Green Spaces and Health: Evidence from Growing Up in New Zealand

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Community Health, University of Auckland, 2018.

Abstract

Background and Aims: Exposure to green space has been linked to increased physical activity and a lower likelihood of antenatal depression amongst pregnant women. However, it is not clear whether this is because active people prefer to live in greener areas, that is, whether these findings are a result of 'self-selection' bias. For the child, exposure to green space during the mother's pregnancy has been found to be associated with increased birth weight and gestational age, two important determinants of health in early childhood. However, limited data exist on the effect modifications of the relationship of exposure to green space during pregnancy with birth weight and gestational age that are due to age, self-identified ethnicity, education, residential rurality, and the socioeconomic status of the pregnant women. There are also limited data that specifically relate to pregnancy, and which investigate the relationship between exposure to green space during pregnancy and antenatal depression whilst also taking onto consideration maternal age, self-identified ethnicity, education, physical activity, residential rurality, and the socioeconomic status of the pregnant women.

In this study, I examined whether exposure to green space for pregnant women was independently associated with their increased participation in physical activity and with a decreased likelihood of them reporting antenatal depression, and with an increase in birth weight and gestational age in their new born infants. My analyses accounted for self-selection bias of residential locality. Effect modifications for birth weight and gestational age were investigated after stratifying for age, education, self-identified ethnicity, residential rurality, and socioeconomic status. Additionally, effect modifications for antenatal depression were explored after stratifying for these same factors, as well as for level of physical activity.

Methods: My study utilised the *Growing Up in New Zealand* cohort study antenatal dataset and the perinatal data of the pregnant women recruited into this study. My study consisted of three main components which respectively investigated: 1) Green space and physical activity in pregnant women; 2) Green space and pregnancy outcomes in pregnant women; and 3) Green space and depression in pregnant women.

The data for estimating green space were obtained from the local City Councils and the New Zealand Land Cover Database. Exposure to green space was assessed by geocoding residential addresses and further estimating the proportion of green space in each census area unit within the Auckland, Counties-Manukau and Waikato District Health Board regions of New Zealand, where pregnant women had to reside in order to be eligible for enrolment into the *Growing Up in New Zealand* cohort. Health data for the pregnant women were obtained from the *Growing Up in New Zealand* antenatal dataset; and the birth data for the new born infants were obtained through the perinatal data assembled from various sources that was linked to the *Growing Up in New Zealand* antenatal dataset. The short version of the International Physical Activity Questionnaire was utilised for estimating physical activity at two-time periods during pregnancy: during the first trimester and during the remainder of pregnancy. Assessment of antenatal depression was through the administration of the Edinburgh Postnatal Depression Scale Questionnaire. Exploration of the associations of green space with physical activity and with antenatal depression were completed using multilevel mixed logistic regression models, while the associations between green space with birth weight and gestational age were completed using multilevel mixed linear regression models.

Results: Exposure to green space for the entire cohort was not associated with participation in physical activity during the first trimester or the remainder of pregnancy after accounting for self-selection bias. Exposure to green space was not associated with birth weight or

gestational age for the entire cohort. However, exposure to green space was associated with gestational age for pregnant women residing in rural areas. Exposure to green space during pregnancy was not associated with the odds of antenatal depression after accounting for self-selection bias, nor was there any evidence of effect modifications for specific population subgroups.

Conclusions: Results suggest that exposure to green space is not associated with participation in physical activity, once preference for living in greener neighbourhoods is taken into account. While exposure to green space was not found to play a role in improving birth weight and gestational age when considering the entire cohort, it was found to be associated with a more mature gestational age for pregnant women residing in rural areas. Exposure to green space during pregnancy was found to not be associated with the odds of a women experiencing depression when considering the entire cohort, nor for any specific subgroups. It can be assumed that the availability of green space is not an important determinant of pregnancy and child health for the entire pregnant population in the cohort, but it is for pregnant women residing in rural areas. However, considering the limitations of the studies, the lack of associations between green space and health outcomes (physical activity, birth weight, gestational age, and depression in this case) for the cohort as a whole does not mean that green space will not affect their outcomes. My findings highlight the importance of considering self-selection bias and accounted for this when investigating relationships between green space and health outcomes in pregnant women and their new born infants. More studies are warranted on green space and maternal and child health outcomes in similar or different contexts overcoming these limitations.

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Role of the candidate

I was involved in acquiring green space data from the local councils and Land Cover Database. My role was to combine health data from *Growing Up in New Zealand* and green space datasets, measure green space in census area units, analyse combined health and green space datasets, and write manuscripts relating to three research projects undertaken as a part of this thesis and chapters of this thesis.

Glossary

ACOG	American College of Obstetricians and Gynaecologists
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
BMI	Body Mass Index
CAS	Census Area Statistics
CAU	Census Area Unit
CCD	Census Collection District
CCHS	Canadian Community Health Survey
CI	Confidence Interval
CSEP	Canadian Society of Exercise Physiology
DASS	Depression, Anxiety, and Stress Scale
DAG	Directed Acyclic Graph
DHB	District Health Board
EPDS	Edinburgh Postnatal Depression Scale
GHQ	General Health Questionnaire
HSE	Health Survey of England
ICC	Interclass Correlation
IPAQ	International Physical Activity Questionnaire
IQR	Interquartile range
IRR	Incidence Rate Ratio
K10	Psychological Distress Scale
LCDB	Land Cover Database
LSOA	Lower Layer Super Output Area
MANSA	Manchester Short Assessment of Quality of Life
MSOA	Middle Super Output Area

MVPA	Moderate-to-Vigorous Physical Activity
NCEA	National Certificate of Educational Achievement
NDVI	Normalised Difference Vegetation Index
NO_2	Nitrogen Dioxide
NZHS	New Zealand Health Survey
NZDep	New Zealand Index of Deprivation
OR	Odds Ratio
$PM_{2.5}$	Particulate Matter of 2.5 micrometres or less in diameter
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PWC	Population Weighted Centroid
RRR	Relative Risk Ratio
SD	Standard Deviation
SHS	Scottish Health Survey
SOGC	Society of Obstetricians and Gynaecologists of Canada
UK	United Kingdom
US	United States
VPC	Variance Partition Coefficient
VVI	Vertical Visibility Index
WEMWBS	Warwick Edinburgh Mental Health and Well-being Scale
WHO	World Health Organisation

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Extent of contribution by PhD candidate (%)	85%

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Bruce Burns	Editing manuscript
Amy Bird	Editing manuscript
Susan Morton	Editing manuscript
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The undersigned hereby certify that:

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Chapter 1. Introduction

1.1 Urbanisation, green spaces and human health

According to recent data from the World Health Organisation (WHO), more than 50% of the human population resides in urban areas. It is expected that this figure will increase to 70% by 2050 (WHO, 2016d). Although living in urban areas can be beneficial in terms of providing increased access to facilities including health care, it can also be detrimental to health due to the introduction of health hazards (WHO, 2016d). Some of the health hazards associated with living in urban areas include overcrowding, increases in the density of motor vehicles and exposure to air pollution, an increase in the number of road traffic accidents, a lack of clean drinking water, and poor sanitation (Moore et al., 2003). Other health threats associated with living in urban areas include the ingestion of unhealthy diets, the intake of high levels of alcohol, a lack of physical activity, and the development of non-communicable diseases (WHO, 2016d).

One environmental factor that can counteract some of the deleterious health effects of urbanisation is green space or "land that is partly or completely covered with grass, trees, shrubs, or other vegetation" (USEPA, 2014). Some of the examples included in the classification of green spaces are parks, beaches, and churchyards (USEPA, 2014). There is a growing body of evidence which suggests that the interaction of adults in the general population with green spaces has benefits to people's health, including better self-reported general health (de Vries et al., 2003, Carter and Horwitz, 2014), a decreased risk of obesity (Astell-Burt et al., 2014b), a decreased risk of Type 2 diabetes (Astell-Burt et al., 2014c), and a reduction in short sleep duration (Astell-Burt et al., 2013a). Additionally, exposure to green spaces for adults in the general population is associated with a reduction in all-cause and disease-specific mortalities (Gascon et al., 2016, Villeneuve et al., 2012). Even social integration and interaction (Sugiyama et al., 2008, Sullivan et al., 2004), social ties (Kuo et al., 1998, Kaźmierczak, 2013), and crime in inner-city neighbourhoods (Kuo and Sullivan, 2001, Bogar and Beyer, 2015) have been associated with green spaces in a positive way. That is, exposure to green spaces is associated with improvements in social integration and interaction (Sugiyama et al., 2008, Sullivan et al., 2004), improvements in social ties (Kuo et al., 1998, Kaźmierczak, 2013), and reduced crime in inner-city neighbourhoods (Kuo and Sullivan, 2001, Bogar and Beyer, 2015).

Recently, research has also focussed specifically on the interaction of pregnant women with green spaces, in particular, measuring the health benefits of green spaces in terms of both pregnancy outcomes and the mental health of the mother. Birth weight and duration of gestation (gestational age) are two pregnancy outcomes that have been used (Dadvand et al., 2012a, Agay-Shay et al., 2014). Of particular relevance to the present thesis are studies showing an increase in birth weight (Dadvand et al., 2012c, Dadvand et al., 2012b, Hystad et al., 2014, Agay-Shay et al., 2014, Markevych et al., 2014, Dadvand et al., 2014b, Ebisu et al., 2016, Laurent et al., 2013) and a reduced risk of preterm birth for infants of pregnant women living in areas with increased levels of green space (Laurent et al., 2013, Hystad et al., 2014, Casey et al., 2016). The most commonly occurring mental disease in pregnant women is depression (Satyanarayana et al., 2011). One study has documented the health benefit of green space exposure in pregnant women in terms of reducing the likelihood of antenatal depression (defined as ‘depression during pregnancy’) (McEachan et al., 2015).

1.2 Role of mediators in the associations between green space and health outcomes

The pathways through which green space benefits health are called ‘mediators’ (Hartig et al., 2014). Over the past few decades, researchers have focussed mainly on determining the relationships between green space and health outcomes by examining four mediators. These include air pollution, physical activity, social interactions (described as interactions amongst members of a group) or cohesion (described as the presence of common values, cordial relationships, and acceptance amongst members of a group), and stress reduction (Hartig et al., 2014). More recently, noise pollution and environmental temperatures have also been proposed as mediators of the associations between green space and health outcomes (James et al., 2015). Exposure to green space reduces air pollution in the environment (e.g., gaseous [ozone, nitrogen dioxide [NO_2], or sulphur dioxide], and non-gaseous [particulate matter] air pollutants) (Nowak et al., 2006). This effect varies for specific types of green space. It has been shown that trees are the most productive whilst grasses are the least productive in terms of removing air pollutants from the environment (Givoni, 1991). Trees can remove gaseous air pollutants from the environment through uptake by leaf stomata and absorption by water within leaflets, whilst non-gaseous air pollutants are deposited on leaves. As a next step, non-gaseous air pollutants are removed by rain droplets or fall to the ground surface (Nowak et al., 2006). In terms of exploring the mediating pathway of physical activity, it has been shown that green spaces provide an impetus for people to engage in physical activity (Bedimo-Rung et al., 2005). While considering social interactions or cohesion as a mediating mechanism, it is thought that green spaces provide a common meeting place whereby people can meet and interact with each other (Bedimo-Rung et al., 2005). It has been demonstrated that the enhancement of social interactions or cohesion, at least in part, is associated with better mental health outcomes (Sugiyama et al., 2008). Ulrich and associates have developed a psycho-physiological model to explain how green space affects health through stress reduction. Contact with green space is associated with the development of a visual stimulus, thereby creating a psycho-physiological response by the brain with a sequence of events leading to excitation of the nervous system, the release of hormones and a reduction in stress (Ulrich et al., 1991). The beneficial effect of exposure to green space on noise-induced health outcomes is brought about by reductions in noise sensitivity (defined as “the internal states of any individual which increases their degree of reactivity to noise in general” (Soames Job, 1999)) and noise annoyance (defined as “a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with someone’s thoughts, feelings or daily activities”(WHO, 2004)) (Dzhambov and Dimitrova, 2015). Finally, green spaces provide shade, and this phenomenon reduces environmental temperatures by 1-5 degrees Celsius (EPA, 2017a). It must be noted that the mediating pathways are inter-related. For example, exposure to green space increases physical activity which in turn reduces stress (Hartig et al., 2014). A diagrammatic representation of mediators of the associations between green space and health outcomes is given in Figure 1-1.

1.3 Role of effect modifiers in the association between green space and health

1.3.1 Role of effect modifiers in the association between green space and health in the general population of adults

The beneficial effects of green space on health are often observed in specific population subgroups, a phenomenon called ‘effect modification’ (WHO, 2016c). In the general population, people living in deprived areas are more likely to report engaging in the use of green spaces close to their homes due to the availability of extra time for leisure activities in comparison to people living in non-deprived areas. Consequently, people living in deprived areas have the potential for more health benefits from exposure to green space compared with people living in non-deprived areas (de Vries et al., 2003). For people living in non-deprived areas, the increased use of green spaces away from their residence seems undoubtedly due to increased ownership of private vehicles within that cohort. An equally important observation in the general population is that the beneficial effects of exposure to green space also appear to be more pronounced in people with medium levels of education compared to people with high levels of education (Maas et al., 2006). Similar reasoning applies to people with no education or low levels of education. That is, people who are uneducated or have low levels of education are less mobile than their counterparts and tend to spend more time near their homes (Maas, 2008). Concurrently, general population studies point towards the moderating role of age in the association between green space and mental health (Barton and Pretty, 2010, Bos et al., 2016). More exactly, general population studies into the associations between exposure to green space and mental health outcomes have demonstrated that green space is beneficial for the mental health of people within specific age groups (e.g., 18–24, <30, and 31–50 years) (Barton and Pretty, 2010, Bos et al., 2016). Also, the relationship between mental health and green space is more pronounced for people who are physically active compared to those who are not (Astell-Burt et al., 2013b).

Some studies of the general population have shown associations between exposure to green space and health outcomes that are dependent on the degree of residential rurality (Maas et al., 2006, de Vries et al., 2003). An exploratory Dutch analysis of the relationship between exposure to green space and health amongst adults in the general population showed that residency in greener areas was associated with better health outcomes (e.g., morbidity symptoms and perceived general health status) than residency in low-green areas, for those in the mid-range of residential rurality (de Vries et al., 2003). Using morbidity symptoms as a health outcome, an association of green space with health was observed for people living independently in moderately urban and slightly urban areas (de Vries et al., 2003).

In the same study, when considering perceived general health status as another health outcome, de Vries and colleagues showed that the association of green space with health existed for people living independently in moderately urban and non-urban areas (de Vries et al., 2003). A cross-sectional Dutch study which investigated the association between exposure to green space around residences based on 1 km and 3 km radii and perceived general health showed that people living in greener neighbourhoods were more likely to report better general health in comparison with people living in less green neighbourhoods (Maas et al., 2006). Although the relationship was evident for all degrees of residential rurality, it is weaker for green space for people living in very urban areas (Maas et al., 2006). In the same study, differences in the perceived general health between urban and rural residents were associated with the amount of environmental greenness, the reason being that residential rurality coefficients attenuate and became non-significant when the amount of environmental greenness is added to regression models (Maas et al., 2006).

1.3.2 Role of effect modifiers in the association between green space and health in pregnant women

Consistent with the observations from the adult general population studies, the beneficial effects of exposure to green space in pregnant women appear to be more pronounced for those living in deprived areas or with low levels of education (Dadvand et al., 2012a, Markevych et al., 2014, Dadvand et al., 2014b, Dadvand et al., 2012c, Agay-Shay et al., 2014). Low levels of education are described in several ways in the literature: achieving less than five general certificates of secondary education (Dadvand et al., 2014b), less than 10 years of school education (Markevych et al., 2014), up to secondary school education (Dadvand et al., 2012c), or not attaining any school education (Dadvand et al., 2012b). It has been shown that pregnant women with low or medium levels of education are more likely to deliver higher birth weight infants compared with pregnant women with high levels of education (Dadvand et al., 2012a, Markevych et al., 2014, Dadvand et al., 2014b, Dadvand et al., 2012c). Even the effects of exposure to green space in pregnant women appear to be more pronounced for those describing their self-identified ethnicity as White British (Dadvand et al., 2014b). Effect modification for birth weight has been documented in the literature through increases in birth weight for new born infants of White British, but not for Pakistani pregnant women (Dadvand et al., 2014b). A potential reason for these ethnic differences in the association between exposure to green space and health is the differential use of green space. As already explained in the Born in Bradford study, White British pregnant women are more likely to use and benefit from green spaces in comparison with non-White British pregnant women (Dadvand et al., 2014b). Contributing factors to the low use of green spaces by non-White pregnant women include a lack of time, a lack of activities of interest that can be carried out in green spaces, past experiences of discrimination in green spaces, a lack of familiarity with green spaces, and financial costs associated with the use of green spaces (Dadvand et al., 2014b). The association between exposure to green space and less depression in pregnant women has been identified for those who have attained low levels of education as well as those who are physically active throughout their pregnancy (McEachan et al., 2015). McEachan and associates have not demonstrated effect modification for the relationship of green space exposure with depression based on specific population subgroups such as age and residential rurality (McEachan et al., 2015).

1.4 Rationale for using pregnant women as a 'target sample' and selecting physical activity, birth weight, gestational age, and depression as outcomes of investigation for this thesis

According to the WHO, pregnancy is a phase of life wherein each woman has a live foetus in her womb (WHO, 2017b). During pregnancy, both the mother and her developing foetus are at increased risk from environmental stressors, including exposure to high levels of air pollution, noise pollution, and environmental temperatures (WHO, 2017b). Of relevance amongst pregnant women are the detrimental effects of these on birth weight or the gestation period of new born infants (Dadvand et al., 2014a, Arroyo et al., 2016). The effect of exposure to air pollution during pregnancy appears to be mediated through oxidative stress, inflammation, endocrine disruption, and a reduction in oxygen transfer through the placenta to the developing foetus (Slama et al., 2008). It is hypothesised that the effect of noise pollution on birth weight or gestation period is mediated through stress and sleep disturbance of the mother (Gehring et al., 2014). Similarly, the effect of high environmental temperature on gestation period is mediated through dehydration and hence reduced blood flow to the foetus (Basu et al., 2016). Apart from the health risks associated with environmental exposures of air pollution, noise pollution, and temperatures; pregnant women are more likely to develop medical conditions during pregnancy which impose risks to maternal and child health. For example, pregnant women are more likely to develop depression during pregnancy (Leigh and Milgrom, 2008). The detrimental effect of depression on birth weight and the gestation period appears to be mediated via the association of depression with hypertension and preeclampsia, gestational diabetes, and the increased used of cigarettes and other drugs (Grote et al., 2010). Considering environmental exposures and medical conditions, it is said that pregnant women represent a 'vulnerable' population subgroup. The rationale for using pregnant women as a 'target sample' for this thesis is that pregnant women are likely to benefit from exposure to green space with health gains not only for themselves, but also for their new born children.

Until now, in New Zealand, the effect of green space on physical activity levels amongst pregnant women has not been investigated. It is not known whether objective health measures such as birth weight and gestational period are influenced by the levels of green space in the residential neighbourhood in New Zealand. The potential for green space to reduce the rate of depression amongst pregnant women in New Zealand has not yet been investigated. Moreover, it is not known the extent to which the green space and health relationships are affected by factors such as age, self-identified ethnicity, education, residential rurality, and the socioeconomic status of pregnant women. There have been few pregnant population studies outside of New Zealand, and the directional trends for the associations of green space with health outcomes across those studies is essentially mixed with limited evidence for effect modifications (Dadvand et al., 2012c, Dadvand et al., 2012b, Hystad et al., 2014, Agay-Shay et al., 2014, Markevych et al., 2014, Dadvand et al., 2014b, Ebisu et al., 2016, Laurent et al., 2013, Casey et al., 2016). Considering all of these factors, the outcomes of physical activity, birth weight, gestational age, and depression in the New Zealand context have yet to be investigated.

1.5 Specific hypotheses and aims of this thesis

My thesis studies combine an objective measure of green space exposure with socioeconomic and health data from the *Growing Up in New Zealand study* to investigate the effect of green space on the health of pregnant women. More specifically, the specific hypotheses and objectives of this thesis are:

- For the study of green space and physical activity, I hypothesised that exposure to green space could provide opportunities for performing physical activity. This could lead to increased levels of physical activity for those exposed to high levels of green spaces. Additionally, I hypothesised that the association between green space and physical activity is likely to be stronger for specific population subgroups (e.g., women with low levels of education, or women residing in rural areas, or women residing in high deprived areas). My objectives are to determine whether exposure to green space during pregnancy is associated with physical activity levels in pregnant women and whether this association is moderated by age, education, self-identified ethnicity, residential rurality and socioeconomic status;
- For the study of green space and pregnancy outcomes, I hypothesised that exposure to green space could be beneficial for pregnancy outcomes through increases in birth weight and gestational age for the entire cohort, and that these associations are likely to be stronger for specific population subgroups (e.g., women with low levels of education, or women residing in rural areas, or women residing in highly deprived areas). My objectives are to determine whether exposure to green space during pregnancy is associated with birth weight and gestational age, and whether these associations are moderated by age, education, self-identified ethnicity, residential rurality and socioeconomic status; and
- For the study of green space and depression, I hypothesised that exposure to green could prove to be beneficial for mental health by reducing depression for the entire cohort and that this association is likely to be stronger for specific population subgroups (e.g., women with low levels of education, or women residing in rural areas, or women who are physically active). My objectives are to determine whether exposure to green space during pregnancy is associated with better mental health

(less depression), and whether this association is moderated by age, education, self-identified ethnicity, physical activity, residential rurality and socioeconomic status.

