilogram. This is because the vast majority of New Zealand sheep and beef farms do not use irrigation (Zonderland-Thomassen et al., 2014).

Compared to plant-based products, New Zealand beef and lamb also compares favourably. In the Mekonnen & Hoekstra (2010) global study of the water footrprint of foods globally, they estimated that fruit production uses on average 236 litres/kilogram, and pulses 875 litres/kilogram, of blue and grey water.

9.6. Water Quality

New Zealand sheep and beef production does have an impact on water quality, as with any human activity or infrastructure. The sheep and beef sector is active in developing solutions to mitigate and reduce contaminant losses to water. The foremost water quality issues facing the red meat sector are sediment caused by erosion,

phosphorus, and *E-coli* travelling overland into waterways during heavy rainfall.

Sediment

Some topographies and soil types can be prone to erosion without appropriate management and land use. Sediment loss is a legacy of forest clearance for farmland, and with New Zealand's young soils and naturally high level of sediment loss, poor land management can exacerbate the loss of sediment. Farmers are taking steps to manage sediment loss through planting native and exotic trees in erosion-prone areas or retiring unstable land from production. New Zealand has long been a leader in land stabilisation and sediment management through plantings, particularly through breeding programmes and research with poplar tree varieties. In addition, the identification and mitigation of critical source areas in grazed paddocks can result in a significant reduction in sediment loss.

Phosphorus

The predominant pathway for phosphorus (P) loss to waterways is via overland flow resulting in losses of soil and sediment. This is because P is attached to soil particles and is lost during erosion events. Losses can also occur from fertiliser and/or effluent, particularly applications followed by a rainfall event and more readily available forms of P fertiliser. High Olsen P levels (above the optimum for pasture or crop) can also result in increased P losses.

While still an issue across the country, recent data from the Ministry for the Environment (MfE) indicated phosphorus levels are improving in 82% of tested sites across the country (MfE &Statistics New Zealand, Environment Aotearoa Report, 2019). The use of phosphorus fertiliser has decreased significantly over the last decade while optimising use through tailored applications to meet soil and plant requirements. Usage peaked in 2005 at 219,000 tonnes, but has reduced to an annual application of around 150,000 tonnes each year over the last decade (155,000 tonnes in 2015) (MfE & Statistics New Zealand, 2019).

Nitrogen

Nitrogen (N) leaching from sheep and beef farms is low compared to other forms of food production due to the generally low stocking rates per hectare and low usage of nitrogen fertiliser. AgResearch modelled estimates of the average nitrogen leaching for sheep and beef farms is 16kg N per hectare, ranging from 11-31kg N/ha/yr (Shepherd et al. 2016), which compares to an average of 0-6kg N/ha/yr for forestry which can peak at 28kg N/ha/yr during harvest (Parfitt et al., 2002). The same AgResearch modelling study estimated dairy leaching at an average of 44kg N/ha/yr and a range of 36-61kg N/ha/yr (Shepherd et al. 2016). Nitrogen losses from the New Zealand arable industry vary widely between crops, seasons, soil types and management systems. Average nitrogen leaching (as modelled by OverseerFM) can be as high as 100kg N/ha/yr for some horticultural crops.

For intensive beef finishing systems and winter grazing of brassica crops where more stock is held on smaller areas at a greater stocking density, nitrogen leaching is an issue that needs to be carefully managed.

Escherichia coli (E.coli)

E. coli is a common indicator bacteria found in animal manure and effluent that is used to indicate the presence of pathogenic microorganisms found in faecal matter that can cause disease in humans. *E. coli* and faecal material is lost to water via overland flow during rain or irrigation events, or by direct deposition into water bodies (McLeod et al., 2014).

Through proposed water quality standards (MfE, 2019b), the New Zealand agricultural industry is addressing water quality concerns, including
E. coli by:

- Controlling the grazing duration of pasture and fodder crops
- Controlling intensive winter grazing
- Excluding stock from waterways
- Restricting use of feedlots
- Increasing farm environment planning
- Reducing pollution from stock holding areas

9.7. Biodiversity

Biodiversity can be a win-win for the environment and for farm businesses. Increased biodiversity can provide more stable and resilient biological systems, which can benefit the relatively low input New Zealand sheep and beef farm systems. Biodiversity is also important to our international customers, contributing to our positive environmental image.