1.6 Background research and significance of this thesis

In New Zealand, people living in the most deprived socioeconomic areas tend to live in closer proximity to recreational amenities (parks, sports and leisure facilities, and beaches) than those living in the least deprived socioeconomic areas (Pearce et al., 2007). The median travel time by car to parks, sports, and leisure facilities is significantly lower for residents living in the most compared with the least deprived areas (1.11 vs 1.56 min for parks [$p<0.001$]; 4.15 vs 6.69 min for sports and leisure amenities [$p<0.001$])(Pearce et al., 2007). In the general population in New Zealand, the availability of green space has been shown to not be an important determinant of health for people residing in the most, moderately, and least deprived areas (Richardson et al., 2010, Witten et al., 2008). One explanation is that New Zealand is a very green country (Nutsford et al., 2013). The amount of green space in urban areas in New Zealand is much higher than the amount of green space in urban areas in the Netherlands (Richardson et al., 2010). New Zealand is known internationally for its clean-green image. According to the estimates by the Ministry for the Environment, the value of New Zealand's clean-green image is billions of dollars, benefiting the tourism industry and exports of dairy and organic products to other countries (MFE, 2001). In New Zealand, there is continuous background exposure to green space, and people are exposed to high levels of green spaces due to outdoor vacationing (camping). As Richardson and colleagues have mentioned, exposure to blue spaces (water bodies) might also be an important determinant of health in New Zealand (Richardson et al., 2010). In general, there is a high level of exposure to green and blue spaces in New Zealand; however, variation in environmental exposures to green and blue spaces is required to investigate associations.

Any significant association between green space and physical activity levels found in my study of green space and physical activity could have implications for the planning of residential areas to enable improvements in physical activity levels and the health of pregnant women living locally. At the same time, the long-term goal would be to prevent future health complications for low birth weight and preterm infants born in New Zealand through increments in their birth weight and/or gestation age. Finally, the present work contributes to knowledge about the role that green space plays in reducing depression during pregnancy for pregnant women in general and for specific population subgroups. This could help prevent adverse health outcomes associated with antenatal depression.

1.7 Structure of this thesis

Chapter 1 of this thesis is the introduction that defines green space, discusses the health benefits associated with green space, the mediators and moderators of the associations between green space and health outcomes, the rationale for using pregnant women as a target sample and selecting physical activity, birth weight, gestational age, and depression as the outcomes of investigation for this thesis, the specific hypotheses and aims of this thesis, and the significance of this thesis. A literature review on relevant green space-health studies is presented in Chapter 2. Chapter 3 describes the methods, Chapter 4 describes the 'Results' of the green space studies and Chapter 5 is a discussion. Finally, Chapter 6 presents the thesis summary, implications of the findings and the recommendations for future investigators and public health policy.

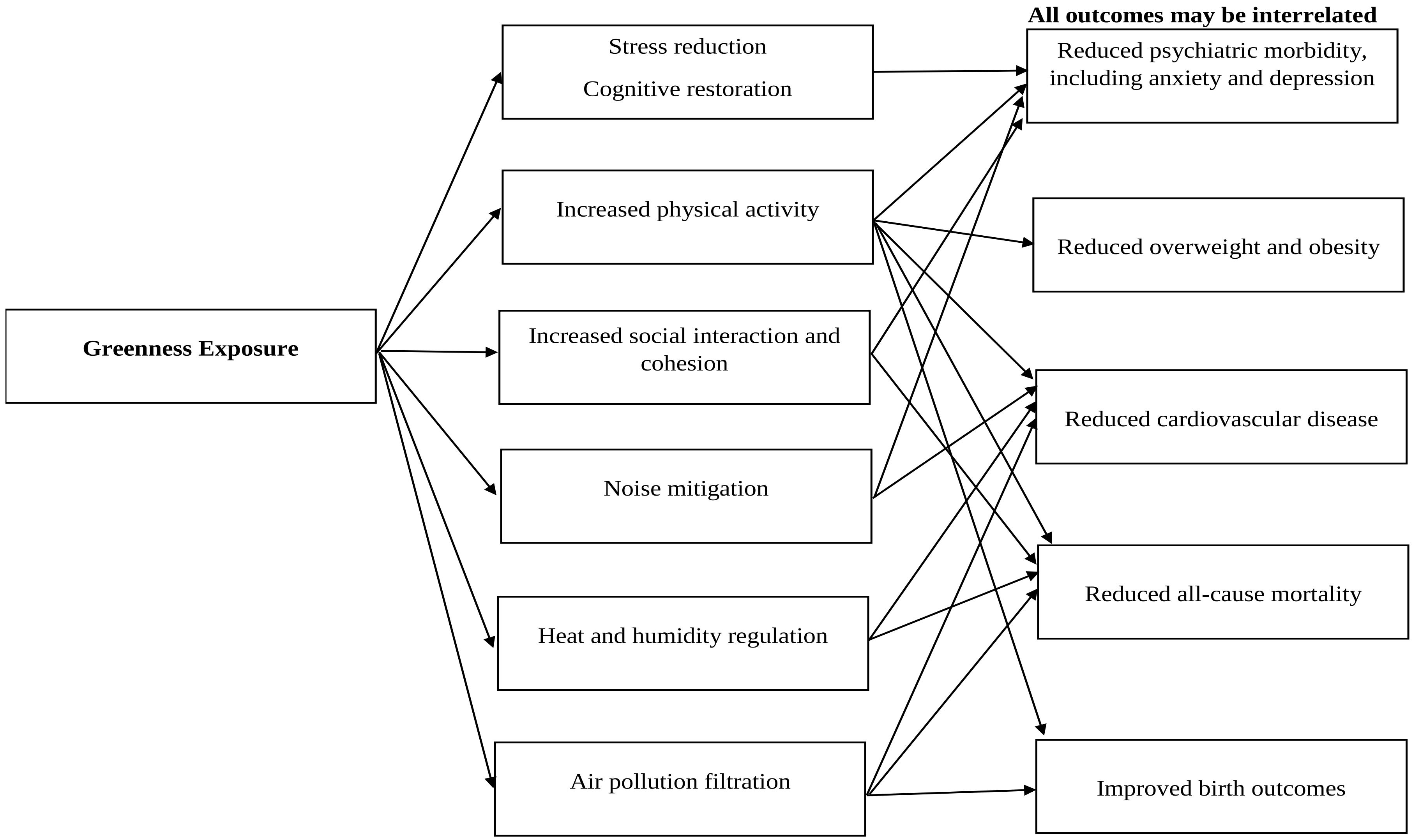


Figure 1-1: Mediators of the associations between green space and health outcomes (James et al., 2015) (reprinted here with permission from Springer Copyright Clearance Centre)

Chapter 2. Literature Review

This chapter presents a literature review for the three studies that make up this thesis: 1) Green space and physical activity in pregnant women, 2) Green space and pregnancy outcomes in pregnant women, and 3) Green space and depression in pregnant women. Of first and foremost importance, in general terms, the literature review chapter begins with a description of how the literature review was conducted for the three studies. Moving forward, ways of measuring green space are described along with the advantages and disadvantages of each of the possible methods. In relation to the first thesis project, a review of physical activity, including a definition of physical activity, the dimensions and domains of physical activity, factors associated with physical activity, the health benefits, and recommendations regarding levels of physical activity are described. Moving forward, the review includes both national and international studies that have investigated associations between exposure to green space and physical activity both in the general population and pregnant women. In relation to the second thesis project, the review of birth weight and gestational age covers current relevant understanding of low birth weight and preterm birth, including an overview of the aetiological factors and complications associated with low birth weight and preterm birth. In the next section of the literature review, I describe national and international studies that have investigated the associations of green space with birth weight and with gestational age. For my third thesis project, a similar approach is taken. That is, the review of depression describes aetiological factors and complications of depression. The review then moves on to a description of national and international studies that have investigated the associations between green space and depression in the general population and specifially in pregnant women. At the end of the literature review chapter, I critique previous general and pregnant population studies on green space and health outcomes (physical activity, birth weight, gestational age, and depression) by pulling out the commonalities and limitations across studies, and explaining how the three thesis projects help to address the limitations of previous studies.

2.1 How the literature review was conducted

A set of guidelines for conducting and reporting of systematic reviews and meta-analysis have been developed called the ‘Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)’ (Moher et al., 2009). Fundamentally, PRISMA is a system of guidelines that allows researchers to conduct and report systematic reviews and meta-analyses in a standardised way (Gascon et al., 2015). I utilised PRISMA to conduct the literature review for my studies on green space and health outcomes.

2.1.1 Eligibility criteria

Previous studies conducted on human subjects were eligible for inclusion in the literature review presented within this thesis if they had examined the associations between green space and health outcomes such as physical activity, birth weight, gestational age, and depression. Studies were included if they were conducted in New Zealand or outside of New Zealand, focussed on the general and pregnant population as the main target groups; only articles written in the English language were included as well as only those published in peer-reviewed journals. It was necessary to include the general population studies on green space and health outcomes as well as there were only a limited number of pregnant population studies on green space and health outcomes.

2.1.2 Search strategy

The search was conducted primarily through three search engines: PubMed, Scopus, and Embase. Studies published up to 31 December 2016 were taken into consideration. Of relevance to the study of green space and physical activity, a combination of keywords was used within the search engines to identify previous studies on green space and physical activity. These keyword combinations were *green space and physical activity or green space and physical exercise.* Of relevance to the study of green space and pregnancy outcomes, a set of combined words were established, and these words were used to search for previous studies within the search engines. The combined words were *green space and pregnancy outcomes, green space and birth weight, green space and low birth weight, green space and gestational age, or green space and preterm birth.* The criteria for selection of studies on green space and depression was similar to those developed for the studies on the other health outcomes. Studies on green space and depression were identified through the use of specific keyword combinations such as *green space and mental health, green space and anxiety, green space and stress, or green space and depression.*

2.1.3 Study selection

Identified studies were screened for eligibility by reading all titles and abstracts. Furthermore, studies with full-text articles available for analyses were selected and checked if they met the inclusion and exclusion criteria.

2.1.4 Study quality

The search for relevant studies was done primarily by one reviewer (Vikram Nichani) and checked by another reviewer (Kim Dirks). The inclusion or exclusion of studies was done after both reviewers agreed on the inclusion or exclusion criteria. Studies were not judged based on quality and were included even if there was a lack of evidence of associations between green space and health outcomes.

2.1.5 Analysis

As the chosen outcomes were both continuous and categorical, the results were reported in terms of beta-coefficients and odds or incidence rate ratios. As the purpose of this literature review was not to perform a meta-analysis, the results of the selected studies were not combined for a meta-analysis.

2.2 Ways of measuring green space

In the literature, green space is primarily quantified in four ways. Each fo these is described below in a detailed manner, including a discussion of both the advantages and disadvantages of each of the methods.

2.2.1 Normalised Difference Vegetation Index

Green space can be estimated objectively based on greenness defined by the normalised difference vegetation index (NDVI). This measure is derived from images obtained by the National Aeronautics Space Administration's satellite called the 'Landsat Enhanced Thematic Mapper' at a spatial resolution of 30 m x 30 m (Dadvand et al., 2012a). NDVI is an indicator of the amount of greenness on the surface of Earth (NASA, 2017). It is known that sunlight is primarily composed of three different wavelengths: ultraviolet, visible, and near-infrared light (EPA, 2017b). To maximise the efficiency of photosynthesis, plants absorb most of the visible fraction of sunlight. Simultaneously, plants reflect most of the near-infrared fraction of sunlight (NASA, 2017). The calculation of NDVI is based on a determination of the ratio of the difference between reflected near-infrared light and visible light to the sum of reflected near-infrared light and visible light (NDVI=reflected near-infrared light – visible light)/(reflected near-infrared light + visible light)(NASA, 2017). Depending on the degree of surface greenness, the values of NDVI range from -1 to +1 (NASA, 2017). For example, an NDVI value of less than or 0.1 is indicative of the presence of a non-green area such as rock, sand, or snow. Higher NDVI values are indicative of the presence of green areas such as shrublands (0.2–0.5), grasslands (0.2–0.5), croplands (0.6–0.9), or forests (0.6–0.9)(Beyer et al., 2014). While determining the associations between green space and health outcomes, the researchers have calculated NDVI in buffers of different sizes (e.g., 50 m, 100 m, 250 m, 300 m, 500 m, 800 m, 1000 m, or 1250 m) around the residences of the study participants (Dadvand et al., 2012c, Dadvand et al., 2012a, Laurent et al., 2013, Dadvand et al., 2014b, Markevych et al., 2014, Casey et al., 2016, Hystad et al., 2014, Agay-Shay et al., 2014). It is thought that green spaces closer to homes are associated with the operation of mediating mechanisms such as reductions in air and noise pollution, temperatures, and stress; meanwhile, green spaces away from homes are associated with the facilitation of physical activity as a mediating mechanism (Dadvand et al., 2012a).

The advantage of NDVI is that it is less subject to temporal mismatch between green space and health data (James et al., 2015). Another advantage of NDVI is that it is obtained using similar techniques across several countries by different investigators; therefore, comparisons of the NDVI indices can be made easily across different studies (James et al., 2015). However, the disadvantage of NDVI is that no distinction can be made about the composition of NDVI (Dadvand et al., 2012c).

2.2.2 Percentage land area covered by green space

The most preferred method for the assessment of green space is based on the determination of the proportion of land area covered by green space through the utilisation of raster or vector databases. Maas and colleagues utilised a raster land cover database in the Netherlands to calculate the proportion of green space within one kilometre and three-kilometre radii around the postal code coordinates of the study participants. They used data from a raster database that stored land use information in 25 m x 25 m grid cells for the assessment of green space within specific radii (Maas et al., 2006, Maas et al., 2009b). In general, a raster database is a collection of rows and columns of cells called pixels or grid cells (ESRI, 2008). Each cell stores data that are represented by a specific value for the type of data (e.g., land use such as parks or grasslands) (ESRI, 2008). The advantage of using a raster land cover database is that it stores information on large areas of green space such as parks, agricultural lands, and forests. However, the raster database does not store information relating to small areas of green space such as gardens and trees (Maas et al., 2009a). Green space can also be assessed objectively based on the determination of the proportion of land area covered by green space through the utilisation of vector land cover databases (Richardson et al., 2010). Unlike raster databases, vector databases do not consist of pixels or grid cells. A vector database is composed of points, lines, and polygons (ESRI, 2017). In comparison with raster databases, higher geographical accuracy and aesthetically pleasing graphic outputs are obtained using vector cover databases. The disadvantages of using a vector database is the lack of proper storage of continuous data (e.g., elevation data) and the use of complex vector manipulation algorithms if the vector database contains a lot of features (GISGeography, 2016). Richardson and colleagues utilised vector land cover databases in New Zealand to calculate the proportion of green space within geographical units called census area units (CAUs) (Richardson et al., 2010, Richardson et al., 2013). In

New Zealand, CAUs are defined as “non-administrative areas that are in between mesh blocks and territorial authorities in size” (Stat, 2006). Determining the percentage of green space within geographical units such as lower layer super output areas (LSOAs) (Alcock et al., 2014), middle super output areas (MSOAs) (Mytton et al., 2012), census collection districts (CCDs) (Astell-Burt et al., 2014a, Astell-Burt et al., 2014b), census area statistics (CAS) (Ord et al., 2013), or wards (Astell-Burt et al., 2014e) is another option.

2.2.3 Distance to the nearest green space

While investigating the relationship between green space and health, green space is estimated objectively based on the proximity of the residence to the nearest green space. This is called ‘access’ to green space (McEachan et al., 2015). The European commission has defined access to a major green space as ‘living within 300 m of a green space with an area of equal or more than 5000 m^2’(Dadvand et al., 2014b). Access to the nearest green space is an important component of green space research because green space closer to the home (<300 m) is more likely to be visited and utilised by people (e.g., for the purpose of performing physical activity) than green space away from the home (≥300 m)(Toftager et al., 2011). Access to green space is estimated in the Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) by the using network analysis tool that requires the use of road network data. That is, the distance from the home to the nearest green space is calculated in ArcGIS by measuring the distance travelled through roads (Boscoe et al., 2012). Alternatively, the distance to the nearest green space can be calculated by measuring the straight line distance between the residence and the nearest green space. This is called the ‘Euclidean’ distance (Boscoe et al., 2012). The advantage of measuring the straight line distance is that it is simple to calculate (Boscoe et al., 2012). The road network distance method is a sophisticated and precise method, but requires specialised ArcGIS software and expensive street network data in order to implement it (Boscoe et al., 2012).

2.2.4 Subjective measurements of green space

The estimation of green space is done subjectively by asking the study participants about the quantity and/or quality of green space in their residential neighbourhood. For example, Sugiyama and associates determined the quantity and quality of green space in a residential neighbourhood by asking the study participants about: 1) Access to a park or nature reserves, 2) Access to bicycle or walking paths, 3) The presence of greenery, 4) The presence of tree cover or canopies along footpaths, and 5) The presence of pleasant natural features in their neighbourhood (Sugiyama et al., 2008). The participants responded to each of the five questions with responses ranging from ‘‘strongly disagree’’ (score 1) to ‘‘strongly agree’’ (score 4) (Sugiyama et al., 2008). The minimum and maximum calculated total scores for any individual were 5 and 20, respectively. Higher total score indicated the presence of higher perceived green space in the residential neighbourhood (Sugiyama et al., 2008). Alternatively, green space is measured subjectively by asking the study participants about their visits to green space. In an European investigation, van den Berg and colleagues determined the frequency and duration of visits to green spaces for their study participants. They combined frequency and duration to produce a combined variable that represented the total duration of visits to green space (measured in hours/month) (van den Berg et al., 2016). Subjective measurement of green space has an advantage over objective measurement of green space as it incorporates a measure of the quality of the green space (Rugel et al., 2017). However, any subjective measurement of green space could be subject to recall bias and overestimation of the quantity and quality of the green space.

2.3 Review of physical activity

2.3.1 Definition, dimensions, and domains of physical activity

According to the WHO, physical activity refers to "any bodily movement produced by skeletal muscles that requires energy expenditure" (WHO, 2016b). The dimensions of physical activity can be categorised into four groups: 1) mode or type of physical activity, 2) frequency of physical activity, 3) duration of physical activity, and 4) intensity of physical activity (Strath et al., 2013). The mode or type of physical activity refers to the specific type of physical activity that is performed by an individual during the performance of the physical activity. Some examples of modes of physical activity include walking, gardening, and cycling (Strath et al., 2013). The frequency of physical activity refers to the number of sessions of physical activity performed by an individual on a daily or weekly basis (Strath et al., 2013). The duration of physical activity refers to the total number of minutes or hours in which a person is engaged in physical activity (Strath et al., 2013). Generally, the intensity of the physical activity is classified as light, moderate, or vigorous, depending on the rate of energy consumption required to perform the activity. Moderate physical activity is one that is associated with modest increases in respiratory and heart rates (OWH, 2016). Vigorous physical activity is one that is associated with substantial increases in respiratory and heart rates (OWH, 2016). Examples of moderate physical activity include brisk walking, bicycling less than 10 miles per hour, water aerobics, doubles tennis, gardening, and ballroom dancing; whereas, examples of vigorous physical activity include jogging, running, singles tennis, aerobic dancing, bicycling more than 10 miles per hour, swimming laps, and climbing stairs (ODPHP, 2016a). The domains of physical activity can be categorised into four groups of: 1) occupational physical activity defined as 'work-related' (e.g., carrying or lifting objects), 2) domestic physical activity defined as 'household-related' (e.g., gardening or household chores), 3) transportation physical activity defined as ‘travel-related’ (e.g., walking or bicycling), and 4) leisure time physical activity defined as ‘recreational-related’ (e.g., sports activities or volunteer work) (Strath et al., 2013).

2.3.2 Factors associated with physical activity

2.3.2.1 Factors associated with physical activity in the general population

A number of general population studies have investigated the factors associated with physical activity in the general population. Amongst the adult population, factors include demographics such as age (Moniruzzaman et al., 2017, Malambo et al., 2016), marital status (Malambo et al., 2016), education (Moniruzzaman et al., 2017, Malambo et al., 2016, Morseth et al., 2016), occupation (Malambo et al., 2016), residential rurality (Moniruzzaman et al., 2017, Malambo et al., 2016), and socioeconomic status (Moniruzzaman et al., 2017); personal behaviour such as smoking (Morseth et al., 2016); and general health status (Solomon et al., 2013).

2.3.2.2 Factors associated with physical activity in pregnant women

Amongst pregnant women in particular, factors associated with physical activity include age (Coll et al., 2017b, Dumith et al., 2012), education (Coll et al., 2017b, Dumith et al., 2012), ethnicity (Gaston and Cramp, 2011), employment status (Liu et al., 2011), parity (Coll et al., 2017b, Dumith et al., 2012), and income (Coll et al., 2017b); health-related factors such as pre-pregnancy physical activity (Coll et al., 2017b) and body mass index (BMI) (Lynch et al., 2012); provision of health care during pregnancy, including antenatal care (Dumith et al., 2012) and explanation of importance of physical activity during antenatal care (Dumith et al., 2012).

2.3.3 Health benefits of physical activity

2.3.3.1 Health benefits of physical activity for adults in the general population

Participation in physical activity amongst adults from the general population is linked to a number of health benefits, including control of body weight; reduction in risk of cardiovascular diseases, type 2 diabetes mellitus, and cancers; strengthening of bones and muscles; improvement of mental well-being and mood; and increasing chances of longevity (CDC, 2015).

2.3.3.2 Health benefits of physical activity for pregnant women

Participation in physical activity for pregnant women during pregnancy has been found to be linked to number of health benefits, including an improvement in mood and self-image; the promotion of sleep; the attainment of appropriate weight; improvement in muscle tone, strength and endurance; improvement in stamina during labour and delivery; improvement in recovery time after labour and delivery; and improvement in energy levels (PHAC, 2012). Additionally, participation in physical activity is associated with a reduced risk of gestational diabetes in obese women (ACOG, 2002). Not surprisingly, participation in regular physical activity during pregnancy is associated with minimal health risks as it does not increase the probability of low birth weight, preterm delivery, or miscarriage (ODPHP, 2016b). It is thought that participation in physical activity during pregnancy affects foetal growth through increased foetal blood flow and delivery of nutrients to the developing foetus; thereby, enhancing the growth of a developing foetus (Clapp Iii et al., 2000).

2.3.4 Recommendations for physical activity

2.3.4.1 Recommendations for physical activity for adults in the general population

The American College of Sports Medicine and the American Heart Association recommend that general population adults aged 18-65 years should engage in at least 150 minutes of moderate or 60 minutes of vigorous physical activity every week (Haskell et al., 2007). According to the WHO, the recommended levels of physical activity for adults aged 18-64 years are 150 minutes/week of moderate physical activity or 75 minutes/week of vigorous physical activity with the duration of each session of physical activity being 10 minutes or more (WHO, 2017a). To gain health benefit, the duration of each session of moderate or vigorous physical activity should be at least 10 minutes (Haskell et al., 2007). Moderate physical activity can be combined with vigorous physical activity so that recommendations for physical activity are achieved (Haskell et al., 2007). For greater health benefits, participation in moderate or vigorous physical activity that exceeds the minimum requirement of 150 minutes/week for moderate and 60 minutes/week for vigorous physical activity is highly recommended (Haskell et al., 2007). Specifically, if the levels of moderate or vigorous physical activity are doubled, then the health benefits are increased (WHO, 2017c). Ideally, people should engage in at least 150 minutes of moderate or 60 minutes of vigorous physical activity every week throughout their young and middle age to prevent occurrence of non-communicable chronic diseases such as cardiovascular diseases, diabetes mellitus, and cancers. Continuation of physical activity in old age is associated with a decreased risk of muscle and bone loss, cardiovascular disease, and osteoporotic fracture (Miles, 2007).

2.3.4.2 Recommendations for physical activity for pregnant women

Specific guidelines for participation in physical activity during pregnancy have been developed for pregnant women. According to those developed by the American College of Obstetricians and Gynaecologists (ACOGs), healthy pregnant women should engage in moderate physical activity for at least 30 minutes duration on most, if not all, days of the week (ACOG, 2002). Healthy pregnant women who engage in vigorous physical activity during the pre-pregnancy period can continue vigorous physical activity during the pregnancy period provided they do not develop any medical condition during the pregnancy period and have regular medical consultations with their physicians regarding adjustment of vigorous physical activity over the three trimesters of pregnancy (ODPHP, 2016b). Activities such as horseback riding, downhill skiing, soccer, and basketball are all associated with an increased risk of trauma; therefore, these activities are considered ‘not permitted’ during pregnancy (NIH, 2016). The Society of Obstetricians and Gynaecologists of Canada (SOGC) and the Canadian Society of Exercise Physiology (CSEP) have produced guidelines for physical activity for pregnant women similar to those developed by the ACOG. Both SOGC and CSEP recommend that pregnant women without any medical or obstetric complications should perform moderate physical activity of at least 30 minutes on most, if not all, days of the week (Artal and O'Toole, 2003).

2.3.5 General adult and pregnant population studies investigating the association of green space with physical activity

Several studies in the general population, from Australia (Astell-Burt et al., 2014a, Astell-Burt et al., 2014b), Canada (McMorris et al., 2015), England (Mytton et al., 2012), New Zealand (Richardson et al., 2013), and Scotland (Ord et al., 2013) have investigated the association between green space and physical activity. Some of these studies clearly highlight associations between green space and physical activity (Astell-Burt et al., 2014b, Astell-Burt et al., 2014a, Mytton et al., 2012, Richardson et al., 2013), whilst other studies find no significant association (Witten et al., 2008, Ord et al., 2013). As pointed out in a recent study by Koohsari and colleagues, a lack of consistency in the results could be due to the variation in the techniques used to classify green spaces, a lack of consideration of green space in non-residential environments (e.g., around work places and schools), the use of subjective measures of physical activity, the assembling green space data from different sources, the use of Euclidean distance, the use of single nearest green space while determining access to green space, and a lack of control of self-selection bias (defined as ‘the tendency of people to choose locations based on their travel needs and preferences’(Mokhtarian and Cao, 2008)) in regression analyses (Koohsari et al., 2015).

Currently, information on the physical activity promoting effect of green space in pregnant women is limited (McEachan et al., 2015). Studies on the general adult and pregnant populations specifically are described below in a detailed and chronological manner, with a summary in tabular form provided in Appendix 6.

2.3.5.1 General adult population studies showing association between green space and physical activity

In 2012, a cross-sectional observational study was carried out by Mytton and colleagues using data from the Annual Health Survey of England (HSE) conducted annually during 2002 to 2004 (Mytton et al., 2012). The primary aim of the study was to determine whether there was an association between green space and overall physical activity (Mytton et al., 2012). In each of three HSE surveys, people were asked to report information regarding intensity, frequency, and duration of physical activity, irrespective of the type of physical activity. The frequency and duration variables of the physical activity were then combined to produce a single dependent variable that represented whether the United Kingdom (UK) government recommendations for participation in moderate or vigorous physical activity (defined as ‘achieving 5 weekly sessions of moderate or vigorous physical activity, with the duration of each session of physical activity being 30 minutes or more’) were met by the study participants (Mytton et al., 2012). Data on green spaces for this study were obtained from the generalised land use database with the inclusion of parks, open spaces, and agricultural lands. The percentage of green space within the MSOA was taken as a surrogate of exposure to green space for the study participants (Mytton et al., 2012). The English study showed that participants living in the greenest quintile (fifth green space quintile) were more likely to perform five sessions of moderate or vigorous leisure type physical activity of at least 30 minutes duration per week than were participants living in the least green quintile (Odds Ratio [OR]=1.24 [95% Confidence Interval [CI]=1.12-1.38]) (Mytton et al., 2012). The authors concluded that exposure to green space was associated with overall physical activity. However, the cross-sectional design and use of self-reported measures of physical activity were limitations of this study (Mytton et al., 2012). Additionally, the authors did not control for season, desire to perform physical activity, the number of sports facilities in the neighbourhood, and self-selection bias in the regression modelling (Mytton et al., 2012). Therefore, a gap remains in term of reducing recall bias and control of covariates (e.g., season, desire to perform physical activity, number of sports facilities in neighbourhood) while estimating the relationship between green space and physical activity.

In a 2013 cross-sectional study by Richardson and colleagues in New Zealand, data collected from adults in the 2006 and 2007 New Zealand Health Survey (NZHS) were utilised to investigate whether greenness in CAUs was associated with morbidity outcomes (obesity, poor general health, poor mental health, and cardiovascular disease) and if those associations could be explained on the basis of physical activity (Richardson et al., 2013). The level of physical activity of the study participants was judged on the basis of participation in moderate or vigorous physical activity of at least 150 minutes duration per week (Richardson et al., 2013). Areas categorised as green spaces included parks, beaches, and sports fields. To account for the daily variability in exposure to green space, the percentages of green space were calculated for each CAU rather than each mesh block (the smallest geographical unit in New Zealand) (Richardson et al., 2013). The New Zealand study showed that exposure to greenness in the CAU was not associated with lowered risks of obesity and poor general health, but with lowered risks of poor mental health and cardiovascular disease. Participants living in greener CAUs were less likely to develop cardiovascular disease than those living in least green CAUs ($OR_{\text{second quartile green space}}$=0.82 [95% CI=0.67-1.00]; $OR_{\text{third quartile green space}}$=0.80 [95% CI=0.64-0.99]; and $OR_{\text{fourth quartile green space}}$=0.84 [95% CI=0.65-1.08]) (Richardson et al., 2013). In the same study, when considering poor mental health as another health outcome, Richardson and colleagues showed that the association of green space with poor mental health existed for people living in greener CAUs in comparison to those living in the least green CAUs ($OR_{\text{third quartile green space}}$=0.87 [95% CI=0.73-1.02]; and $OR_{\text{fourth quartile green space}}$=0.81 [95% CI=0.66-1.00]) (Richardson et al., 2013). While determining the association between green space and physical activity, the investigators found that participants living in greener CAUs were more likely to meet the recommendations for physical activity than those living in the least green CAUs ($OR_{\text{second quartile green space}}$=1.10 [95% CI=0.96-1.28]; $OR_{\text{third quartile green space}}$=1.10 [95% CI=0.94-1.28]; and $OR_{\text{fourth quartile green space}}$=1.44 [95% CI=1.19-1.74]). The inclusion of physical activity variables in regression models for analyses of cardiovascular disease and poor mental health outcomes resulted in a weakening of the associations between green space and cardiovascular disease and poor mental health outcomes indicating that physical activity was a mediator for each of those associations (Richardson et al., 2013). Overall, the authors were of the view that exposure to green space was a determinant of cardiovascular and mental health and that physical activity partially mediated the associations between exposure to green space and the risks of poor mental health and cardiovascular disease. However, the authors did not consider other mediating mechanisms (e.g., stress reduction and social support) and did not account for the New Zealand Index of Deprivation (NZDep) and self-selection bias while examining the associations of green space with morbidity outcomes (Richardson et al., 2013). This study differed from other green space-physical activity studies as the investigators choose not to include area deprivation in their data analyses (Richardson et al., 2013).

In a 2014 cross-sectional study by Astell-Burt and colleagues, adults participating in the 'Australian 45 and Up Study' were randomly selected to fill in questionnaires (Active Australia Survey) aimed at determining the association between green space and physical activity (Astell-Burt et al., 2014a). Physical activity was estimated on the basis of time spent walking, and engaged in moderate-to-vigorous physical activity (MVPA), with the duration of each session of physical activity being 10 minutes or more (Astell-Burt et al., 2014a). The definition of green space included areas characterised as parklands. Green space was estimated on the basis of the percentage of green space within 1 km buffers around the population-weighted centroid (PWC) of each CCD-the second smallest geographical unit for the dissemination of Census data in Australia (Astell-Burt et al., 2014a). The Australian study revealed that participants residing in the greenest areas had a higher prevalence of walking and MVPA (walking prevalence=88%; MVPA prevalence=90%) in comparison with those residing in least green areas (walking prevalence=86%; MVPA prevalence=86%). A linear dose-response relationship was observed for walking and MVPA for at least once a week as each 20% increase in green space resulted in increased odds of walking by 6% ($OR_{walking}$=1.06 [95% CI=1.05-1.08]) and odds of MVPA by 8% (OR_{MVPA}=1.08 [95% CI=1.07-1.10]) (Astell-Burt et al., 2014a). Additionally, participants residing in greener areas were more likely to participate in walking (incidence rate ratio [IRR]=1.09 [95% CI=1.05-1.13]) and MVPA (IRR=1.10 [95% CI=1.05-1.15]) than were participants residing in the least green areas. The authors concluded that exposure to green space was a promotor of walking and MVPA (Astell-Burt et al., 2014a). However, authors received a low response rate of 18% while recruiting participants in their study and causality could not be determined due to the cross-sectional nature of this study. More importantly, the authors did not control for self-selection bias in the regression modelling (Astell-Burt et al., 2014a). This study differed from other studies on green space and physical activity as green areas, apart from parks, were not included in the classification of green spaces (Astell-Burt et al., 2014a).

In another 2014 Australian cross-sectional study by Astell-Burt and associates, adults who were participants of 'The 45 and Up Study' were randomly selected to take part in a study with the aim of understanding the relationship between exposure to green space and weight status, and whether physical activity (MVPA) and sedentary behaviour (sitting time) mediated the associations between green space and weight status (Astell-Burt et al., 2014b). Green spaces were defined as parks, with the Australian Bureau of Statistics providing the data. Exposure to green space for 'The 45 and Up Study' participants was estimated on the basis of the percentage of green space within 1 km buffers around the PWC of each CCD (Astell-Burt et al., 2014b). The dependent variable considered in this study was one that described weight status (BMI) (Astell-Burt et al., 2014b). The Australian study showed that the prevalence of obesity was 1% lower for men and 2.4% lower for women who resided in the greenest areas compared to residents of the least green areas, though the association for women was statistically significant. Additionally, men and women who resided in the greenest areas had higher participation rates in MVPA and lower sedentary behaviours in comparison to residents of the least green areas (Astell-Burt et al., 2014b). Female participants residing in the greenest areas were less likely to be overweight (relative risk ratio [RRR]=0.90 [95% CI=0.83-0.97]) and obese (RRR=0.83 [95% CI=0.74-0.94]) than were female participants residing in the least green areas after controlling for confounders including socioeconomic status. Further adjustment of the regression models for MVPA and sitting time slightly attenuated the associations between green space and BMI for women indicting that MVPA and sitting time mediated those associations ($RRR_{overweight}$=0.92 [95% CI=0.85-0.99]; and RRR_{obese}=0.87 [95% CI=0.77-0.98]) (Astell-Burt et al., 2014b). The authors were of view that exposure to green space increased MVPA and reduced sedentary behaviour for the entire population, but reduced overweight and obesity for women. However, the authors did not consider the types and quality of green space while examining the association of green space with BMI. Additionally, the authors did not control for self-selection bias in the regression modelling (Astell-Burt et al., 2014b). Consistent with a previous study by Astell-Burt and colleagues (Astell-Burt et al., 2014a), this study did not include green spaces like forests, grasslands, and shrub lands in classification of green spaces (Astell-Burt et al., 2014b).

In 2015, McMorris et al. evaluated the association between green space and physical activity in Canada using data collected from children and adults participating in the 2001 Canadian Community Health Survey (CCHS)(McMorris et al., 2015). The physical activity levels of the survey participants were assessed in a comprehensive way by means of the level of physical activity for a usual day based on participation in usual daily activities such as standing, walking, lifting light or heavy loads, or climbing stairs; participation in 21 different kinds of leisure type physical activity within the last 3 months; the frequency of the physical activity in the last month with the duration of physical activity of at least 15 minutes; the frequency of physical activity based on the ranking of the monthly frequency of physical activity and categorised as high (≥12), medium (≥4 and <12), or low (<4); the daily energy expenditure assessed in kilocalories burned per kilogram of body weight; and the physical activity index described as a variable of participation in 21 different kinds of physical activity and categorised as active (≥3 Kcal/kg/day), moderate (1.5 to <3 Kcal/kg/day), or inactive (<1.5 Kcal/kg/day) (McMorris et al., 2015). Exposure to green space for the CCHS participants was determined based on residential greenness defined by the satellite derived NDVI (McMorris et al., 2015). The Canadian investigators found that participants living in greener areas were more likely to meet the recommendations for leisure time physical activity than those living in the least green areas ($OR_{\text{second greenness quartile}}$=1.20 [95% CI=1.13-1.29]; $OR_{\text{third greenness quartile}}$=1.27 [95% CI=1.18-1.36]; and $OR_{\text{fourth greenness quartile}}$=1.34 [95% CI=1.25-1.44]). More importantly, the associations of green space exposure with leisure time physical activity were stronger for people aged 20 to <30 years who were living in the greenest quartile in relation to those aged 20 to <30 years and living in the least green quartile ($OR_{\text{fourth greenness quartile}}$=1.82 [95% CI=1.40–2.37]). Additionally, the association of green space with the monthly frequency of physical activity was statistically significant (β=0.59 [95% CI=0.34–0.83]) (McMorris et al., 2015). The authors concluded that exposure to green space was associated with increased participation in physical activity. However, the authors utilised self-reported measurements of physical activity and did not account for self-selection bias while evaluating the association between green space and physical activity (McMorris et al., 2015). This study differed from other studies on green space and physical activity as information on physical activity was gathered in a comprehensive way and green space measured by means of NDVI (McMorris et al., 2015). It is thought that self-reported measures of physical activity overestimate the effect size for physical activity (Ord et al., 2013). Therefore, a gap still remains in terms of the use of objective measures of physical activity in relation to the relationship between green space and physical activity.

2.3.5.2 General adult population studies not showing association between green space and physical activity

In a 2008 national study by Witten and associates in New Zealand, the associations between access to green space and the levels of physical activity were examined, irrespective of type of physical activity and BMI of the study participants (Witten et al., 2008). Access to green space for the study participants was defined in terms of the time taken to travel from the mesh block population-weighted centroid to the nearest green space (e.g., park, or beach) and calculated in ArcGIS through the road network distance method (Witten et al., 2008). The dependent variables for this study were BMI, sedentary (non-engagement in physical activity, of at least moderate intensity, for at least 30 minutes during the past week) or non-sedentary behaviour (engagement in physical activity, of at least moderate intensity, for at least 30 minutes during the past week), and physical activity (non-engagement or engagement in physical activity, of at least moderate intensity, for at least 30 minutes on at least five days during the past week) (Witten et al., 2008). The New Zealand study showed that access to the nearest park was not associated with BMI ($\beta_{\text{worst quartile of park access}}$= -0.02 [95% CI= -0.08-0.05], sedentary/non-sedentary behaviour ($OR_{\text{worst quartile of park access}}$=0.84 [95% CI=0.63-1.11], nor the levels of physical activity of the study participants ($OR_{\text{worst quartile of park access}}$=1.15 [95% CI=0.96-1.37]). Conversely, access to the nearest beach was marginally associated with BMI ($\beta_{\text{worst quartile of beach access}}$=0.13 [95% CI=0.07-0.18]) and the levels of physical activity of the study participants ($OR_{\text{worst quartile of beach access}}$=0.88 [95% CI=0.76-1.03]) (Witten et al., 2008). According to the authors, access to green space was weakly associated with BMI and physical activity. However, the authors did not determine the associations between access to green space and physical activity, and access to green space and BMI for different types of physical activity (e.g., leisure, transport, or sports). Furthermore, physical activity measures were self-reported and self-selection bias was not considered (Witten et al., 2008).

In a 2008 Dutch study by Maas and colleagues, children and adults were randomly selected from a dataset of the 'Second Dutch National Survey of General Practice' (Maas et al., 2008). The aims of this study were to determine whether exposure to green space would be an important determinant of physical activity and the specific type of physical activity (e.g., walking, bicycling, gardening, and sports), and if the relationship between green space and general health could be explained based on physical activity conducted specifically in green space (Maas et al., 2008). Green space was defined as urban green space, agricultural green space, and forest and nature conservation areas. Exposure to green space was determined on the basis of the percentage of land area covered by green space within buffers of 1 km and 3 km radii around the residences of the study participants (Maas et al., 2008). The physical activity of the study participants was assessed through the 'Short Questionnaire to Access Health Enhancing Physical Activity' with a focus on estimation of physical activity defined as 'participation in physical activity for at least 30 minutes on at least five days per week' and specific type of physical activity (Maas et al., 2008). The study found that exposure to green space in 1 km and 3 km radii was not associated with the study participants meeting Dutch recommendations for physical activity (parameter [standard error] for green space in 1 km radius= -0.0004 (0.002), p=0.808; and parameter [standard error] for green space in 3 km radius= -0.0001 (0.002), p=0.966) (Maas et al., 2008). Exposure to green space in buffers of 1 km radius was independently associated with higher likelihoods of cycling during leisure time and gardening (Maas et al., 2008). Conversely, exposure to green space was not associated with sports and walking for commuting. The relationship between exposure to green space and general health was not attenuated on the addition of specific types of physical activities, such as cycling for commuting and gardening, to the regression models (Maas et al., 2008). Subgroup analyses indicated that the relationship between green space and physical activity was stronger for residents of rural areas (considering physical activity), children (considering cycling during leisure time), adults within the age group of 12-25 years (considering walking during leisure time), adults within the age group of 17-25 years (considering gardening), and the elderly (considering walking during leisure time; cycling for commuting; and gardening) (Maas et al., 2008). Overall, the authors were of the view that exposure to green space was hardly related to physical activity. However, the authors did not have any data on the use of green space by the study participants. Additionally, the authors did not control for the density of the recreational facilities, dog ownership, and self-selection bias in the regression analyses (Maas et al., 2008). This study differed from other green space-physical activity studies because effect modifications were demonstrated for physical activity as well as specific type of physical activity for specific population subgroups. However, the relationship between green space and health could not be explained on the basis of physical activity in the green space (Maas et al., 2008).

In 2013, Ord and colleagues conducted a study of adults in urban areas of Scotland to determine the association between green space and physical activity by utilising data from the 2008 Scottish Health Survey (SHS) (Ord et al., 2013). The aim of this Scottish study was to determine whether exposure to neighbourhood green space was associated with overall physical activity (irrespective of the location in which the physical activity took place), walking, and physical activity that occurred specifically in the green space described as ‘green physical activity’ (Ord et al., 2013). For each type of physical activity, the frequency and duration of the physical activity were combined to produce a single variable that represented whether the UK government recommendations for participation in physical activity (moderate or vigorous physical activity for at least 30 minutes for five to seven days a week) were met by the study participants. While considering walking as a separate physical activity entity, at least thirty minutes of brisk walking on at least 5 times a week was taken as an indication of achievement of government guidelines on walking (Ord et al., 2013). More importantly, for participants taking part in this study, the ‘green physical activity’ variable was created by considering the frequency of access to different types of green neighbourhoods (Ord et al., 2013). Areas characterised as green spaces included parks, beaches, and agricultural lands with the exclusion of water bodies and private gardens. The percentage of green space in each CAS in Scotland was used as a surrogate measure for exposure to green space for the study participants (Ord et al., 2013). Exposure to green space was not associated with participation in overall physical activity for the study participants (ORs for overall physical activity were not reported by investigators). Exposure to green space was neither associated with participation in walking ($OR_{\text{fourth greenness quartile}}$=0.77 [95% CI=0.59–1.02]) nor associated with participation in green physical activity ($OR_{\text{fourth greenness quartile}}$=1.20 [95% CI=0.83–1.74]) (Ord et al., 2013). According to the authors, physical activity was not an important mediator of the association between green space and health in Scotland. However, the authors did not consider green space quality which is an important determinant of the use of green spaces for physical activity, neighbourhood safety or crime, neighbourhood density, and a measure of self-selection bias (Ord et al., 2013). Additionally, measurements of physical activity were self-reported (Ord et al., 2013).