New Zealand sheep and beef farmers are improving biodiversity on their properties through a number of measures:

- Using native trees as shelterbelts, providing stock with shelter, creating a habitat for birds and insects, preventing soil erosion.
- Developing the organic soil horizon using the soil biota and improving pasture production.
- Riparian enhancement, improving water quality and providing a habitat for native fish and waterfowl.
- Grazing management, for example, in combination with pasture types and nutrient application, the organic horizon in the soil can be developed and in turn improve soil biodiversity and health.
- Flora diversity can improve and lengthen flowering, which benefits bee populations and hive health and other insect and bird pollinators. A diversity of pollinators can benefit the farming systems.
- There are a variety of formal and informal organisations that are centred on farming, such as specific ecosystem projects through Landcare Groups, Farm Forestry, Tree Croppers, Regional Council partnerships, catchment groups and soil conservation programmes, Red Meat Profit Partnership Action Networks, and discussion groups.
- Protecting special natural and cultural areas through Queen Elizabeth II Trust (QEII) covenants. Two thirds of existing covenants are on primary production land and 47% of all covenants are on sheep and beef properties (B+LNZ, 2020).

Norton & Pannell Report on Native Vegetation on Sheep and Beef Farms

There are significant strands of indigenous biodiversity on sheep and beef farms. Research conducted by the University of Canterbury and Auckland University showed that there are some 2.8 million hectares of native vegetation on sheep and beef farms, including 1.4 million hectares of native forest (Norton & Pannell, 2018).

The study found around 13% of the total area of New Zealand's sheep and beef farms is covered by native forest, making up approximately 17% of all New Zealand's native forest (Norton & Pannell, 2018). Importantly, in eight of the nineteen native woody vegetation ecosystem types of Land Environment of New Zealand (LENZ), there is proportionally more native forest on sheep and beef farms than on public conservation land. These environments occur at lower altitudes and in drier areas of New Zealand where there is the least remaining native vegetation.

Norton & Pannell (2018) estimated 24% of New Zealand's remaining native vegetation cover, including both native grasslands and native forest, to be on sheep and beef farms. Their calculations excluded shelter belts, erosion planting, or riparian planting.

9.8. Other Factors

9.8.1. Innovation

The New Zealand sheep and beef industry is highly innovative. New Zealand's agricultural industry moved from a highly-protected and subsidised system in the mid-1980s, to operating with negligible subsidies and no tariff or trade protection. Without industry protections, the sector has needed to be innovative, responding to market signals and improving efficiency – not necessarily total production. For example, while New Zealand's ewe flock has fallen by 58% since 1990, lamb production has only fallen by 10% and – adjusting for inflation – lamb exports rose by 43% to $3.4 billion (B+LNZ Economic Service).

The sector is also leading the way on innovation to improve the environmental sustainability of sheep and beef farming, from breeding lower methane-emitting sheep breeds, researching vaccines to reduce methane emissions in animals, and developing lower greenhouse gas-emitting grasses. Innovation has also led to significant productivity gains on-farm and in processing plants. The introduction of more processing technologies, robotics and best practice food hygiene processes has resulted in 88% productivity gain on plant between 1980 and 2013 (MIA, 2013). This, in turn, has improved regulatory compliance, improved product quality and reduced workplace injuries (MIA, date).

The industry will continue to invest in collaborative research and development projects to support growth and sustainability to increase the value of products, improve food safety and security and reduce the environmental impact of sheep and beef production. Two recent examples are the establishment of Beef + Lamb New Zealand Genetics and the Future Farm program. Beef + Lamb New Zealand Genetics enables farmers in making smarter breeding decisions, including breeding sheep which emit less methane, and the use of Monitor and Innovation Farms. The Future Farm program launched its first Farm at Lanercost in North Canterbury in November 2018.

9.8.2. Antibiotics

New Zealand has among the lowest usage globally of antibiotics in cattle and sheep production (O'Neill, 2015). The extensive outdoor farming systems mean animals are less likely to catch infections requiring antibiotics caused by being in close proximity to one another.

New Zealand has strict controls around the usage of antibiotics, mandated by the Ministry for Primary Industries (MPI). Antibiotics are only available from a veterinarian and cannot be bought over the counter. They can only be used sparingly in animals for therapeutic (medical) reasons and any treatment with antibiotics is recorded with statutory declarations made (Animal Status Declaration). Antibiotic-treated animals have a market withholding period.

9.8.3. Hormonal Growth Promotants

Hormonal growth promotants are almost never used in New Zealand, only approximately 0.001% of livestock (MPI, 2019). On the rare occasion they are used, they are strictly controlled. Use is restricted to veterinary supervision, and any animals receiving hormones must be tagged and included in a central government database. The New Zealand Beef and Lamb Quality Mark standards also certifies to consumers that products do not originate from animals treated with hormonal growth promotants.

9.8.4. Genetically Modified Organisms

New Zealand maintains one of the most comprehensive and rigorous approval regimes for genetically modified organisms in the world (United States Department of Agriculture (USDA), 2010). No genetically modified commercial crops, fresh produce or meat are grown in New Zealand (MPI, 2013). Imported processed food containing genetically modified ingredients are assessed for safety and must comply with labelling requirements (MfE, 2013a). Research into the use of genetic modification in specific applications is on-going, for example, pest control, pharmaceuticals or production enhancement in crops or animals (MfE, 2013a), but none of the products resulting from this research has been put into practice.