2.3.6 Pregnant population study investigating the association of green space with physical activity

2.3.6.1 Pregnant population study showing association between green space and physical activity

One study has documented the health benefit of green space exposure in pregnant women in terms of increasing the likelihood of physical activity during pregnancy (McEachan et al., 2015). In 2015, McEachan and associates utilising the "Born in Bradford" cohort data from England investigated the relationship between green space and depression for pregnant women and whether physical activity mediated the relationship between green space and depression (McEachan et al., 2015). Depression was diagnosed through an assessment of severe depression subscales of the General Health Questionnaires (GHQs) (McEachan et al., 2015). More specifically, a total of four questions were answered on a four-point Likert scale (i.e., 0 to 3) by the study participants. These questions were as follows: 1) Whether life was entirely hopeless, 2) Whether life was not worth living, 3) Whether the study participants could not do anything because their nerves were too bad, and 4) Whether the study participants might make away with themselves. A binary variable, representing the likelihood of depression, was constructed and categorised as "non-depression" (scores of 0 on all four questions) and "depression" (score of 1 on at least 1 question)(McEachan et al., 2015). Residential greenness (NDVI) and proximity to green space (defined as living within 300 m of a major green space) were used as separate green space variables in regression analyses (McEachan et al., 2015). The investigators found that participants living in the greenest quintile had a lower prevalence of depression than those living in the least green quintile (prevalence of depression $_{\text{fifth greenness quintile}}$=31%; and prevalence of depression $_{\text{first greenness quintile}}$=39%). Pregnant women living in greener quintiles (OR $_{\text{third greenness quintile}}$=0.77 [95% CI=0.65–0.91]; OR $_{\text{fourth greenness quintile}}$=0.77 [95%

CI=0.65–0.92]; and $OR_{\text{fifth greenness quintile}}$=0.82 [95% CI=0.69–0.98]) were 18% to 23% less likely to report depression than were women living in the least green quintile. Similarly, pregnant women living within 300 m of major green spaces were 13% less likely to report depression than others ($OR_{\text{access to green space}}$=0.87 [95% CI=0.77–0.99]) (McEachan et al., 2015). Additionally, associations between residential greenness and depression were robust for pregnant women with low educational qualifications ($OR_{\text{second greenness quintile}}$=0.77 [95% CI=0.63–0.94]; $OR_{\text{third greenness quintile}}$=0.72 [95% CI=0.58–0.90]; $OR_{\text{fourth greenness quintile}}$=0.71 [95% CI=0.57–0.88]; and $OR_{\text{fifth greenness quintile}}$=0.74 [95% CI=0.59–0.94]) and those who were physically active ($OR_{\text{second greenness quintile}}$=0.64 [95% CI=0.41–0.99]; $OR_{\text{third greenness quintile}}$=0.72 [95% CI=0.47–1.11]; $OR_{\text{fourth greenness quintile}}$=0.56 [95% CI=0.37–0.86]; and $OR_{\text{fifth greenness quintile}}$=0.63 [95% CI=0.41–0.97]) (McEachan et al., 2015). No significant green space-depression associations were identified for specific pregnant population subgroups (e.g., those with low levels of education or those who were physically active) while considering access to green space (McEachan et al., 2015). Physical activity was shown to mediate the association between green space and depression as a small amount of the variation in depression (range of 5.6-7.8%) was explained by physical activity. According to the authors, physical activity was thought to be a partial mediator of the association between green space and depression. However, access to green space was measured on the basis of Euclidean distance and the authors did not control for self-selection bias in their regression analyses (McEachan et al., 2015).

2.4 Review of birth weight and gestational age

2.4.1 Factors associated with low birth weight or preterm birth and complications of low birth weight or preterm birth

Low birth weight, defined by the WHO as a "birth weight of less than 2500 grams", and preterm delivery, defined by the WHO as a "live birth born before 37 weeks completed gestation," are important determinants of infant mortality and morbidity in developing and developed nations (WHO and UNICEF, 2004). Multiple factors contribute to the risk that an infant will be of low birth weight or be delivered preterm. These include aspects of maternal demographics, physical and mental health, access to health care during pregnancy, and environmental exposures. Maternal demographics such as extremes of age (Lu et al., 2015, Xu et al., 2015), low education (Bhaskar et al., 2015, Coutinho et al., 2009, Xu et al., 2015), short stature (Derraik et al., 2016, Bhaskar et al., 2015), being underweight (Han et al., 2011, Coutinho et al., 2009) and living in deprived areas (Kramer et al., 2000, Pei et al., 2016) significantly contribute to the risk of delivery of a low birth weight or preterm infant.

A review of the literature on the relationship between maternal ethnicity and both birth weight and gestational age in new born infants has shown that maternal ethnicity is an important predictor (Goldenberg and Culhane, 2007). For example, in New Zealand, Māori (New Zealand's indigenous population) pregnant women are more likely to give birth to low birth weight infants than women from non-Māori ethnic backgrounds. The prevalence of low birth weight in Māori, Pacific, Asian, and Other [defined as European or Middle Eastern, Latin American and African] ethnic pregnant women is 6.8%, 4.5%, 6.5%, and 5.3%, respectively (MOH, 2012b). Similarly, Māori pregnant women are more likely to give birth to new born infants born before 37 weeks of gestation in comparison to women of non-Māori ethnicities (preterm birth prevalence $_{\text{Māori}}$=8.2%; preterm birth prevalence $_{\text{Pacific}}$=6.5%; preterm birth prevalence $_{\text{Asian}}$=6.5%; and preterm birth prevalence $_{\text{Other}}$=7.5%)(MOH, 2012b). Aspects of physical and mental health related to the delivery of a low birth weight or preterm infants include chronic hypertension (Bhaskar et al., 2015, Odell et al., 2006, Coutinho et al., 2009), preeclampsia (Iyoke et al., 2015, Odell et al., 2006), infectious diseases, antepartum haemorrhages (Coutinho et al., 2009), and antenatal depression (Grote et al., 2010). Fewer antenatal visits during pregnancy are correlated with a higher odds of delivering low birth weight infants; women visiting antenatal health care facilities only once or twice for the provision of health care services during pregnancy are more likely to give birth to low birth weight infants in comparison with those visiting more than four times (Bhaskar et al., 2015). Not having any antenatal care visits during pregnancy is associated with a higher risk of delivering a low gestation period infant (Vintzileos et al., 2002). Low birth weight and preterm birth in new born infants are associated with health complications in later life such as anxiety, depression, and disability (Morse et al., 2009, Day et al., 2016).

2.4.2 Pregnant population studies investigating the associations of green space with birth weight and gestational age

Few pregnant population studies have been published on the association between green space and birth weight and gestational age. These have been conducted in Germany (Markevych et al., 2014), Israel (Agay-Shay et al., 2014), Lithuania (Grazuleviciene et al., 2015), Spain (Dadvand et al., 2012c, Dadvand et al., 2012a), the UK (Dadvand et al., 2014b), and the United States (US) (Laurent et al., 2013, Ebisu et al., 2016). All of those studies have shown associations between green space and pregnancy outcomes either for the entire cohort of pregnant women or for specific population subgroups (Dadvand et al., 2012c, Dadvand et al., 2012a, Dadvand et al., 2014b, Markevych et al., 2014, Agay-Shay et al., 2014, Grazuleviciene et al., 2015, Ebisu et al., 2016). Most, if not all, of the pregnant population studies, have found associations between green space and birth weight (Dadvand et al., 2012c, Dadvand et al., 2012b, Hystad et al., 2014, Agay-Shay et al., 2014, Markevych et al., 2014, Dadvand et al., 2014b, Ebisu et al., 2016, Laurent et al., 2013). Only a limited number of studies have found associations between green space and preterm birth (Laurent et al., 2013, Hystad et al., 2014, Casey et al., 2016). Some studies have shown effect modifications for birth weight, with increases in birth weight in infants in relation to increases in residential greenness for pregnant women with low (Dadvand et al., 2012a, Dadvand et al., 2014b, Markevych et al., 2014, Dadvand et al., 2012c), or moderate levels of education (Dadvand et al., 2012c). A schematic diagram of criteria for selection of pregnant population studies on green space and birth weight and gestational age from the literature and inclusion in this thesis is given in Appendix 4. A summary of pregnant population studies on green space and birth weight and gestational age is presented in Appendix 6. The relevant pregnant population studies on green space and pregnancy outcomes are described below in a detailed and chronological manner.

2.4.3 Pregnant population studies showing associations between green space and birth weight and gestational age

In 2012, two Spanish studies conducted by Dadvand et al. (2012) investigated the relationships between exposure to green space and/or proximity to green space and adverse pregnancy outcomes (birth weight and gestational age), and whether these associations were moderated by maternal education (Dadvand et al., 2012a, Dadvand et al., 2012c). The first Spanish study, based in Barcelona, Spain, in which green space exposure was defined as NDVI within 100 m buffers around the residences of the study participants, and access to green space measured as the presence of residential addresses within buffers of 500 m of major green space, recruited participants from a university hospital during 2001-2005 (Dadvand et al., 2012a). In the first study, a 10% increase in NDVI in buffers of 100 m around maternal residences was independently associated with a reduction in birth weight by 19.8 grams (95% CI= - 67.6-28.1) and a reduction in gestational age by 0.04 of a week (95% CI= - 0.27-0.20) for the entire cohort, though these associations were not found to be statistically significant when considering the entire cohort (Dadvand et al., 2012a). In the same study, living within 500 m of a major green space was independently associated with a reduction in birth weight by 15.8 grams (95% CI= -36.3-4.8) and a reduction in gestational age by 0.06 of a week (95% CI= - 0.16-0.04) for the entire cohort (Dadvand et al., 2012a). Interaction tests showed that the interaction term for education was significant for birth weight analyses (*p-value* for NDVI-100 m=0.005 and *p-value* for proximity-500 m=0.029). A 10% increase of NDVI in buffers of 100 m around maternal residences was associated with a huge increase in birth weight by 436.3 grams (95% CI=43.1-829.5), and living within 500 m of a major green space was associated with an increase in birth weight by 189.8 grams (95% CI=23.9-355.7) for pregnant women who had not acquired any level of education, and these associations were statistically significant (Dadvand et al., 2012a). Dadvand and colleagues concluded that exposure to green space affected birth weight for population subgroups of low education. Limitations of the study include lack of control for household income, paternal occupation and education, and residential mobility in the regression analyses (Dadvand et al., 2012a). Additionally, this study was not able to estimate the effect of mediators such as physical activity, air and noise pollution, temperature, social contacts and stress on pregnancy outcomes as measures of exposure and access to green space were not associated with pregnancy outcomes (Dadvand et al., 2012a). This is the first study to demonstrate effect modification for birth weight analyses for pregnant women with the lowest level of education (Dadvand et al., 2012a). The interaction between green space and education is not significant for gestational age (interaction term *p-value* for NDVI-100 m=0.759 and interaction term *p-value* for proximity-500 m=0.846) (Dadvand et al., 2012a), so a gap remains in terms of consideration of a broad range of educational qualifications in relation to the relationship between green space and gestational age.

The aim of the second study, based in the Iberian Peninsula, by Dadvand et al. (2012) was to determine whether exposure to neighbourhood greenness was associated with birth weight, head circumference, and gestational age (Dadvand et al., 2012c). Four Spanish birth cohorts from the Euro Siberian and Mediterranean regions of the Iberian Peninsula were utilised to recruit pregnant women in this study. Green space was determined by means of the amount of greenness in buffers of 100 m, 250 m, and 500 m around the residences of the study participants (Dadvand et al., 2012c). An interquartile range (IQR) increase in NDVI in the buffers of 100 m, 250 m, and 500 m around maternal residences was associated with an increase in birth weight (birth weight $_{100\ m\ buffer}$=36.1 grams [95% CI=16.4-55.7]; birth weight $_{250\ m\ buffer}$=38.3 grams [95% CI=17.1-59.5]; and birth weight $_{500\ m\ buffer}$=44.2 grams [95% CI=20.2-68.2]). Additionally, investigators controlled the regression model for air pollution and found that there was a slight attenuation of the effect estimate for birth weight. Air pollution was thought to be a mediator of the association between green space and birth weight (Dadvand et al., 2012c). Similarly, an IQR increase in NDVI was associated with an increase in head circumference (head circumference $_{100\ m\ buffer}$=1.2 mm [95% CI=0.4-2.00]; head circumference $_{250\ m\ buffer}$=1.4 mm [95% CI=0.4-2.3]; and head circumference $_{500\ m\ buffer}$=1.7 mm [95% CI=0.5-2.9]) (Dadvand et al., 2012c). Considering gestational age, an IQR increase in NDVI in the buffers of 100 m, 250 m, and 500 m around maternal residences was associated with a reduction in gestational age, though these associations were not statistically significant (gestational age $_{100\ m\ buffer}$= -0.04 of a week [95% CI= - 0.13-0.04]; gestational age $_{250\ m\ buffer}$= -0.04 of a week [95% CI= -0.14-0.06]; and gestational age $_{500\ m\ buffer}$= -0.00 of a week [95% CI= -0.13-0.13]) (Dadvand et al., 2012c). The results of this study were indicative of effect modification for birth weight and head circumference due to levels of education. An IQR increase in the NDVI in buffers of 100 m, 250 m, or 500 m around maternal residences was associated with an increase in birth weight for pregnant women acquiring low (birth weight $_{500\ m\ buffer}$=63.3 grams [95% CI=1.7-124.9]) or moderate level of education (birth weight $_{100\ m\ buffer}$=43.6 grams [95% CI=13.9-73.3]; birth weight $_{250\ m\ buffer}$=44.1 grams [95% CI=11.7-76.4]; and birth weight $_{500\ m\ buffer}$=43.8 grams [95% CI=6.2-81.5]) (Dadvand et al., 2012c). On the other hand, an IQR increase in NDVI in the buffers of 100 m, 250 m, or 500 m around maternal residences was associated with an increase in head circumference for pregnant women with moderate level of education (head circumference $_{100\ m\ buffer}$=2.1 mm [95% CI=1.0-3.10]; head circumference $_{250\ m\ buffer}$=2.6 mm [95% CI=1.5-3.7]; and head circumference $_{500\ m\ buffer}$=3.0 mm [95% CI=1.7-4.2]) (Dadvand et al., 2012c). The investigators concluded that exposure to green space did not affect the gestation period, but affected foetal growth. However, this study was limited as it could not account for area-level socioeconomic status, residential mobility nor the use of green space by the study participants (Dadvand et al., 2012c). Consistent with the first Spanish study (Dadvand et al., 2012a), this study has demonstrated effect modification for birth weight for pregnant women with low levels of education. Additionally, effect modification for birth weight is seen for the first time for pregnant women who have acquired a moderate level of education (Dadvand et al., 2012c). Consistent with the first Spanish study (Dadvand et al., 2012a), the interaction between green space and education in this study is not significant for gestational age (Dadvand et al., 2012c), so a gap still remains in terms of consideration of a broad range of educational qualifications in relation to the relationship between green space and gestational age.

In 2013, Laurent and colleagues analysed maternal and neonatal data extracted from neonatal records in the US to determine the associations of green space with pregnancy outcomes of birth weight, preterm birth and preeclampsia and whether those associations were mediated by air pollution (Laurent et al., 2013). Exposure to green space in this study was characterised by NDVI within buffers of 50 m, 100 m, and 150 m around the residences of the study participants. The dependent variables considered in this study were those that described term birth weight, preterm birth, and preeclampsia (blood pressure>140/90 mm Hg and signs of haemolysis, elevated liver enzymes and low platelet counts) (Laurent et al., 2013). An IQR increase in NDVI in buffers of 50 m and 100 m around maternal residences was associated with increased term birth weight for the entire cohort after adjustment for confounders ($\beta_{50\ m\ buffer}$=6.09 grams [95% CI=3.11-9.06]; and $\beta_{100\ m\ buffer}$=1.43 grams [95% CI=0.01-2.84]). Further control of regression models by air pollution did not significantly change the effect estimates for term birth weight ($\beta_{50\ m\ buffer}$=6.22 grams [95% CI=3.22-9.22]; and $\beta_{100\ m\ buffer}$=2.17 grams [95% CI=0.59-3.75]) (Laurent et al., 2013). On the other hand, an IQR increase in NDVI in buffers of 150 m around maternal residences was associated with a lower risk of preterm birth for the entire cohort after adjustment for confounders ($OR_{150\ m\ buffer}$=0.985 [95% CI=0.972-0.997]). The association of green space with preterm birth was not evident after controlling for air pollution ($OR_{150\ m\ buffer}$=0.984 [95% CI=0.967-1.00]) (Laurent et al., 2013). Finally, exposure to green space was not associated with preeclampsia before and after adjustment of air pollution (Laurent et al., 2013). The authors concluded that green space exposure was independently associated with term birth weight and preterm birth and suggested that air pollution was not a mediator of the associations between green space and pregnancy outcomes (term birth weight and preterm birth in this case). Maternal smoking, BMI, and a variable for self-selection bias were not added to the regression models (Laurent et al., 2013). This study differs from other studies on green space and pregnancy outcomes in terms of the selection of covariates. Other studies have controlled for important factors such as maternal smoking (Dadvand et al., 2012a, Dadvand et al., 2012c, Dadvand et al., 2014b, Casey et al., 2016, Ebisu et al., 2016, Grazuleviciene et al., 2015, Hystad et al., 2014, Markevych et al., 2014), BMI (Dadvand et al., 2012c, Dadvand et al., 2014b, Grazuleviciene et al., 2015, Casey et al., 2016), and self-selection bias (Grazuleviciene et al., 2015) and found that green space is associated with pregnancy outcomes.

The aim of an English 'Born in Bradford' study by Dadvand et al. (2014) was to determine whether exposure to neighbourhood greenness was associated with birth weight and whether this association could be explained by maternal socioeconomic status, ethnicity, and education (Dadvand et al., 2014b). Assessment of green space in this study was characterised by NDVI within buffers of 50 m, 100 m, 250 m, 500 m, or 1000 m around the residences of the study participants and living within 300 m of a major green space (Dadvand et al., 2014b). The English study showed that an IQR increase in NDVI in buffers of 100 m, 250 m, or 500 m around maternal residences was associated with an increase in birth weight while considering the entire cohort of pregnant women ($\beta_{100\text{ m buffer}}$=15.8 grams [95% CI=1.1-30.6]; $\beta_{250\text{ m buffer}}$=16.2 grams [95% CI=1.7-30.8]; and $\beta_{500\text{ m buffer}}$=15.8 grams [95% CI=0.9-30.7]) (Dadvand et al., 2014b). The interaction analyses showed that most of the interactions terms were significant while taking the cut-off *p-value* as 0.05 (interaction term *p-value* for 250 m buffer=0.019; interaction term *p-value* for 500 m buffer=0.021; interaction term *p-value* for 1000 m buffer=0.008; and interaction term *p-value* for 100 m buffer=0.089). Subgroup analyses based on ethnicity showed that the association between residential greenness and birth weight was not significant for Pakistani pregnant women, but significant for White British pregnant women. An IQR increase in NDVI in buffers of 50 m, 100 m, or 250 m around maternal residences was associated with an increase in birth weight while considering White British pregnant women ($\beta_{50\ m\ buffer}$=27.2 grams [95% CI=3.5-50.8]; $\beta_{100\ m\ buffer}$=27.7 grams [95% CI=3.8-51.5]; and $\beta_{250\ m\ buffer}$=26.2 grams [95% CI=3.1-49.3])(Dadvand et al., 2014b). Despite the lack of interaction between green space and socioeconomic status for birth weight analyses, effect modification was seen for birth weight while considering maternal residents of the most deprived neighbourhoods. An IQR increase in NDVI in buffers of 50 m, 100 m, 250 m, 500 m, or 1000 m around maternal residences was associated with an increase in birth weight for residents of the most deprived neighbourhoods ($\beta_{50\ m\ buffer}$=38.9 grams [95% CI=13.6-64.3]; $\beta_{100\ m\ buffer}$=38.1 grams [95% CI=11.7-64.4]; $\beta_{250\ m\ buffer}$=35.8 grams [95% CI=9.9-61.7]; $\beta_{500\ m\ buffer}$=39.7 grams [95% CI=13.8-65.5]; and $\beta_{1000\ m\ buffer}$=37.2 grams [95% CI=11.6-62.7])(Dadvand et al., 2014b). The authors concluded that exposure to green space affected foetal growth and this effect varied for specific population subgroups. The study did not control for self-selection bias, nor the use of green space quality in the regression analyses. More importantly, the study was not able to identify the pathways through which green space affected birth weight (Dadvand et al., 2014b). While the sample in the Born in Bradford study is considered to be ‘ethnically diverse’, it is largely based on White British or Pakistani descent women (Dadvand et al., 2014b). In particular, there are no Pacific or Māori ethnic subgroups that are of relevance to New Zealand, so a gap remains in term of consideration of a broader range of ethnicities in relation to the relationship between green space and pregnancy outcomes.

In 2014, Hystad and colleagues analysed data from pregnant women recruited in a population-based birth cohort study in Vancouver, Canada to determine the associations of green space with pregnancy outcomes and elucidate mediating mechanisms underlining those relationships (Hystad et al., 2014). Consistent with other green space-pregnancy outcome studies, exposure to green space in this study was characterised by the amount of greenness in buffers of 100 m around the residences of the study participants (Hystad et al., 2014). For analyses relating to this study, birth weight was used as a continuous variable; gestational age was categorised as very preterm birth (<30 weeks of gestation), moderately preterm birth (30-36 weeks of gestation), and full term birth (≥37 weeks of gestation); and small for gestational age was categorised as birth weight below 10^{th} percentile and birth weight above 10^{th} percentile (Hystad et al., 2014). An IQR increase in NDVI in buffers of 100 m around maternal residences was associated with an increase in birth weight ($\beta_{100\ m\ buffer}$=20.6 grams [95% CI=16.5-24.7]) and a reduced risk of moderately preterm birth (OR=0.95 [95% CI=0.91-0.99]) while considering the entire cohort. Conversely, very preterm birth (OR=0.91 [95% CI=0.77-1.07]) and small for gestational age (OR=0.97 [95% CI=0.94-1.00]) were not associated with green space exposure (Hystad et al., 2014). This investigation also showed that the associations of green space with pregnancy outcomes were not affected after regression models were adjusted for mediating variables such as air pollution, noise pollution, neighbourhood walkability, and park proximity (Hystad et al., 2014). The authors concluded that exposure to green space was associated with pregnancy outcomes and suggested that other mediating pathways such as social support, social ties, and stress could play a role in mediating green space-pregnancy outcome relationships. However, the investigators could not control for diabetes mellitus and long term residential mobility in the regression modelling (Hystad et al., 2014). This is first study to investigate the effects of green space on moderately and very preterm births (Hystad et al., 2014). As this study did not demonstrate the protective effect of green space on very preterm births (Hystad et al., 2014), a gap remains in term of finding an effect for very preterm birth while determining the relationship between green space and very preterm birth.

The aim of a German study by Markevych et al. (2014) was to determine whether exposure to surrounding greenness and neighbourhood green spaces were associated with birth weight and whether these associations could be explained by air pollution, noise pollution, distance to major roads, and population density (Markevych et al., 2014). The assessment of green space exposure for mothers was done in two ways: 1. Amount of surrounding greenness (NDVI) in buffers of 100 m, 250 m, 500 m, or 800 m, and, 2. Amount of neighbourhood green spaces (defined as parks, forests, parks, and forests) in buffers of 500 m around the residences of the study participants (Markevych et al., 2014). Separate analyses were conducted to determine whether air pollution (NO_2 and $PM_{2.5}$), noise pollution, distance to major roads (used as a surrogate for air pollution and noise pollution), and population density (used as a surrogate for urbanity) altered the main effect of green space exposure on birth weight (Markevych et al., 2014). An IQR increase in surrounding greenness (NDVI) in the buffers of 500 m around maternal residences was associated with an increase in birth weight [birth weight $_{500\ m\ buffer}$=17.6 grams (95% CI=0.5-34.6)]. Adjustment of regression models for air pollution, noise pollution, distance to major roads, and population density while considering surrounding greenness in the buffers of 500 m produced similar results, but associations were mostly stronger than the main effect results (Markevych et al., 2014). The German study also showed effect modification for birth weight with stronger surrounding greenness-birth weight associations for pregnant women who had less than 10 years of school education (birth weight $_{500\ m\ buffer}$=58.2 grams [95% CI=2.0-114.4]). Exposure to neighbourhood green space was not associated with birth weight for the entire cohort (birth weight $_{forests}$=0.3 grams (-2.4-2.9); birth weight $_{parks}$=1.0 grams (-10.4- 12.4); and birth weight $_{forests\ and\ parks}$=1.8 grams (-11.0-14.7)) (Markevych et al., 2014). The German investigators concluded that exposure to surrounding greenness was associated with birth weight for the entire cohort. However, the investigators could not account for self-selection bias and area-level socioeconomic status, and could not determine the mediating mechanisms underlining green space-birth weight associations (Markevych et al., 2014). Consistent with two Spanish studies (Dadvand et al., 2012a, Dadvand et al., 2012c), this study has demonstrated effect modification for birth weight for pregnant women with low levels of education (Markevych et al., 2014). This study did not demonstrate effect modification for gestational age based on the level of education (Markevych et al., 2014), so a gap still remains in term of consideration of a broad range of educational qualifications in relation to the relationship between green space and gestational age. Another gap is the control of covariates such as income which is an important determinant of socioeconomic status and residential mobility while estimating the association between green space and birth weight.

In 2015, Agay-Shay and colleagues evaluated the associations between exposure to surrounding greenness and proximity to green space and adverse pregnancy outcomes by recruiting a sample of pregnant women who were registered with the National Birth Registry of the Israel's Ministry of Health and Interior (Agay-Shay et al., 2014). Residential maternal addresses were geocoded and linked to two measures of green space: 1. Average of NDVI within a buffer of 250 m around street centre point of each maternal address and 2. Access to green space was defined as 'presence of residential address within 300 m of a major green space.' Six dependent variables (birth weight, gestational age, low birth weight, very low birth weight, preterm birth, and very preterm birth) were created so that measures of green space exposure and access could be linked to adverse pregnancy outcomes. Additionally, subgroup analyses were undertaken based on the quartiles of ward-based socioeconomic status of pregnant women and their level of education (Agay-Shay et al., 2014). The Israeli study showed that an IQR increase in NDVI in buffers of 250 m around maternal residences was associated with an increase in birth weight by 19.2 grams [95% CI=13.3-25.1] and a reduced risk of low birth weight (OR=0.84 [95% CI=0.78-0.90]) while considering the entire cohort of pregnant women (Agay-Shay et al., 2014). Similarly, an increase in infantile birth weight by 18.10 grams [95% CI=8.7-27.6] and a reduced risk of low birth weight (OR=0.89 [95% CI=0.80-0.99]) was observed for pregnant women living within 300 m of a major green space. Associations between measures of green space exposure and very low birth weight, gestational age, preterm birth, and very preterm birth were not seen (Agay-Shay et al., 2014). The Israeli study showed effect modification for low birth weight with stronger green space-low birth weight association for pregnant women residing in the most deprived areas (Agay-Shay et al., 2014). An IQR increase in NDVI in buffers of 250 m around maternal residences was associated with an increase in birth weight of 26.0 grams [95% CI=6.8-45.1] and a reduced risk of low birth weight (OR=0.72 [95% CI=0.59-0.88]) when considering the cohort of pregnant women who were residents in the most deprived areas. While determining the role of air pollution as a mediator of the associations between green space and pregnancy outcomes (birth weight and low birth weight in this case), the investigators found that the effect estimates for birth weight and low birth weight were not attenuated on addition of an air pollution variable to the regression models. This study was not able to determine any other mechanisms (e.g., social interactions, stress, or noise pollution) that might have mediated the associations between green space and pregnancy outcomes (Agay-Shay et al., 2014). No effect modifications were seen for birth weight and low birth weight while considering the level of education of the pregnant women (Agay-Shay et al., 2014). Unlike other studies, this study demonstrated effect modification for birth weight for pregnant women residing in the most deprived areas (Agay-Shay et al., 2014). The authors were of a view that their study results were consistent with the results of previous pregnant population studies on the relationship between green space and birth weight. The authors did not consider confounders such as maternal health status, smoking and alcohol intake during pregnancy, and residential mobility in their regression analyses (Agay-Shay et al., 2014). Another gap that remains is consideration of residential mobility in relation to the relationship between green space and birth weight.

In a 2015 study, Grazuleviciene and colleagues conducted a study of pregnant women in Kaunas, Lithuania to determine the associations of surrounding greenness and proximity to parks with pregnancy outcomes (Grazuleviciene et al., 2015). The participants recruited in this study were registered with Kaunas Birth Cohort, Lithuania who had delivered between 2007 and 2009 (Grazuleviciene et al., 2015). Residential maternal addresses were geocoded and linked to two measures of green space: 1. Average of NDVI within buffers of 100 m, 300 m, and 500 m around residences of the study participants, and 2. Access to green space defined as Euclidean distance from each maternal address to the nearest park (Grazuleviciene et al., 2015). Six dependent variables [birth weight (grams), low birth weight, term low birth weight, gestational age (weeks), preterm birth, and small for gestational age] were created so that measures of green space could be linked to pregnancy outcomes (Grazuleviciene et al., 2015). Pregnant women living >1000 m from the nearest park were independently more likely to give birth to low birth weight and preterm infants than women living <300 m from the nearest park ($OR_{\text{low birth weight}}$=1.17 [95% CI=0.70-1.97]; $OR_{\text{preterm birth}}$=1.86 [95% CI=1.18-2.94]), though significant association was significant for preterm infants. Additionally, pregnant women who were exposed to lower surrounding greenness were more likely to give birth to term low birth weight infants than women exposed to higher surrounding greenness ($OR_{\text{term low birth weight for 500 m buffer}}$=2.37 [95% CI=1.14-4.95]) (Grazuleviciene et al., 2015). A striking feature of this investigation was that pregnant women who were exposed to lower surrounding greenness and residing >1000 m from the nearest park were independently more likely to give birth to term low birth weight ($OR_{\text{term low birth weight}}$=2.97 [95% CI=1.04-8.45]), low birth weight ($OR_{\text{low birth weight}}$=2.23 [95% CI=1.20-4.15]), or preterm infants (OR_{preterm}=1.77 [95% CI=1.10-2.81]) than women exposed to higher surrounding greenness and living within 1000 m of the nearest green space (Grazuleviciene et al., 2015). The Lithuanian investigators concluded that the effect of exposure to surrounding greenness on foetal growth was more robust than the effect from proximity to green space on foetal growth. However, investigators did not have any data on the use of green spaces by pregnant women (Grazuleviciene et al., 2015). This study differed from other studies on green space and pregnancy outcomes because participants were excluded from participating in this study if they had lived at their current residence for less than a year. That is, this study has accounted for self-selection bias while determining the associations between green space and pregnancy outcomes (Grazuleviciene et al., 2015). This study did not investigate effect modifications for pregnancy outcomes (Grazuleviciene et al., 2015) and did not look at mediators, so a gap remains in term of consideration of specific population subgroups (e.g., socioeconomic status and residential rurality) and mediators in relation to the relationship between green space and pregnancy outcomes.

A recent study conducted in Pennsylvania, US, investigated the relationship between exposure to residential greenness and diverse birth outcomes ranging from birth weight to low Apgar score (Casey et al., 2016). This study was carried out using data from electronic health records and included pregnant women who were residents of different types of communities such as cities, boroughs, or townships. Green space was assessed by average of NDVI within buffers of 250 m and 1250 m around residences of the study participants. The dependent variables selected for analyses were term birth weight (continuous), small for gestational age (categorical), preterm birth (categorical), and 5 minute Apgar score (categorical) (Casey et al., 2016). In the fully adjusted regression analysis, in comparison to the infants of mothers residing in an area of low greenness in cities, the odds of preterm birth and small for gestational age were independently decreased for infants of mothers residing in an area of higher greenness in cities ($OR_{\text{preterm birth in cities}}$=0.78 [95% CI=0.61-0.99] and $OR_{\text{small for gestational age in cities}}$=0.73 [95% CI=0.58-0.97]) (Casey et al., 2016). The associations for preterm birth and small for gestational age were not observed for infants of mothers residing in boroughs or townships (Casey et al., 2016). The authors concluded that exposure to green space was associated with birth outcomes for pregnant women residing in cities. This study did not account for mediators (e.g., physical activity and stress), indicators of personal-level socioeconomic status (e.g., maternal occupation, income, education), and long term residential mobility (Casey et al., 2016). Other studies on green space and preterm birth have controlled for indicators of personal-level socioeconomic status and found green space to be associated with preterm birth (Hystad et al., 2014, Grazuleviciene et al., 2015). Another gap is consideration of residential mobility while determining the association between green space and preterm birth.

In another recent study conducted in Connecticut, US, Ebisu et al. (2016) investigated the relationship between exposure to green space, urbanity and birth outcomes of birth weight and small for gestational age (Ebisu et al., 2016). The participants recruited in this study were registered with the Connecticut Department of Public Health who had delivered between 2000 and 2006 (Ebisu et al., 2016). Examples of green spaces included in this study were forests, shrubs, herbaceous and cultivated crops. Assessment of exposure to green spaces in this study was done by measuring the proportion of land covered by green spaces, urban spaces (land covered by urban structures), and urban open spaces (land covered by urban structures and green spaces) in buffers of 250 m around the residences of the study participants. For analyses relating to this study, birth weight was used as a continuous (grams) and a categorical variable; and small for gestational age was used as a categorical variable. Sensitivity analyses were conducted for 1. Investigation of the relationship between exposure to green spaces and urbanity and birth outcomes in buffers of 100 m, 500 m, 1000 m, or 2000 m around the residences of the study participants, 2. Adjustment of main effect models for $PM_{2.5}$ and traffic density (as a surrogate for NO_2 and carbon monoxide exposures), 3. Low or high levels of urbanity, and 4. Subgroup analyses based on ethnicity, education, and marital status (Ebisu et al., 2016). An IQR increase in proportion of land covered by green spaces in buffers of 250 m around maternal residences was associated with an increase in birth weight by 3.2 grams [95% CI=0.4-6.0 grams] and a 7.6% reduced risk of low birth weight [95% CI=2.6-12.4%] while considering the entire cohort sample. Conversely, an IQR increase in proportion of land covered by urban spaces in buffers of 250 m around maternal residences was independently associated with a decrease in birth weight by 5.9 grams [95% CI=1.6-10.2 grams], a 16.2% increased risk of low birth weight [95% CI=7.8-25.3%], and a 6.5% increased risk of small for gestational age [95% CI=2.6-10.5%] (Ebisu et al., 2016). The results of sensitivity analyses for different buffer sizes while analysing all three birth outcomes were less strong than main results for the 250 m buffer size. Adjustment of the main models for $PM_{2.5}$ and traffic density resulted in stronger associations for the associations of land-use with low birth weight and small for gestational age. However, associations between land-use and birth weight were weakened after adjustment of $PM_{2.5}$ and traffic density pointing towards the fact that these were mediators (Ebisu et al., 2016). No effect modification was seen for any of the studied birth outcomes based on ethnicity, education, or marital status of the study participants (Ebisu et al., 2016). The authors concluded that exposure to green space was associated with birth outcomes and suggested that urban planners could plan for the provision of more green spaces and/or less urban spaces so that the risk of adverse birth outcomes could be reduced. This study had a limitation of not taking into account the long-term residential mobility of the study participants (Ebisu et al., 2016). This is the first study to investigate the associations between urban spaces and pregnancy outcomes (Ebisu et al., 2016). As this study did not account for residential mobility (Ebisu et al., 2016), a gap still remains in term of consideration of residential mobility while determining the relationship between green spaces and pregnancy outcomes and the relationship between urban spaces and pregnancy outcomes.

2.5 Review of depression

2.5.1 Factors associated with depression and complications of depression

2.5.1.1 Factors associated with depression and complications of depression in adults from the general population

According to the WHO, the most common mental health disorder affecting adults in the general population is depression (WHO, 2016a). Depression is clinically diagnosed by the presence of unhappiness; feelings of guilt; tiredness; and lack of appetite, sleep, concentration, and pleasure (WHO, 2016a). The prevalence rate of depression amongst adults in the general population is country-specific, ranging from 11% for low and medium income countries to 15% for high income countries (Bromet et al., 2011). Multiple predictors of depression have been identified in the general population. These include gender (Oliver-Quetglas et al., 2013), stress (Kader Maideen et al., 2014), anxiety (Kader Maideen et al., 2014), domestic violence (Kader Maideen et al., 2014), marital status (Oliver-Quetglas et al., 2013), relationship issues (Kader Maideen et al., 2014, Oliver-Quetglas et al., 2013), low self-esteem (Kader Maideen et al., 2014), financial problems (Kader Maideen et al., 2014), issues in the work place (Kader Maideen et al., 2014, Oliver-Quetglas et al., 2013), chronic diseases (Kader Maideen et al., 2014), general health status (Oliver-Quetglas et al., 2013), sedentary lifestyle (Oliver-Quetglas et al., 2013), racial discrimination (Oliver-Quetglas et al., 2013), use of drugs (Oliver-Quetglas et al., 2013), family history of psychological problems (Oliver-Quetglas et al., 2013), and income (Oliver-Quetglas et al., 2013). Depression can manifest as a chronic condition, and, if left untreated, leads to a loss of productive life years during the life course of the affected individual (WHO, 2016a, Andrews, 2001). In 2001, depression was regarded as the fourth leading cause of disability (WHO, 2001). By 2020, depression is projected to become the second most important factor associated with disability (WHO, 2001). Some of the complications associated with depression include obesity, heart diseases, diabetes mellitus, drug abuse, anxiety, social phobia, and social isolation (MFMER, 2017b). In the most severe cases, depression culminates into suicide (WHO, 2016a).

2.5.1.2 Factors associated with antenatal depression and complications of antenatal depression in pregnant women

Globally, variable prevalence rates of antenatal depression have been observed ranging from 12% to 20% (Leigh and Milgrom, 2008). In New Zealand, it is estimated that 15% of pregnant women suffer from mental disorders, including anxiety and depression (MOH, 2012a). Multiple factors are associated with antenatal depression. These include age (Ayele et al., 2016), education (Coll et al., 2017a), marital status (Thompson and Ajayi, 2016), parity (Coll et al., 2017a), planning of pregnancy (Thompson and Ajayi, 2016), pre-pregnancy chronic diseases (Melville et al., 2010), past history of depression (Bisetegn et al., 2016), past history of abortions and still births (Bisetegn et al., 2016), gender-based violence (Thompson and Ajayi, 2016), smoking during pregnancy (Dagklis et al., 2016), lack of antenatal care (Ayele et al., 2016) and social support (Biaggi et al., 2016), occupation (Ayele et al., 2016) and socioeconomic status (Rwakarema et al., 2015). Depression during pregnancy is associated with poor mental health; the adverse pregnancy outcomes of low birth weight, preterm birth, small for gestational age, smaller head infants and adverse child health outcomes of low Apgar scores, and infant mortality (Accortt et al., 2015, Goedhart et al., 2010). Additionally, pregnant women suffering from antenatal depression are more likely to suffer from postnatal depression than those not affected by depression during pregnancy (Leigh and Milgrom, 2008). Postnatal depression, if left untreated, can lead to a chronic depressive disorder in mothers and emotional/behavioural disorders in their children such as insomnia, excessive crying, and attention deficit hyperactivity disorder (MFMER, 2017a).

2.5.2 General adult population and pregnant population studies investigating the associating of green space with mental health disorders

Several general population studies, from Australia (Astell-Burt et al., 2013b), Europe (van den Berg et al., 2016), the Netherlands (Bos et al., 2016), New Zealand (Nutsford et al., 2013, Nutsford et al., 2016), Sweden (Annerstedt et al., 2012), and the US (Beyer et al., 2014) have investigated the association between green space and mental health disorders. Some of these studies clearly show a protective effect of green space on mental health disorders (Nutsford et al., 2013, Richardson et al., 2013, Astell-Burt et al., 2013b, Beyer et al., 2014) whilst other studies do not show an effect (Nutsford et al., 2016, Annerstedt et al., 2012, Bos et al., 2016). As previously described, one pregnant population study has investigated the relationship between green space and depression (McEachan et al., 2015). A schematic diagram of criteria for selection of general population and pregnant population studies on green space and mental health disorders from the literature and inclusion in this thesis is given in Appendix 5 and their summary is provided in Appendix 6. The general population studies are described below in a detailed and chronological manner.

2.5.2.1 General adult population studies showing association between green space and mental health disorders

In 2009, an exploratory study by Maas and colleagues investigated the relationship between exposure to green space and morbidity outcomes (cardiovascular, musculoskeletal, mental, respiratory, neurological, digestive, and miscellaneous) and whether this relationship differed according to age and socioeconomic status subgroups. Green space exposure for the participants was determined by calculating the proportion of green space within 1 km and 3 km radii around the postal code coordinates (Maas et al., 2009b). The dependent variables used in this study were mental (depression and anxiety disorder) and a range of other health conditions (Maas et al., 2009b). In the fully adjusted regression analyses, each 10% increase in percentage of green space within 1 km radius resulted in a decrease in likelihood of morbidity outcomes, including anxiety disorder ($OR_{anxiety}$=0.95 [95% CI=0.94-0.97]) (Maas et al., 2009b). Each 10% increase in percentage of green space within 3 km radius resulted in a decrease in likelihood of morbidity outcomes, including anxiety disorder ($OR_{anxiety}$=0.96 [95% CI=0.93-0.99]) (Maas et al., 2009b). Stratification of analysis according to different age groups indicated that the relationship between green space and morbidity outcomes was strongest for depression in children aged <12 years (OR

$_{\text{green space within 1 km radius}}$=0.79 [95% CI=0.72-0.88]; and OR $_{\text{green space within 3 km radius}}$=0.84 [95% CI=0.78-0.91]) (Maas et al., 2009b). While considering urban subgroups, the relationship between green space within 1 km radius and prevalence rates of morbidity outcomes was strongest in the slightly urban areas in comparison to other areas of urbanity such as very strongly urban, strongly urban, moderately urban, and non-urban areas (ORs not reported by the investigators) (Maas et al., 2009b). The Dutch authors concluded that their study confirmed the already established relationship between green space and self-reported morbidity outcomes of physical and mental health. Additionally, green space closer to the residence was observed to be a more important determinant of morbidity than green space further away from residence. The Dutch authors suggested that a reduction in stress and increased social contacts could possibly be mechanisms underlying the associations between green space and morbidity outcomes (Maas et al., 2009b). However, the authors did not have any data on income and area-level socioeconomic status of the participants. Further, the authors did not include small-sized green spaces such as gardens, street trees, and green verges in their classification of green spaces (Maas et al., 2009b). This study differed from most other studies of the relationship between green space and mental health with morbidity data gathered from people who were registered with their general practitioners and had lived in their current neighbourhood for a period of at least 12 months (Maas et al., 2009b). Thus this study accounted for self-selection bias while determining the associations between green space and morbidity outcomes, including mental health outcomes (Maas et al., 2009b). A gap still remains in term of the inclusion of small-sized green spaces in the classification of green spaces and control for personal-level or area-level socioeconomic status while determining the associations between green space and mental health outcomes.

Astell-Burt and colleagues (2013) hypothesised that exposure to green space would be associated with better mental health amongst physically-active middle-aged to older-aged adults in comparison to their physically inactive counterparts (Astell-Burt et al., 2013b). The aims of this investigation were to determine whether there was an association between exposure to green space and mental health (defined as the 'presence of psychological distress') and whether the association between green space and mental health was moderated by physical activity (Astell-Burt et al., 2013b). In this study, green space was determined based on the percentage of land area covered by parklands within buffers of 1 km radius around addresses of the study participants. The physical activity of the study participants was determined through the 'Active Australia Survey' with emphasis on moderate physical activity, vigorous physical activity, and walking (Astell-Burt et al., 2013b). In this green space-mental health study, the participant's mental health was assessed through the administration of the Kessler Psychological Distress Scale (K10) Questionnaire which indicated psychological distress. Each questionnaire consisted of 10 questions (e.g., feeling tired for no reason, nervous, hopeless, restless, depressed, sad and worthless) which were answered on five-point Likert scales (e.g., 1=none of the time to 5=all the time). Total scores of $\geq$22 were indicative of the presence of psychological distress (Astell-Burt et al., 2013b). Participants living in the greenest quintile were independently less likely to develop psychological distress (OR=0.83 [95% CI=0.76-0.92]) and be less physically inactive (OR=0.82 [95% CI=0.77-0.87]) in comparison to residents of the least green quintile (Astell-Burt et al., 2013b). Interaction tests showed that there was an interaction between green space and physical activity (trend *p-value*=0.0028). Participants living in the greenest quintile who were physically active were less likely to develop psychological distress when compared to those living in the least green quintile (OR=0.82 [95% CI=0.67-0.99])(Astell-Burt et al., 2013b). The authors were of the view that exposure to green space was associated with physical activity and better mental health. The authors did not have access to any data on the use of green space by the study participants, could not identify mediators, and did not control for self-selection bias (Astell-Burt et al., 2013b). This study differs from other studies on green space and mental health outcomes because it shows that the association between green space and psychological distress is moderated by physical activity (Astell-Burt et al., 2013b). However, this study could not determine whether the green spaces were actually used by the study participants for engagement in physical activity (Astell-Burt et al., 2013b).