There is on-going discussion on the potential impact on science and/or economic development of these strict controls (Gorman, 2012), but there have been no official changes to New Zealand's general approach of proceeding cautiously, but not completely "closing the door" (MfE, 2013b) to genetic modification, as concluded by the Royal Commission into Genetic Modification in July 2001 (MfE, 2001).

9.8.5. Animal Welfare

New Zealand has some of the strictest animal welfare standards in the world, including a suite of codes and regulations that are regularly updated to reflect changes in public perception and advances in research in technology. Participation in schemes such as the New Zealand Farm Assurance Programme and Taste Pure Nature requires farmers to have a documented animal health plan and adhere to animal welfare principles above the minimum legal standard.

9.8.6. Food Safety

New Zealand has an international reputation for excellence in food safety and quality. The Animal Products Act 1999 (APA) requires all animal products traded and used in New Zealand to be fit for the intended purpose. This is achieved through risk management programmes identifying and managing hazards and other risks (MPI, 2020). All individual meat production plants must operate a risk management programme that is independently audited by MPI.

Risk management programmes must comply with the required industry standards. Plants may also operate International Organisation for Standardisation (ISO) standards that incorporate Hazard Analysis and Critical Control Points (HACCP).

Plants supplying markets overseas must also comply with the standards of the destination country. For example, the United States Department of Agriculture (USDA) market access standards or the European Union (EU) standards.

MPI veterinarians are present at every processing plant to certify any meat exported from New Zealand meets both New Zealand standards and exporting country standards, while ensuring it is suitable, safe and compliant with animal welfare standards. Every carcass is inspected by an independent inspector (AsureQuality) before being certified as fit for human consumption and export quality.

Contaminants and Residues

Meat processed in New Zealand is regularly tested for a wide range of contaminants and residues, providing assurances to overseas regulatory authorities and giving consumers confidence in the meat we produce. This is done by MPI though the National Chemical Residues Programme (NCRP) that is operated by MPI.

Traceability

Livestock (cattle and deer) in New Zealand are identified and movements traced through the National Animal Identification and Tracing (NAIT) scheme. NAIT links people, property and livestock, and can provide fast, reliable and accurate information on stock location and movements. It enables New Zealand to quickly respond to a biosecurity incursion or exotic diseases, and provides assurance to local and overseas markets about food safety standards and product integrity. It also supports traceback in the event of a food safety incident, residue or contamination issue.

9.8.7. Halal Processing

Halal processing has been present in New Zealand for 40 years and is a cornerstone of the industry business model of finding the best market for each part of the carcass. Halal certification enables access to Muslim countries and consumers in other markets. Over 90% of animals are processed as halal and some 43% of red meat exports are halal certified (MIA, 2019).

Halal processing is overseen by MPI and legislated for under the Animal Products Act 1999. Any plant undertaking halal slaughter must be listed with MPI and operate under specific programs that meet both halal and all other regulatory requirements, including food safety and animal welfare. In New Zealand, all animals must be stunned before commercial slaughter, ensuring immediate loss of consciousness to prevent pain during the process. Unlike in some other countries, there are no exceptions to this requirement, mandated by law under the Animal Welfare (Commercial Slaughter) Code of Welfare 2010.

9.8.8. Eating Quality and Provenance Programs

Industry-wide eating quality, food safety, provenance and environmental programmes include the New Zealand Beef and Lamb Quality Mark, Taste Pure Nature and the New Zealand Farm Assurance Programme.

New Zealand Beef and Lamb Quality Mark

The New Zealand Beef and Lamb Quality Mark was introduced in 1997 to ensure consistent quality of New Zealand beef and lamb sold domestically. It provides assurance that the highest standards have been met for leanness, tenderness and food safety.

Meat must be trimmed to a maximum of 5mm external fat and internal fat removed, where practical. Cuts are often trimmed completely of visible fat. Mince must contain less than 10% fat.

Taste Pure Nature

Taste Pure Nature is a New Zealand origin brand used as a global brand platform to underpin exporters' marketing programmes and enhance the positioning of New Zealand red meat. It was developed in partnership with meat processors and farmers. Only product that is New Zealand Farm Assurance Programme (NZFAP) assured can be sold under the Taste Pure Nature origin brand.

Consumer research across key markets identified a segment of consumers who want quality and experiences from their food, are interested in provenance, and the raising of food in an environmentally and ethically conscious way, and are prepared to pay a premium for it. Taste Pure Nature will connect these consumers and their values with New Zealand's naturally raised, grass-fed, free range beef and lamb.

New Zealand Farm Assurance Programme

The New Zealand Farm Assurance Programme (NZFAP) establishes a single standard for the entire industry to work towards. Set up in 2016, it continually builds on improving and streamlining processes for farmers and provides consumer assurance on integrity, origin, traceability, biosecurity, environmental sustainability, and animal welfare.

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