The aim of the New Zealand study by Nutsford et al. (2013) was to determine whether urban green space was associated with mental health (Nutsford et al., 2013). The definition of green space included areas classified as ‘useable’ (e.g., parks and sports fields) and ‘total’ green spaces (e.g., parks, forests, grasslands, etc.). Exposure and access to green space for the study participants was characterised by six measures of 1. Distance from PWC to nearest useable green space, 2. Distance from PWC to nearest total green space, 3. Proportion of land area covered by useable green space within a buffer of 300 m of each PWC, 4. Proportion of land covered by total green space within a buffer of 300 m of each PWC, 5. Proportion of land area covered by useable green space within a buffer of 3 km of each PWC, and 6. Proportion of land covered by total green space within a buffer of 3 km of each PWC (Nutsford et al., 2013). The dependent variable considered in this study was one that described the number of people treated for anxiety/mood disorders, termed as ‘anxiety/mood disorder treatment count’ and expressed as a continuous variable (Nutsford et al., 2013). The number of anxiety/mood disorder treatment counts included people who had received secondary treatments for mental health disorders, or who had received subsidised prescription drugs for anxiety/mood disorders, or those diagnosed for mental health disorders on the basis of positive laboratory tests for lithium (Nutsford et al., 2013). This New Zealand study showed that a 1% increase in the proportion of land area covered by useable green space within a buffer of 3 km of PWC was associated with a 4% lower risk of anxiety/mood disorder treatment count (IRR=0.964 [95% CI=0.950-0.979]). Similarly, a 1% increase in the proportion of land area covered by total green space within a buffer of 3 km of PWC was associated with a 4% lower risk of anxiety/mood disorder treatment count (IRR=0.956 [95% CI=0.943-0.970]) (Nutsford et al., 2013). On the other hand, every 100 m decrease in distance to nearest useable green space was associated with a 3% lower risk of anxiety/mood disorder treatment count (IRR=1.352 [95% CI=1.024-1.785]). In the adjusted multivariate analyses, the remaining measures of green space exposure and access were found not to be associated with anxiety/mood disorder treatment count (Nutsford et al., 2013). The authors concluded that access and exposure to green space in terms of a decreased distance to useable green space and the proportion of land covered by useable and total green space within broader environment were associated with better mental health. Psychological restoration and physical activity were implicated as mediators of the associations between green space and anxiety/mood disorder treatment counts (Nutsford et al., 2013). The authors did not include private gardens in their classification of green spaces and did not control for the length of stay at the current residence, gender, nor the ethnicity in their regression analyses (Nutsford et al., 2013). Therefore, a gap still remains in terms of the inclusion of private gardens in the classification of green spaces and the control of covariates (gender, ethnicity, and self-selection bias in this case) while determining the associations between green space and mental health outcomes.

It is thought that physical activity conducted in greener neighbourhoods has a greater potential to cause improvement in mental health than physical activity in non-green neighbourhoods. To test this hypothesis, Mitchell conducted an observational design study in 2013 utilising data from the 2008 SHS (Mitchell, 2013). In this study, green space exposure was determined through estimation of the proportion of land within each CAS ward covered by green space. Physical activity was estimated by calculating the frequency of physical activity during the past 4 weeks, with the location of the physical activity being green (e.g., parks, forests, grass, and woodlands) or non-green neighbourhoods (e.g., gymnasiums, local pavements, and non-tarmac paths)(Mitchell, 2013). The dependent variables used in this study were the GHQ12 and the Warwick Edinburgh Mental Health and Well-being Scale scores (WEMWBS). The GHQ12 questionnaires assessed symptoms of difficulty in sleep, an inability to make decisions, a lack of self-confidence and stress among the study participants. The GHQ12 scores were transformed into a binary variable with scores of ≥4 indicated the presence of minor psychiatric morbidity. The WEMWBS score, an indicator of well-being, was expressed as a continuous variable (Mitchell, 2013). This Scottish study revealed that respondents utilising open spaces/parks for physical activity at least once a week were less likely to develop minor psychiatric morbidity compared with respondents not using open spaces/parks for physical activity (OR=0.570 [95% CI=0.369-0.881]). A similar trend was observed for use of woods/forests with respondents utilising woods/forests at least once a week being less likely to develop minor psychiatric morbidity compared with respondents not using woods/forests for physical activity (OR=0.557 [95% CI=0.323-0.962]). No such associations were seen for use of other types of green (e.g., beaches or home gardens) or non-green neighbourhoods (e.g., gymnasiums, local pavements, or non-tarmac paths)(Mitchell, 2013). The use of open spaces/parks less than once a week, sports pitches for at least once a week, and gymnasiums for at least once a week were associated with WEMWBS scores and better well-being ($\beta_{\text{open spaces/parks}}$=2.442 [95% CI=0.769-4.115]; $\beta_{\text{sports pitches}}$=2.366 [95% CI=0.393-4.339]; and $\beta_{\text{gymnasiums}}$=1.411 [95% CI=0.083-2.739](Mitchell, 2013). The authors concluded that physical activity in a greener neighbourhood was a more important determinant of better mental health than physical activity in a non-green neighbourhood and suggested that the promotion of physical activity in a greener neighbourhood could prove to be an important factor associated with better mental health at a population-level. However, the authors did not consider duration of physical activity and did not control for self-selection bias in their regression analyses (Mitchell, 2013).

In 2014, Beyer and colleagues investigated the relationship between exposure to green space and mental health (Beyer et al., 2014). This study, based in Wisconsin, US, in which green space exposure was defined as greenness (NDVI) within each Census Block Group or percent tree canopy coverage within each Census Block Group (geographical unit smaller than the census tract in the US). Additionally, a combined measure of average NDVI and percent tree canopy coverage within each Census Block Group was utilised in the regression analyses (Beyer et al., 2014). In this study, the mental health of the participants was accessed by means of the 42-item Depression, Anxiety, and Stress Scale (DASS) which represented symptoms of depression (self-disparaging, discouraged, gloomy, sad, convinced that life has no meaning or value, pessimistic, lack of enjoyment or satisfaction, and lack of interest), anxiety (apprehensive, panicky, trembly, shaky, dryness of the mouth, difficulty in breathing, palpitations, sweatiness of the palms, worried about performance, and possible loss of control), and stress (over-aroused, tense, unable to relax, touchy, easily upset, irritable, easily startled, nervy, jumpy, fidgety, and intolerant of interruption or delay). Higher DASS scores were indicative of the presence of poor mental health. Three dependent variables (DASS depression score, DASS anxiety score, and DASS stress score) were created so that measures of green space exposure could be linked to mental health along after adjustment for confounders, including length of residence in the neighbourhood (Beyer et al., 2014). In the fully adjusted regression analyses, each 25% increase in measures of green space exposure within each Census Block Group resulted in a decrease in depression ($\beta_{\text{tree canopy}}$= -1.005; β_{NDVI}= -1.369; and $\beta_{\text{NDVI and tree canopy}}$= -1.379), anxiety ($\beta_{\text{tree canopy}}$= -0.273; β= $_{\text{NDVI}}$= -0.512; and $\beta_{\text{NDVI and tree canopy}}$= -0.427), and stress scores ($\beta_{\text{tree canopy}}$= -0.548; β= $_{\text{NDVI}}$= -0.701; and $\beta_{\text{NDVI and tree canopy}}$= -0.735) (Beyer et al., 2014). Beyer and colleagues concluded that exposure to green space was associated with less depression, anxiety, and stress and they suggested that the “greening” of residential areas could prove to be beneficial to the mental health of US residents (Beyer et al., 2014). However, drawbacks of this study were the temporal disconnection between mental health data and green space data due to not acquiring data on mental health and green space in the same year (for e.g., tree canopy data were collected in 2001, NDVI data were collected in 2009, and mental health data were collected during 2008-2011). The investigators did not acquire socioeconomic status data at the level of Census Block Group (Beyer et al., 2014). Consistent with the study by Maas and colleagues (Maas et al., 2009b), this study has included a variable of residential mobility as a surrogate measure for self-selection bias in the regression analyses.

In a 2014 longitudinal study by Astell-Burt and colleagues, the British Household Panel Survey was utilised to study the association between exposure to green space and mental health (Astell-Burt et al., 2014e). Green space exposure was accessed by the estimation of the proportion of land covered by green spaces within each ward–the smallest geographical unit in the UK. Green space was utilised as a continuous and a categorical variable based on the percentage of ward green space (Astell-Burt et al., 2014e). Mental health was defined as the 'presence of minor psychiatric morbidity' and determined through the 12-item GHQ. The general health scores obtained from the 12-item GHQs were used to assess the mental health statuses with higher scores indicating the presence of minor psychiatric morbidity. The general health construct within a 12-item GHQ examined a range of questions on mental health issues such as concentration, insomnia, lack of confidence, self-worthiness, happiness, and depression (Astell-Burt et al., 2014e). In this study, the variable GHQ was taken as a continuous variable because it was found to be normally distributed within the population (Astell-Burt et al., 2014e). The British study revealed that average GHQ scores for men ($GHQ_{\text{low green space}}$=17.6; $GHQ_{\text{medium green space}}$=15.7; and $GHQ_{\text{high green space}}$=16.0) and women ($GHQ_{\text{low green space}}$=24.6; $GHQ_{\text{medium green space}}$=23.4; and $GHQ_{\text{high green space}}$=23.6) varied across green space areas, being lower in high green space areas than in low green space areas (Astell-Burt et al., 2014e). In men, a linear dose-response relationship between green space and minor psychiatric morbidity was observed. On the other hand, in women, the dose-response relationship between green space and minor psychiatric morbidity was 'U' shaped with the lowest GHQ scores being evident in moderate green space areas (Astell-Burt et al., 2014e). In men aged 15-20 years, there were no differences in the average GHQ scores between those living in low, medium, or high green space areas. At the age of 30, differences in average GHQ scores appeared between men living in medium and high green space areas in comparison to men residing in low green space areas. The GHQ scores for men living in medium and high green space areas were lower than the GHQ scores for men living in low green space areas. This trend persisted until the age of 60 years but was not apparent in older age groups (Astell-Burt et al., 2014e). In women, aged 15-20 years, differences in average GHQ scores were evident between women living in medium green space areas in comparison to women residing in low and high green space areas. The GHQ scores for women living in medium green space areas were higher than the GHQ scores for women residing in low and high green space areas. These green space related differences in mental health were not evident in women 20 to 40 years old. After the age of 41 years, women living in areas of medium green space had lower GHQ scores and this trend persisted until old age (Astell-Burt et al., 2014e). The authors concluded that the association of green space with mental health differed across the life course for men and women (Astell-Burt et al., 2014e). However, the authors did not investigate mediating mechanisms (e.g., physical activity and social contacts) while determining the association between green space and minor psychiatric morbidity (Astell-Burt et al., 2014e). This study differed from most of other mental health studies as adults were excluded from participation if they had not lived in their current residence for at least 12 months (Astell-Burt et al., 2014e).

The aim of British longitudinal 2014 study by Alcock and colleagues aimed to determine whether exposure to green space following selective migration from less green to greener areas and vice versa was associated with mental health (Alcock et al., 2014). People who moved from less green to greener areas and from greener to less green areas were included in this study after restricting analysis to English urban residents (Alcock et al., 2014). The data collection wave consisted of the administration of survey questionnaires once every year to the study participants over a 5-year period (2 years before and 3 years after migration) (Alcock et al., 2014). Exposure to green space (defined as green area, including private garden) for people migrating from less to more green areas and vice versa was measured based on the percentage of land surface covered by green space within each LSOA. The dependent variable included in the analysis of association of green space with mental health was a reverse coded 12-item GHQ score with a higher score indicative of better mental health (Alcock et al., 2014). Alcock and colleagues showed that the percentage of green space within LSOA increased from 58.01% (standard deviation [SD]=16.06%) for less green areas to 74.08% (SD=13.34%) for greener areas. Conversely, the percentage of green space within LSOA decreased from 74.13% (SD=13.67%) for greener areas to 59.21% (SD=15.01%) for less green areas (Alcock et al., 2014). This study revealed that people moving from less to more green areas had better mental health after moving in comparison to their mental health before moving, though the largest effect size for mental health was observed in the 3rd year after moving ($\beta_{\text{1st year post move}}$=0.369, p=0.015; $\beta_{\text{2nd year post move}}$=0.378, p=0.016; and $\beta_{\text{3rd year post move}}$=0.431, p=0.008). Conversely, people moving from more to less green areas showed no change in mental health following the move in comparison to their mental health before moving ($\beta_{\text{1st year post move}}$= -0.123, p=0.456; $\beta_{\text{2nd year post move}}$=0.027, p=0.871; and $\beta_{\text{3rd year post move}}$=0.163, p=0.354) (Alcock et al., 2014). The authors concluded that selective migration from less to more green areas was associated with better mental health (Alcock et al., 2014). However, the authors did not control for stress and stress reducing life events in regression modelling. Additionally, mediators of the association between exposure to green space and mental health could not be determined (Alcock et al., 2014). This study differed from other studies that have investigated the relationship of green space with mental health outcomes because participants who migrated from less to more green areas and vice versa were targeted for enrolment and followed for a period of 3 years (Alcock et al., 2014). In fact, this is the paired study in the general population adults determining the association between green space and mental health (Alcock et al., 2014). As a consequence, indicators of personal-level and area-level socioeconomic status were most likely to be better controlled for in regression analyses (Alcock et al., 2014). Despite these benefits, a gap remains in terms of finding mediators of the associations between green space and mental health outcomes.

In a most recent 2016 Dutch study by Bos and colleagues, the associations between exposure to green spaces and mental health and quality of life were explored using a sample of adults. Additionally, this study aimed to determine whether the associations of exposure to green spaces with mental health and with quality of life were moderated by age and gender (Bos et al., 2016). Consistent with other green space-health studies from the Netherlands, exposure to green space was determined on the basis of the proportion of land covered by green space (e.g., parks, agricultural land, or private gardens) within buffers of 1 km and 3 km radii around 4-digit postal code centroid of home addresses (Bos et al., 2016). The dependent variables used in this study were DASS (42 items on anxiety, stress, and depression, and each item was answered on a 4-point Likert scale) and the Manchester Short Assessment of Quality of Life (MANSA) scores (12 items on satisfaction with life and each item answered on a 7-point Likert scale) (Bos et al., 2016). This Dutch study showed there was a lack of interaction between green space and other variables of interest (gender and age) while considering analyses of mental health and quality of life. Exposure to green space within buffers of 1 km radius was not associated with DASS and MANSA (β_{DASS}= -0.3, standard error=1.8, and *p-value*=0.883; β_{MANSA}= -0.5, standard error=0.9, and *p-value*=0.569) (Bos et al., 2016). In the same study, the association of exposure to green space within buffers of 3 km radius was not associated with MANSA (β_{MANSA}=6.3 and standard error=4.5), but was associated with DASS (β_{DASS}= -16.9 and standard error=8.1) (Bos et al., 2016). For the DASS analysis, green space interacted with gender and age and the largest effect size for DASS was observed in women aged 18 to 24 years (effect size $_{\text{DASS}}$= -0.2). Conversely, in men aged 45-54 years, exposure to green space was associated with poorer mental health (effect size $_{\text{DASS}}$=0.15). An interaction was seen between green space and age while considering MANSA analysis, and the largest effect size for MANSA was observed in adults aged 45-54 years (effect size $_{\text{MANSA}}$= -0.125) (Bos et al., 2016). The Dutch authors concluded that exposure to green space was associated with better mental health for certain age and gender subgroups, and the moderating effects of age and gender on mental health could be explained based on the differential use of green spaces by different age and gender subgroups. The cross-sectional nature of this investigation, lack of socio-demographic diversity in terms of the gender and education, and lack of proper control for self-selection bias were limitations of this study (Bos et al., 2016). Unlike other studies on green space and mental health outcomes, residential addresses were geocoded through the use of incomplete postal code digits resulting in an inaccurate estimation of green space exposure (Bos et al., 2016). Another gap is the control of mental health determinants such as gender and education which are important for producing robust estimations of the associations between green space and mental health outcomes.

The aim of the most recent European cross-sectional study by Magdalena van den Berg and colleagues (2016) was to evaluate the association between exposure to green space in terms of visits to green space and the mental health of European adults, and whether the association was moderated by age, gender, education, attitude for nature, and childhood nature experience (van den Berg et al., 2016). For this study, data were gathered through the administration of questionnaires to residents of four European cities of Barcelona, Doetinchem, Kaunas, and Stoke-on-Trent (van den Berg et al., 2016). Green spaces were defined as green and/or blue areas, including parks, forests, reserves and water bodies (van den Berg et al., 2016). The mental health of European adults was assessed by the administration of a short form of a general health survey that measured two different mental health indices of perceived mental health (defined as nervousness and depression) and vitality (defined as energy and fatigue). Higher scores on perceived mental health and vitality indicated better mental health and higher vitality, respectively (van den Berg et al., 2016). The European study revealed that there were significant differences in total duration of visits to green space for the study participants across the four European cities (*p-value*$<$ 0.001). The total duration of hours spend in green space by residents of Kaunas City was significantly higher than the total duration of hours spend in green spaces by residents of the remaining three European cities (Kaunas=38.6 hours/month; Doetinchem=27.2 hours/month; Barcelona=23.9 hours/month; and Stoke-on-Trent=21.9 hours/month) (van den Berg et al., 2016). Exposure to green space was associated with better perceived mental health and vitality, although the effect sizes of these significant associations were small ($\beta_{\text{mental health for the entire cohort}}$=0.03 [95% CI=0.02-0.04]; and $\beta_{\text{vitality for the entire cohort}}$=0.04 [95% CI=0.03-0.06]) (van den Berg et al., 2016). Effect modifications for perceived mental health and vitality were observed based on childhood nature experience (interaction term *p-value*=0.001), and the education level (interaction term *p-value* for medium level of education=0.017 and interaction term *p-value* for high level of education=0.046) of the study participants, respectively. This meant that the association between visits to green space and perceived mental health was stronger for participants with little childhood nature experience compared with participants with high childhood nature experiences ($\beta_{\text{low childhood nature experience}}$=0.07 [95% CI=0.04-0.09]; and $\beta_{\text{high childhood nature experience}}$=0.02 [95% CI=0.01-0.03]). On the other hand, participants with low level of education had higher vitality scores than participants with medium or high levels of education ($\beta_{\text{vitality for people with low level of education}}$=0.13 [95% CI=0.06-0.20]; $\beta_{\text{vitality for people with medium level of education}}$=0.05 [0.00-0.07]; and $\beta_{\text{vitality for people with high level of education}}$=0.03 [95% CI=0.01-0.05]) (van den Berg et al., 2016). The authors concluded that visits to green space were associated with better mental health and vitality, though associations were stronger for specific subgroups. The study used self-reported measures of access to green space, perceived mental health and vitality and did not control for self-selection bias nor performed mediation analyses to determine mediators (van den Berg et al., 2016). This study differed from other studies on green space and mental health outcomes as participants were asked to report time spent in green space (van den Berg et al., 2016).

2.5.2.2 General adult population studies not showing any association between green space and mental health

Annerstedt and colleagues (2012) conducted a longitudinal study exploring the relationships between green qualities in the environment (defined as Serenity [places of peace, silence, and care], Space [places offering sensation of "entering another world"], Wild [places of fascination with wild nature], Culture [places offering fascination with course of time], and Lush [places with variety of species]) and mental health. Additionally, the aim of this study was to test whether effects of green qualities on mental health were moderated by social and health factors such as financial stress, living conditions, and physical activity (Annerstedt et al., 2012). Health data for this study were obtained from a survey administered to Swedish adults who were residents of rural or suburban areas. The mental health of the study participants was assessed through administration of the GHQ12 questionnaire. The GHQ12 scores were transformed into a binary variable with categorisations as good mental health (scores of 0-2) and not good mental health (scores of 3-12) (Annerstedt et al., 2012). All residential addresses were geocoded and green space was determined through: 1. Amount of green space qualities within 300 m of geocoded property, and 2. Access to green space qualities (Annerstedt et al., 2012). Overall, the results of the Swedish study revealed that the associations of green space qualities with mental health were not significant with respect to quantity or access in men and women. Conversely, in women, an interaction was observed between physical activity and access to Serenity or Space. That is, women who were physically active and had access to Serenity (OR=0.2 [95% CI=0.06-0.9]) or Space (OR=0.3 [95% CI=0.1-0.9]) had a lower risk of poor mental health in comparison to women who were physically inactive. No significant interactions were seen between physical activity and access to Serenity or Space for men (Annerstedt et al., 2012). The authors concluded that access to green qualities did not affect mental health for the entire population, but for women who were physically active. Additionally, the authors suggested that interaction analyses should be conducted while determining the associations between mental health and exposure to green space (Annerstedt et al., 2012). However, the authors used non-validated measures of physical activity and stress while analysing the association between green space exposure and mental health (Annerstedt et al., 2012). This study differed from other studies on green space and mental health outcomes because participants were asked to report their exposure and access to green space qualities (Annerstedt et al., 2012). As validated measures of physical activity and stress were not available in this study (Annerstedt et al., 2012), a gap remains in term of utilisation of validated measures of physical activity and stress so that mediators could be identified.

Exposure to green and blue spaces is associated with better mental health through a reduction in sensory stimuli to the brain and prolongation of mental relaxation (Nutsford et al., 2016). In a most recent cross-sectional study conducted in Wellington, New Zealand, Nutsford et al. (2016) investigated the relationships between exposure to green and blue spaces and mental health (Nutsford et al., 2016). This study was carried out using health data from adults who were participants of the 2011/2012 NZHS (Nutsford et al., 2016). Exposure to green and blue spaces was estimated in terms of the visibility of green and blue spaces in the surrounding residential environment by calculating the Vertical Visibility

Index (VVI) (Nutsford et al., 2016). Mental health was assessed by the administration of psychological distress questionnaires to respondents of NZHS. The dependent variable selected for analyses was psychological distress score with higher scores indicating the presence of psychological distress (Nutsford et al., 2016). The results of this investigation revealed that average psychological distress scores differed by the demographic characteristics of the study participants. Higher psychological distress scores were seen in females than males (psychological distress score $_{\text{females}}$=6.1; psychological distress score $_{\text{males}}$=5.5), adults in age group of 15-44 years than adults in other age groups (psychological distress score $_{\text{15-44years}}$=6.4; psychological distress score $_{\text{45-65 years}}$=4.8; and psychological distress score $_{\text{>65 years}}$=6.0), and Māori than non- Māori (psychological distress score $_{\text{Māori}}$=8.9; psychological distress score $_{\text{non-Māori}}$=5.5) (Nutsford et al., 2016). In the regression analyses, green space visibility was not associated with the psychological distress score (β= -0.09; *p-value*=0.455). Conversely, blue space visibility was (β= -0.28; *p-value*<0.001). An increase in blue space visibility by 10% was associated with a 0.28 point reduction in the psychological distress score (Nutsford et al., 2016). The authors concluded that residential exposure to visible blue space was associated with better mental health. However, the authors did not account for the length of residence in the neighbourhood and did not include private green spaces (private gardens) in their classification of green spaces (Nutsford et al., 2016). Unlike other studies on green space and mental health outcomes, a unique measure of VVI was used to assess the degree of visibility of green spaces for the study participants (Nutsford et al., 2016). However, a gap still remains in terms of the inclusion of private gardens in the classification of green spaces and in the control of self-selection bias while determining the associations between green space and mental health outcomes.

The aim of a recent systematic review by Gascon and colleagues was to determine whether exposure to green or blue spaces for prolonged periods was associated with better mental health outcomes (Gascon et al., 2015). This systematic review was carried out by selecting studies which utilised objective measurements of exposure and mental health variables and allocated measurements of exposure variables to the study participants based on their residential addresses. A mix of six longitudinal, one ecological, and twenty-one cross sectional European and non-European studies were analysed (Gascon et al., 2015). For four studies, the data collection wave consisted of the administration of the Strengths and Difficulties Questionnaires and/or the Attention-deficit Hyperactivity Disorder Symptom Criteria of Diagnostic and Statistical Manual of Mental Health to children aged 3-10 years. The aim was to extract information on emotional and behavioural problems in children (Gascon et al., 2015). For 12 of the studies, data on the general mental health status was collected through the administration of GHQs or Short Forms or the mental health inventory to the general population adults. For the remaining 12 studies, these were also conducted on general population adults and focussed on the determination of specific mental health disorders such as anxiety, stress, depression, or mood disorders through use of specific tools (e.g., K10, DASS, or WEMWBS)(Gascon et al., 2015). In 22 of the studies, exposure to green space was characterised by calculating the percentage land covered by green space through the use of land-cover maps (e.g., green space in buffers of 300 m to 3 km or CAU). The remaining studies characterised exposure to green space by calculating NDVI in buffers of 100-800 m around the residences of the study participants or in CAU. Access to green space was measured in nine studies. Out of 28 studies, 2 studies determined the associations between the quality of the green space (not quantity of green space) and mental health (Gascon et al., 2015). Characterisation of exposure or access to blue spaces was done in three studies by calculating the amount of blue spaces in buffers of 1 km and

3 km or estimating whether participants lived within 5 km of coastal margins, respectively (Gascon et al., 2015). The systematic review showed that exposure to green space was related to mental health outcomes in adults, but the evidence was limited. For children, there was inadequate evidence of the associations between exposure (access and exposure to green spaces, quality of green spaces, and exposure and access to blue spaces) and outcome variables. Similarly, in adults, there was inadequate evidence of the associations between other exposures of interest (access to green spaces, quality of green spaces, and exposure and access to blue spaces) and outcome variables (Gascon et al., 2015). As this review included a limited number of mental health studies which measured exposure variables in a different way, the authors recommended that more studies of the associations between green or blue spaces and mental health should be conducted (Gascon et al., 2015).

2.6 Critique of the literature on general adult and pregnant population studies investigating the associations of green space with health outcomes

2.6.1 Commonalities across general adult and pregnant population studies

2.6.1.1 Definition of dependent variables

Of first and foremost importance, one commonality across general and pregnant population studies investigating the relationships between exposure to green space and health outcomes is the definition of the dependent variables. In several, if not all studies, physical activity was defined as participation in physical activity, of at least moderate intensity, for at least 30 minutes on at least five days during the past week. That is, a variable which represented whether participants participated in physical activity for at least 150 minutes per week was used as a dependent variable (Mytton et al., 2012, Richardson et al., 2013, Witten et al., 2008, Maas et al., 2008, Ord et al., 2013). In relation to the type of physical activity that was under investigation, studies included different types of physical activity in their analyses such as walking, jogging, swimming, bicycling, gardening, or sports (Mytton et al., 2012, Richardson et al., 2013, Witten et al., 2008, Maas et al., 2008, Ord et al., 2013, Astell-Burt et al., 2013b, Astell-Burt et al., 2014b). In studies investigating the associations between green space and pregnancy outcomes, birth weight was consistently defined as 'weight of new born infant at birth (grams)' and low birth weight was defined as 'birth weight below 2500 grams' (Dadvand et al., 2012c, Dadvand et al., 2012b, Hystad et al., 2014, Agay-Shay et al., 2014, Markevych et al., 2014, Dadvand et al., 2014b, Ebisu et al., 2016, Laurent et al., 2013). Simultaneously, gestational age was consistently defined across studies as 'period of gestation' and preterm birth was defined as 'period of gestation less than 37 weeks' (Laurent et al., 2013, Hystad et al., 2014, Casey et al., 2016). For studies concentrating on the associations between green space and mental health outcomes, the pattern of definition of dependent variables indicated that the investigators relied on measuring symptoms of anxiety, stress, or depression (Beyer et al., 2014, Maas et al., 2009b, Bos et al., 2016, van den Berg et al., 2016).

2.6.1.2 Classification and measurement of green spaces

A trend that appeared in previous investigations on green space and health outcomes was the inclusion of different types of green spaces in the classification of green spaces. Areas characterised as green spaces by most investigators included parks, beaches, forests, agricultural lands, or sports fields (Mytton et al., 2012, Richardson et al., 2013, Witten et al., 2008, Maas et al., 2008, Ord et al., 2013, Nutsford et al., 2013, Bos et al., 2016, van den Berg et al., 2016, Astell-Burt et al., 2014a, Astell-Burt et al., 2014b, Astell-Burt et al., 2013b). Private gardens were excluded in some investigations as the use of land cover databases did not capture data on private gardens (Astell-Burt et al., 2014e, Ord et al., 2013, Nutsford et al., 2013, Nutsford et al., 2016). Surprisingly, in the most recent European investigation of green space and mental health, investigators have included blue spaces in the classification of green spaces (van den Berg et al., 2016).

Regarding the method of assessment of green spaces, most investigators used the percentage land area covered by green space as a method for the assessment of green spaces while determining the associations between green space and physical activity (Mytton et al., 2012, Richardson et al., 2013, Ord et al., 2013, Maas et al., 2008, Astell-Burt et al., 2014a, Astell-Burt et al., 2014b). Conversely, McMorris and investigators utilised the NDVI method for the assessment of green spaces while determining the association between green space and physical activity. NDVI was calculated by McMorris and investigators in circular buffers of 500 m around centroids of the post codes of the study participants (McMorris et al., 2015). Similarly, McEachan and associates measured green spaces in the residential environment through the NDVI method. NDVI was calculated in buffers of 100 m, 300 m, and 500 m around each maternal address and linked to physical activity (McEachan et al., 2015). While reviewing previous investigations into green space and pregnancy outcomes, it was found that investigators had utilised the NDVI method as a preferred method of assessment of green spaces (Dadvand et al., 2012a, Dadvand et al., 2012c, Dadvand et al., 2014b, Laurent et al., 2013, Hystad et al., 2014, Markevych et al., 2014, Agay-Shay et al., 2014, Grazuleviciene et al., 2015, Casey et al., 2016). Consistent with most investigations of green space and physical activity, the percentage of land covered by green spaces was used as the preferred method for the assessment of green spaces while examining the associations between green space and mental health outcomes (Alcock et al., 2014, Nutsford et al., 2013, Bos et al., 2016, Maas et al., 2009b, Astell-Burt et al., 2013b, Astell-Burt et al., 2014e).

2.6.1.3 Effect modifications

Whether effect modifications were seen for physical activity in specific population subgroups was an area of investigation, at least in some studies, on green space and physical activity. For example, Maas and colleagues conducted subgroup analyses to determine whether the relationship between green space and physical activity differed according to specific subgroups of age, residential rurality, and socioeconomic status (Maas et al., 2008). McMorris and colleagues investigated whether the associations of green space exposure with leisure time physical activity were stronger for specific age subgroups (McMorris et al., 2015). As far as investigations of green space and pregnancy outcomes are concerned, some investigators conducted interaction analyses and sought to determine whether the associations differed for specific population subgroups (e.g., pregnant women with low levels of education or those living in high deprivation areas) (Dadvand et al., 2012a, Dadvand et al., 2014b, Markevych et al., 2014, Dadvand et al., 2012c). Examination of the relationships between green space and mental health outcomes revealed that some associations differed for specific populations subgroups (e.g., age and physically active subgroups)(Maas et al., 2009b, Bos et al., 2016, van den Berg et al., 2016, Annerstedt et al., 2012).

2.6.1.4 Multilevel statistical modelling

A review of the prior research has shown that investigators have consistently adopted a statistical approach of multilevel modelling which is an industry gold standard for investigating relationships between green space and health outcomes (Dadvand et al., 2014b, Dadvand et al., 2012c, Maas et al., 2008, Astell-Burt et al., 2013b, Astell-Burt et al., 2014e, Witten et al., 2008, Maas et al., 2006, de Vries et al., 2003, van den Berg et al., 2016, Astell-Burt et al., 2014b, Ebisu et al., 2016, Maas et al., 2009b). Multilevel models are also referred to as mixed, hierarchical, random effects, random coefficients, variance components, or covariance components models (Diez Roux, 2002). It is known that if people are randomly selected from one neighbourhood and their health characteristics are examined, then they are likely to have similar health characteristics in comparison to people selected from a different neighbourhood. That is, there is a clustering of health statuses within neighbourhoods. This is called the ‘contextual phenomenon’ (Merlo et al., 2005). As the name suggests, multilevel modelling is applicable to data that has hierarchical structure consisting of several levels. Each level is a unit of analysis (for example, level 1 (lowest level), level 2, level 3 and so forth). An example of a nested design where the clustering of health statuses is observed is people residing within different census tracts of a county (level-1 is people, level-2 is census tracts, and level-3 is county)(Blakely and Woodward, 2000).

If the clustering of respondents in neighbourhoods is not accounted for within the regression models, standard errors of contextual effect estimates are likely to be downwardly biased (Diez Roux, 2002). Additionally, not accounting for clustering in regression analyses can also make a difference to the size or magnitude of the effects (Zhou et al., 2017). Multilevel modelling is ideally suited to the analysis of neighbourhood effects by simultaneously analysing individual and neighbourhood-level variables, whilst accounting for the non-independence in the data (Diez Roux, 2002).

Multilevel modelling is a powerful tool for analysing three kinds of relationships 1) Whether the differences in health outcomes between neighbourhoods can be explained on the basis on personal characteristics, 2) Whether any relationships between health outcomes and characteristics of neighbourhoods exist after controlling for personal characteristics, and 3) Whether there are any interactions between personal and neighbourhood characteristics, referred to as 'cross-level' interactions (Leyland and Groenewegen, 2003).

To produce correct standard errors and effect sizes, two types of multilevel models are developed. In the first type of multilevel model, called an 'intercept-only' multilevel model, random error terms are included for each level of analyses. It is mathematically expressed as $y_{ij}=\beta_0 + \beta_1 x_{ij} + u_j + e_{ij}$ [β_0=intercept, β_1=slope, uj=higher level unit residual and eij=individual residual] (Blakely and Woodward, 2000). In the second type of multilevel model, called a 'slope-only' multilevel model, random error terms are included for individual-level parameters. This model is mathematically expressed as $y_{ij}=\beta_0 + \beta_1 x_{ij} + u_{0j} + u_{1j}x_{ij} + e_{ij}$ [β_0=intercept, β_1=slope, u_{1j}=slope residual and u_{oj}=intercept residual] (Blakely and Woodward, 2000). One feature of multilevel modelling is that it correctly estimates the amount of variation in the health outcome that could be explained by the neighbourhood (referred to as 'interclass correlation' (ICC) or 'variance partition coefficient (VPC)'). To calculate ICC, the variation in the dependent variable attributable to the neighbourhood is divided by the total variation in the dependent variable which is the variation attributable to the neighbourhood and the individual (ICC=$\text{Variation}_{\text{neighbourhood}}/\text{Variation}_{\text{neighbourhood}} + \text{Variation}_{\text{individual}}$). The value of ICC ranges from 0 to 1 (Merlo et al., 2005).

2.6.2 Limitations of general adult and pregnant population studies

Limitations of prior research on green space and health outcomes are chiefly grouped into three categories. These limitations are described below.

2.6.2.1 Lack of control for self-selection bias in regression modelling

The importance of self-selection bias has been recognised in studies on green space and health. For example, a systematic review of the association between measures of the built environment (e.g., parks and public open spaces) and physical activity amongst adults from the general population has identified that neighbourhood self-selection is likely to be a confounder of the association between measures of the built environment and physical activity (McCormack and Shiell, 2011). People who are physically active are inclined to reside in greener areas compared to those who are physically inactive (Groenewegen et al., 2006). This choice could, at least in part, explain the association between green space and physical activity. Consequently, self-selection bias has to be taken into account while examining the association between exposure to green space and physical activity (Groenewegen et al., 2006). Another example of self-selection is that pregnant women belonging to higher socioeconomic status groups may choose to live in neighbourhoods containing high levels of green space (Dadvand et al., 2014b). It is likely that the association between exposure to green spaces and depression is also confounded by the process of neighbourhood self-selection (Beyer et al., 2014). If self-selection bias is not accounted for within the regression models, then the effect sizes for the associations between green space and health outcomes are likely to be biased (Boone-Heinonen et al., 2010). The lack of control for self-selection bias is one that may be a limiting factor in most previous studies on green space and health (Mytton et al., 2012, Richardson et al., 2013, Astell-Burt et al., 2014a, Astell-Burt et al., 2014b, Ord et al., 2013, Witten et al., 2008, McMorris et al., 2015, Maas et al., 2008).

2.6.2.2 Lack of control for socioeconomic status in regression analyses

Another major limitation that appears in many studies that have investigated the relationships between green space and health outcomes is lack of adequate control for personal (e.g., income, education, or employment status) or area-level socioeconomic status (area deprivation) (Markevych et al., 2014, Hystad et al., 2014, Laurent et al., 2013, Casey et al., 2016, Dadvand et al., 2012c, Dadvand et al., 2012a, Richardson et al., 2013, Maas et al., 2009b, Beyer et al., 2014, Bos et al., 2016). The most common reason is the lack of availability of data on socioeconomic status. Contingent upon the availability of data, the role of personal and area-level socioeconomic status should be considered while determining the associations between green space and health outcomes.

2.6.2.3 Lack of determination of mediators

As observed in some studies, exposure to green space is not associated with health outcomes while considering the entire cohort (Dadvand et al., 2012a, Bos et al., 2016, Annerstedt et al., 2012). In such cases, mediation analyses cannot be conducted so that the mediating pathways are determined. However, some investigators have not determined mediators even when green space is found to be associated with health outcomes while considering the entire cohort (Dadvand et al., 2014b, Markevych et al., 2014, Grazuleviciene et al., 2015, Casey et al., 2016, Astell-Burt et al., 2013b, Astell-Burt et al., 2014e, Alcock et al., 2014, van den Berg et al., 2016). In such cases, it is likely that data for mediators are not available so that mediation analyses are not performed. If green space is found to influence the health outcomes and data on mediators are available for analyses, then mediation analyses could be conducted so that the underlining mechanisms are ascertained.

2.6.3 What this thesis work adds to the body of literature on green space and health outcomes

By selecting a reliable method of assessment of green space and performing multilevel analyses, this thesis aims to determine the directional trend for the associations of green space with health outcomes and search for evidence of effect modifications across population subgroups. More importantly, this thesis work aim to overcome limitations of previous studies, at least partially, by including variables representing self-selection bias and socioeconomic status in the regression analyses and performing mediation analyses if the data for mediators are available. This New Zealand research will balance other studies using similar methods and studying similar outcomes (but in different settings) and serve to contribute knowledge to the scientific debate in the area of maternal and child health.

Chapter 3. Methods

This chapter describes the methods utilised to conduct the three studies: 1) Green space and physical activity in pregnant women, 2) Green space and pregnancy outcomes in pregnant women, and 3) Green space and depression in pregnant women. More specifically, this chapter describes the sections such as the source of health data: *Growing Up in New Zealand* study; conceptual framework, data collection and the measurement of variables for the *Growing Up in New Zealand* study; a description of the dependent variables and confounders; the classification of effect modifiers; a description of variables representing self-selection bias; the classification and measurement of green spaces; and the statistical analyses employed.

3.1 Source of health data: Growing Up in New Zealand study

The three studies within this thesis were conducted utilising a common health data source called "*Growing Up in New Zealand*." The New Zealand's contemporary child cohort study *Growing Up in New Zealand* is a longitudinal study focussing on the multiple influences that shape children's development from before birth (Morton et al., 2010). The generalisability of the recruited cohort to the national birth cohort from 2007 to 2010 has been demonstrated (Morton et al., 2015). The cohort was created through the recruitment of 6822 pregnant women whose expected delivery date was between April 2009 and March 2010, and who resided within a geographical region defined by three adjacent District Health Boards (DHBs): Auckland, Counties-Manukau and Waikato (MOH, 2014). According to the Ministry of Health, DHBs are defined as 'organisations responsible for providing or funding the provision of health services in their district' (MOH, 2017). This region was selected to enable the enrolment of a sample with sufficient diversity to have adequate explanatory power for analyses within socioeconomic and ethnic population subgroups (Morton et al., 2013). Eligibility was defined by residence during pregnancy within the study region (Morton et al., 2013). Multiple recruitment strategies were employed within the *Growing Up in New Zealand* study using a non-probability based sampling technique. Referrals were obtained from pregnant women through free phone number/website/mobile text, Lead Maternity Carers, antenatal clinics, and face-to-face invitations from recruiters of the *Growing Up in New Zealand*. After receiving 10, 315 referrals, recruiters of the *Growing Up in New Zealand* contacted pregnant women for the possibility of enrolment of themselves and their future children in the child cohort study (Morton et al., 2013). After utilising multiple recruitment strategies, *Growing up in New Zealand* recruited 6822 pregnant women for the first data collection wave called the 'antenatal wave' (Morton et al., 2013). The cohort of 6853 children born to these 6822 pregnant women represented 11% of births in New Zealand over the study recruitment period (Morton et al., 2013). Ethical approval for *Growing Up in New Zealand* was granted by the Ministry of Health Northern Y Regional Ethics Committee (NTY/08/06/055), and written informed consent was obtained from all women (Morton et al., 2013).

3.2 Conceptual framework, data collection and measurement of variables for the *Growing Up in New Zealand* study

The conceptual model of *Growing Up in New Zealand* study was deliberately designed to understand the dynamic interactions between each child and their environment across a broad range of influences from the immediate family environment to the wider societal context (Morton et al., 2013). To achieve this, research constructs were created and data gathered within six research domains: (i) health and well-being (ii) psychosocial and cognitive development (iii) education (iv) family and whānau (v) culture and identity and (vi) the societal context (Morton et al., 2013) (Figure 3-1).

In the *Growing Up in New Zealand* study, data were collected at the computer assisted face-to-face computer-assisted personal interviews completed by pregnant women during late pregnancy, at a telephone interview completed when their infant was approximately six weeks post their expected date of delivery and from linkage to the maternity hospital records to obtain recorded birth weight and gestational age at delivery (Morton et al., 2013). Pregnant women were usually interviewed in their home. Data describing demographics, health behaviours, health history and household characteristics were collected during interviews (Morton et al., 2013).

Each maternal participant's residential address was geocoded to a CAU. The available green space within each CAU was quantified using ArcGIS. Each CAU is a collection of mesh blocks which are the smallest census geographical units in New Zealand (Stat, 2006). CAUs are the second smallest geographical units used in New Zealand. Each urban CAU in New Zealand has a population of 3000 to 5000 (Stat, 2006). A small number of the maternal participants recruited in the *Growing Up in New Zealand* study resided in CAUs outside of the study region (n=50). These fifty participants were living within New Zealand, but outside of the study region (i.e., Auckland, Manukau, or Waikato). They did not belong to a specific socioeconomic or ethnic group. As these participants resided outside of the study region, they were not included in the analyses. The final sample for analyses of outcomes of physical activity and depression, after this exclusion, consisted of 6772 pregnant women. Of these, 83% were interviewed prior to the cohort child's birth (n=5615) and the remaining 17% (n=1157) after the cohort child's birth. The final sample of 6615 mother-new born pairs from the original cohort of 6822 pregnant women for analyses of birth weight and gestational age was created by restricting to those pregnant women who had a singleton pregnancy and for whom each maternal address could be geocoded to CAUs within the study region. Women who were interviewed prior to birth did not differ in demographic and residential characteristics from women who were interviewed after birth (Appendix 2). Therefore, the two groups were analysed by combining them into a single group.

3.3 Dependent variables

3.3.1 Physical activity

The dependent variable utilised for the study of green space and physical activity was participation in physical activity during pregnancy. The levels of physical activity during pregnancy were self-reported using the short version of the International Physical Activity Questionnaire (IPAQ) (Sallis and Saelens, 2000). The reliability and validity of this version of the IPAQ have been established for the measurement of physical activity in both the general population adults (Craig et al., 2003) and in pregnant women (Bertolotto et al., 2010, Marshall et al., 2013).

Each woman participating in the *Growing Up in New Zealand* study was asked to estimate the frequency and duration of both the moderate and vigorous physical activity in which they engaged at three-time intervals: before their pregnancy; during the first three months of their pregnancy; and for the remainder of their pregnancy (Morton et al., 2013). The frequency and duration of moderate or vigorous physical activity engaged in at each of these time intervals were dichotomised as 0 (not meeting the ACOG guidelines for frequency and duration) or 1 (meeting the ACOG guidelines for frequency and duration)

(ACOG, 2002). The dichotomised frequency and duration variables created for physical activity were then combined to produce a single variable that represented whether recommendations for participation in moderate or vigorous physical activity were met (0=not physically active; 1=physically active) (Morton et al., 2013). The dependent variables used in the regression analyses for the study of green space and physical activity were these variables that described moderate or vigorous physical activity, with separate regression analyses for the first trimester and the remainder of the pregnancy. As physical activity differs across trimesters of pregnancy (Duncombe et al., 2009, Hayes et al., 2015), this trimester separation was considered necessary. As the physical activity variable was meant to be participation in physical activity during pregnancy, analysis of a sample of women who were only interviewed after the birth of new born infants would lead to the possibility of recall bias with overestimation in the estimates of physical activity.

3.3.2 Birth weight and gestational age

Birth weight, measured in grams, and gestational age, measured in weeks, were utilised as the dependent variables for the study of green space and pregnancy outcomes. Gestational age was measured as the period between the fourteenth day of a mother's last menstrual period and the delivery day (Morton et al., 2012).

3.3.3 Depression

The dependent variable utilised for the study of green space and depression was the Edinburgh Postnatal Depression Scale (EPDS). It is a validated and commonly used screening instrument for the detection of antenatal and post-natal depression in women (Cox et al., 1987, Matthey et al., 2003). The EPDS questionnaire consists of 10 questions that extract in-depth information on depression (Cox, Holden, & Sagovsky, 1987). Each question has a rating score of 0-3 points, with the maximum calculated total score for any individual being 30 points (Waldie et al., 2015). Both the validity and reliability of the EPDS have been demonstrated for its usage in diverse cultures (Tsai et al., 2013, Kheirabadi et al., 2012, Ekeroma et al., 2012) and in both ante- and postnatal samples.

In the *Growing Up in New Zealand* study, women were asked to recollect information over the past seven days (Morton et al., 2010) while answering the following ten questions of the EPDS questionnaire: 1. I have been able to laugh and see the funny side of things, 2. I have looked forward with enjoyment to things, 3. I have blamed myself unnecessarily when things went wrong, 4. I have been anxious or worried for no good reason, 5. I have felt scared or panicky for no very good reason, 6. Things have been getting on top of me, 7. I have been so unhappy that I have had difficulty sleeping, 8. I have felt sad or miserable, 9. I have been so unhappy that I have been crying, and 10. The thought of harming myself has occurred to me (Morton et al., 2010). After gathering information from the EPDS questionnaires, the categorisations of depression and non-depression in the *Growing Up in New Zealand* study were made at a cut-off value of a total score of 13 points. That is, a total score of $\geq$13 points was considered to be associated with a high risk for depression (Waldie et al., 2015). At a threshold value of 13 points, the sensitivity for antenatal depression is 0.83 and specificity for antenatal depression is 0.90 (Waldie et al., 2015). For the analyses relating to the study of green space and depression, the EPDS scores for women were dichotomised as 0 (defined as 'absence of depression' with EPDS scores of <13) or 1 (defined as 'presence of depression' with EPDS scores of $\geq$13) using the same cut-off value of 13 points.

3.4 Confounders

In recent years, diagrammatic representations of causal pathways has gained importance in the field of epidemiology. One way to represent causal pathways is called a 'directed acyclic graph' (DAG) (Suttorp et al., 2015). The aim of a DAG is to identify research questions and confounders (Suttorp et al., 2015). A large range of maternal and child confounders were derived from the *Growing Up in New Zealand* antenatal dataset and available for analyses for the three studies presented within this thesis (Figures 3-2, 3-3, and 3-4). Maternal confounders included demographics (age, self-identified ethnicity, education, and employment status [defined as the status in the labour force service and categorised as employed, unemployed, student, and not in work force]), pregnancy-related behaviours (smoking cigarettes [defined as smoking of cigarettes during pregnancy, and categorised as yes or no] and alcohol consumption [defined as consumption of alcohol during pregnancy, and categorised as no drinking during pregnancy or any drinking during pregnancy]), the presence of pre-existing doctor diagnosed chronic disease (depression, heart disease or high blood pressure, and diabetes mellitus), physical activity during and after the first trimester of pregnancy [defined as participation in recommended levels of moderate physical activity of at least 150 min per week, and categorised as yes or no)], general health status [defined as general health status during pre-pregnancy period and categorised as poor/fair, good, very good, or excellent], parity [defined as the number of pregnancies and categorised as first or subsequent], relationship status [defined as social relationship status with biological father of the new born infant, and categorised as no relationship; dating, not cohabiting; cohabiting; and married or civil union], birth place [defined as region of maternal birth and categorised into New Zealand, Australia, Other Oceania, Asia, Europe, Africa, The Americas or Middle East or Other], type of delivery method [whether women delivered by spontaneous vaginal, planned caesarean, emergency caesarean, or other assisted techniques] access to health care during pregnancy (whether women had a lead maternity carer during the pregnancy), district health board of maternal domicile (whether the women had their domicile in Auckland, Manukau, or Waikato regions), preference for the local lifestyle of the neighbourhood and time lived in the current neighbourhood (measured in years) utilised as surrogates for self-selection bias, residential rurality, and socioeconomic status (Morton et al., 2013). Child confounders included gender (categorised as male or female) and gestational age (utilised for birth weight analyses) (Morton et al., 2013).

3.5 Classification of effect modifiers

For the analyses presented within this thesis, education was defined as 'the highest level of education attained' and classified into five levels: no secondary school, secondary school (defined as attainment of National Certificate of Educational Achievement [NCEA] 1-4), diploma (defined as attainment of Trade Certificate or NCEA 5-6), bachelor's (defined as attainment of level 7 or 8), and higher degrees (defined as attainment of master's or doctoral degrees with levels 9 and 10, respectively) (Morton et al., 2013). According to Statistics New Zealand, ethnicity is defined as 'self-identified ethnicity.' It is a measure of cultural connection (Stat, 2017). An ethnic group is made up of people having common characteristics such as name, religion, customs, language, interests, feelings and actions, ancestry, and geographic origin (Stat, 2017). In New Zealand, ethnicity is an important demographic characteristic that is used to describe the population (Stat, 2017). Data on ethnicity in New Zealand is used to measure temporal changes in health outcomes and ethnic diversity at local, regional, or national levels. It measures the social and economic well-being and effect of government policies on the social and economic well-being of ethnic groups. An additional advantage of using ethnicity data is the identification of special communities for liaison and development purposes (Stat, 2017). Ethnicity was gathered from each maternal participant at the most detailed level possible, and then coded into six Level 1 categories following the Statistics New Zealand coding criteria: (1) European, (2) Māori, (3) Pacific, (4) Asian, (5) Middle Eastern, Latin American and African, and (6) New Zealander or Other (Morton et al., 2013). The age of the pregnant women was measured in years and divided into five categories: <20, 20-24, 25-29, 30-34, 35-39, ≥40 years (Morton et al., 2013). Residential rurality was defined as residence in urban areas (derived from a combination of main urban areas, satellite urban areas, and independent urban areas) or rural areas (derived from a combination of rural areas with high urban influence, rural areas with moderate urban influence, rural areas with low urban influence, highly rural/remote areas, and areas outside urban/rural) consistent with Morton et al (2013). NZDep2006, an area level measure of deprivation, was used as a proxy for the area-level socioeconomic status of the study participants (Salmond et al., 2007). This index is a small area measure of deprivation derived from variables collected at the 2006 national census (e.g., income, home ownership, living space, access to telephone, access to car, support, education, and employment) (Salmond et al., 2007). NZDep2006 is an ordinal scale from 1 to 10 (1=area of least deprivation; 10=area of most deprivation) (Salmond et al., 2007). The NZDep2006 deciles were grouped into low, medium, and high deprivation (Low: deciles 1-3, Medium: deciles 4-7, High: deciles 8-10).

3.6 Description of variables representing self-selection bias

In the *Growing Up in New Zealand* study, one of the variables representing self-selection bias was described as the preference for the local lifestyle of the neighbourhood. More specifically, the preference for the local lifestyle of the neighbourhood provided information on why people currently lived in a particular location (Morton et al., 2013).

Question on the preference for the local lifestyle of the neighbourhood was informed by an earlier qualitative study completed in Auckland on socio-geographical dimensions of New Zealand neighbourhoods and caregiver access to community resources (Witten et al., 2003) and the Los Angeles Study of Families and Neighbourhoods (Clark and Ledwith, 2006). It was worded as, “Why do you live in this neighbourhood? With “I like the local lifestyle” as one of the possible response options (Morton et al., 2013). Other response options were as follows: 1) For work, 2) Good education, 3) Friends/family nearby, 4) Better or more affordable housing/rental, 5) With similar population groups, 6) Good and safe neighbourhood, 7) Handy to shops and other amenities, 8) Pregnancy related reason, 9) My spouse/partner/family have a house here, and 10) Other (please specify) (Morton et al., 2013). Respondents were asked to respond “yes” or “no” depending on whether they preferred to live in their neighbourhood because of its lifestyle, including locational access to community resources (i.e., access to green spaces and other recreational, public transport, shopping, education, health care, and social and cultural facilities) (Morton et al., 2013). It is likely that many people responded to this question that they liked their neighbourhood because of its lifestyle, but this had nothing to do with the absence or presence of green space in the neighbourhood. In other words, people preferred to live in neighbourhoods with better access to public transport, shopping, education, health care, and social and cultural facilities. This variable was used as a proxy measure of self-selection bias as it represents, at least in part, a participant’s preference for living in a neighbourhood with better locational access to green spaces and other recreational facilities.

In the *Growing Up in New Zealand* study, the variable ‘length of stay at the current residence’ was described as the number of years that pregnant women had lived in their current residence (Morton et al., 2010), framed as “How long have you lived in this current home?” and specifying the number of months, or number of years, or both that they lived in their current home (Morton et al., 2010). Consistent with previous research on exposure to green space and mental health amongst adults from the general population (Beyer et al., 2014, Zhang et al., 2015), the variable ‘length of stay at the current residence’ was used as a surrogate measure for self-selection bias. This is taken as a measure of self-selection bias because people move in and out of the green areas. Additionally, a minimum length of time (usually one year of stay at the current residence (Alcock et al., 2014)) is needed after which the beneficial effects of green space on health become prominent (Beyer et al., 2014).

3.7 Classification and measurement of green spaces

All green areas were categorised as green spaces and included parks, public outdoor spaces, urban parklands/open spaces, forests, grasslands, croplands, and other green areas (e.g., domains and reserves). Public outdoor spaces are classified as green spaces as they are easily accessible by road and classified in the literature as green spaces (Ord et al., 2013, Richardson et al., 2010). The areas surrounding green spaces of other land-use types (“non-green spaces”) were not classified as green spaces. These non-green spaces included built-up or settlement areas (e.g., commercial, industrial, and residential buildings), transport infrastructures (e.g., roads, rail-yards, and airport runways), and water bodies (e.g., rivers and lakes). An example of green space classification is presented in Figure 3-5.

Data on green spaces in Auckland and Counties-Manukau DHB regions were obtained from the Auckland Council. This feature class was an amalgamation of a few different existing sources (e. g., public open space zones from the operative district plans and the proposed unitary plan, and reserves derived from Land Information New Zealand). Metadata on green spaces in the Auckland and Counties-Manukau DHB regions were not available from the providers. Data on green spaces in the Waikato DHB region were obtained from the Waikato District Council and provide an accurate representation of the Waikato District Council's recreation reserve network with a scale of 1:50,000 and an accuracy of 90.0%. In addition, data on green spaces were obtained from the New Zealand Land Cover Database (LCDB) of the Land Resource Information Systems portal (Appendix 1) (LCDB, 2013). The advantage of combining the two different green space data sources is that the combined dataset provided more attributes than those obtained from a single data source. For example, data for public outdoor spaces, domains, and reserves were available from the councils and not from the LCDB. Similarly, data for forests, grasslands, and croplands were available from the LCDB and not from the councils. The scale of the LCDB is 1:50,000 and the minimum mapping unit is one hectare. Its overall user accuracy is 93.9% (LCDB, 2013).

Exposure is defined as 'visual or physical contact with a green environment.' Dose is defined as 'the amount of exposure to a green environment' (Bixby et al., 2015, Hartig et al., 2014, Shanahan et al., 2015). It is known that people travel daily from one mesh block to another mesh block for work-related and leisure-related opportunities. Consequently, they are exposed to green space within and outside their mesh block of residence. Richardson and colleagues called this phenomenon 'the daily variability in exposure to green space.' To do this, they calculated the percentages of green space for each CAU rather than each mesh block (Richardson et al., 2013). Consistent with previous New Zealand investigations (Richardson et al., 2010, Richardson et al., 2013), the studies of green space and health outcomes presented within this thesis are based on the determination of the proportion of green space in CAUs by using vector land cover databases. The rationale for using the method is that green space in the wider environment (CAUs) is likely associated with the mediating mechanism of physical activity, vector green space databases are available free of cost from the sources (Local City Councils and LCDB), and the process for estimating green space in the CAUs is easy to implement in ArcGIS software.

The digital boundary shaped files (CAU files for New Zealand) were downloaded from Statistics New Zealand (Stat, 2013). These were clipped to the Auckland and Waikato regions using regional shape files from Statistics New Zealand (Stat, 2013). The union and dissolve tools in ArcGIS were used to determine the proportion of green space in each CAU (ESRI, 2006). For the two studies presented within this thesis (green space and physical activity; and green space and depression), green space was expressed as a categorical variable. This approach enabled comparability with previous general population studies in New Zealand (Richardson et al., 2010, Richardson et al., 2013), general population studies outside New Zealand (Mytton et al., 2012, Astell-Burt et al., 2014a, Astell-Burt et al., 2014b), and pregnant population study in England in which green space was used as a categorical variable (McEachan et al., 2015). The 25th, 50th, and 75th percentiles were used as break points for the categorisation of green space, and selected to ensure an approximately equal number of maternal participants in each category of green space. The cut-offs for percentage of green space that divided the study sample into quartiles categorised green space as low (0-<12%), medium (12-<21%), high (21-<38%), or very high (38-100%). However, for the study of green space and pregnancy outcomes presented within this thesis, green space was expressed as a continuous variable. Firstly, this approach enabled comparability with previous pregnant population studies outside of New Zealand in which green space was utilised as a continuous variable (Dadvand et al., 2012a, Dadvand et al., 2012c, Laurent et al., 2013, Dadvand et al., 2014b, Hystad et al., 2014, Markevych et al., 2014, Agay-Shay et al., 2014, Ebisu et al., 2016). Secondly, women recruited in the

Growing Up in New Zealand study and residing in rural areas were not exposed to low or medium levels but high or very high levels of green space. That is, rural women were residing in areas of either high or very high green space. Considering these two factors, it was necessary to utilise green space as a continuous variable for the study of green space and pregnancy outcomes. While utilisng green space as a continuous variable, values of green space were in range of 0.00 to 100.00%. All green space analyses were conducted in ArcGIS (Environmental Systems Research Institute, Redlands, California, US) Version 10.2.

3.8 Statistical analyses

Most variables except 'length of stay at the current residence' and 'gestational age' were expressed as categorical variables. There were 613 different-sized CAUs within the study regions. On average, 11 respondents resided in each CAU. A multilevel modelling method was selected to analyse the associations of green space with health outcomes. This design approach could address, at least in part, the difference in measurement errors between the DHB regions due to the wide range in size of the CAUs in each DHB region. Two levels were specified in multilevel analyses. The first level was an individual-level representing pregnant women, while the second level was the neighbourhood-level representing the DHB regions of Auckland, Counties-Manukau and Waikato. Due to evidence of more clustering in the DHB regions than in CAUs, random effects were specified for the DHB regions. The associations between exposure to green space and physical activity and depression were determined using 'logistic mixed effect models' with the DHB of maternal domicile taken as a random effect in the mixed models. Simultaneously, the associations between exposure to green space and birth weight as well as gestational age were determined using 'linear mixed effect models' with the DHB of the maternal domicile taken as a random effect in the mixed models. Only random intercept models were developed in multilevel analyses as the inclusion of slopes in models did not lead to a better fit, as shown by the likelihood ratio tests. Initially univariate regression analyses (unadjusted Models) were conducted followed by analyses including the addition of confounders in a sequential manner (adjusted Models). The green space variable was examined for its possible interactions with factors such as age, education, self-identified ethnicity, physical activity, area deprivation, and residential rurality. As previous general and pregnant population studies have identified effect modifications for the associations between green space and health outcomes in specific population subgroups (Barton and Pretty, 2010, Bos et al., 2016, McEachan et al., 2015, Dadvand et al., 2014b, Dadvand et al., 2012a, Dadvand et al., 2012c, Markevych et al., 2014, Agay-Shay et al., 2014, Maas et al., 2009b, Astell-Burt et al., 2013b, van den Berg et al., 2016, Annerstedt et al., 2012), the testing for interactions in my studies is justified as it allows for the searching of the presence of similar effect modifications. The adjusted final models contained the green space variable, confounders and significant interaction terms if they led to a better fit in the likelihood ratio tests. Likelihood ratio tests were conducted to determine the effect of interaction terms in improving the fitness of the final regression models. Subgroup analyses were performed for factors which interacted with green space so that the effect modifications for health outcomes could be studied. Statistical significance was determined by using cut-off p-value of 0.05. The software Stata Version 13 (Stata Corporation, Texas) was used for the statistical analyses.

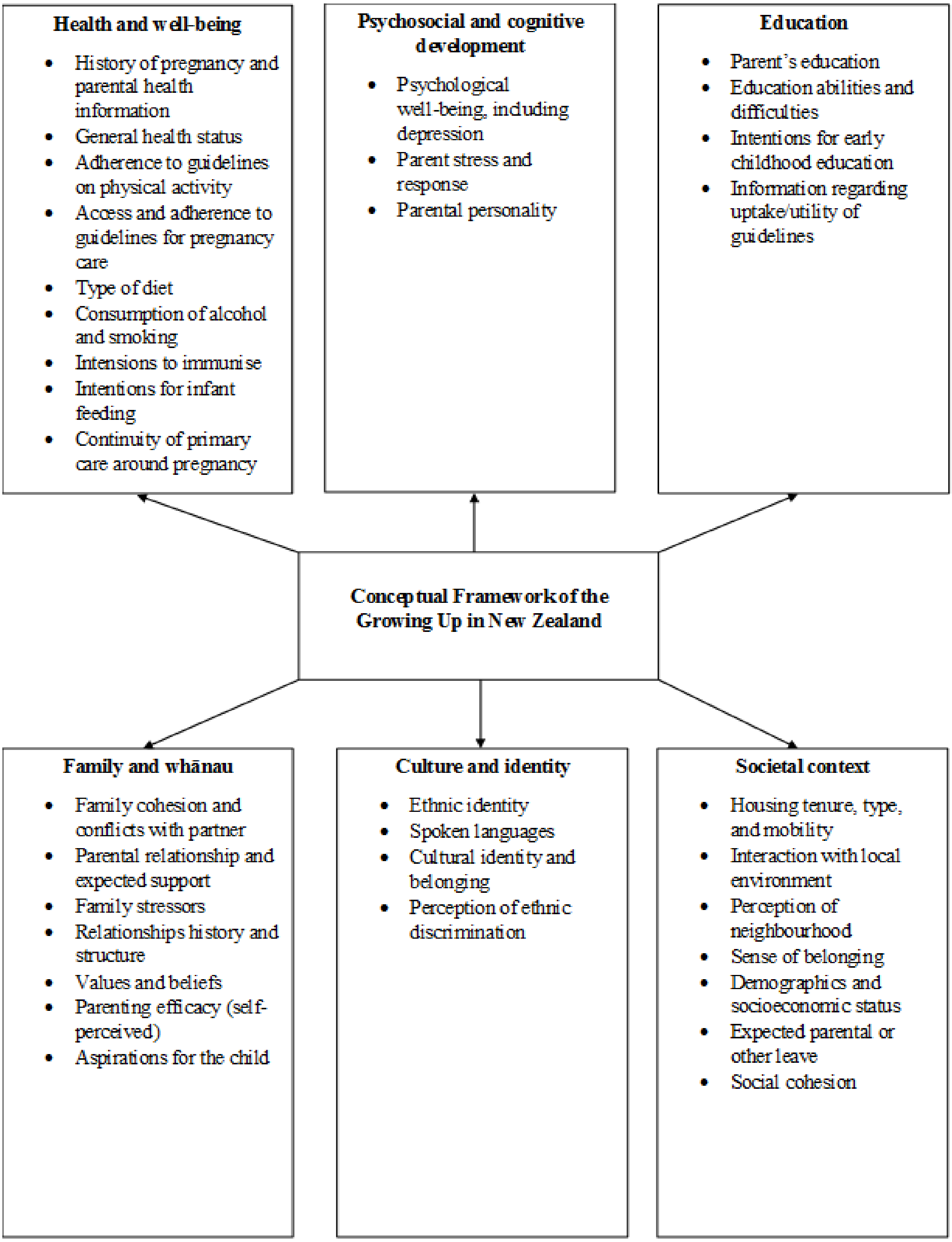


Figure 3-1: Types of data collected within research constructs of the Growing Up in New Zealand study (Morton et al., 2013)

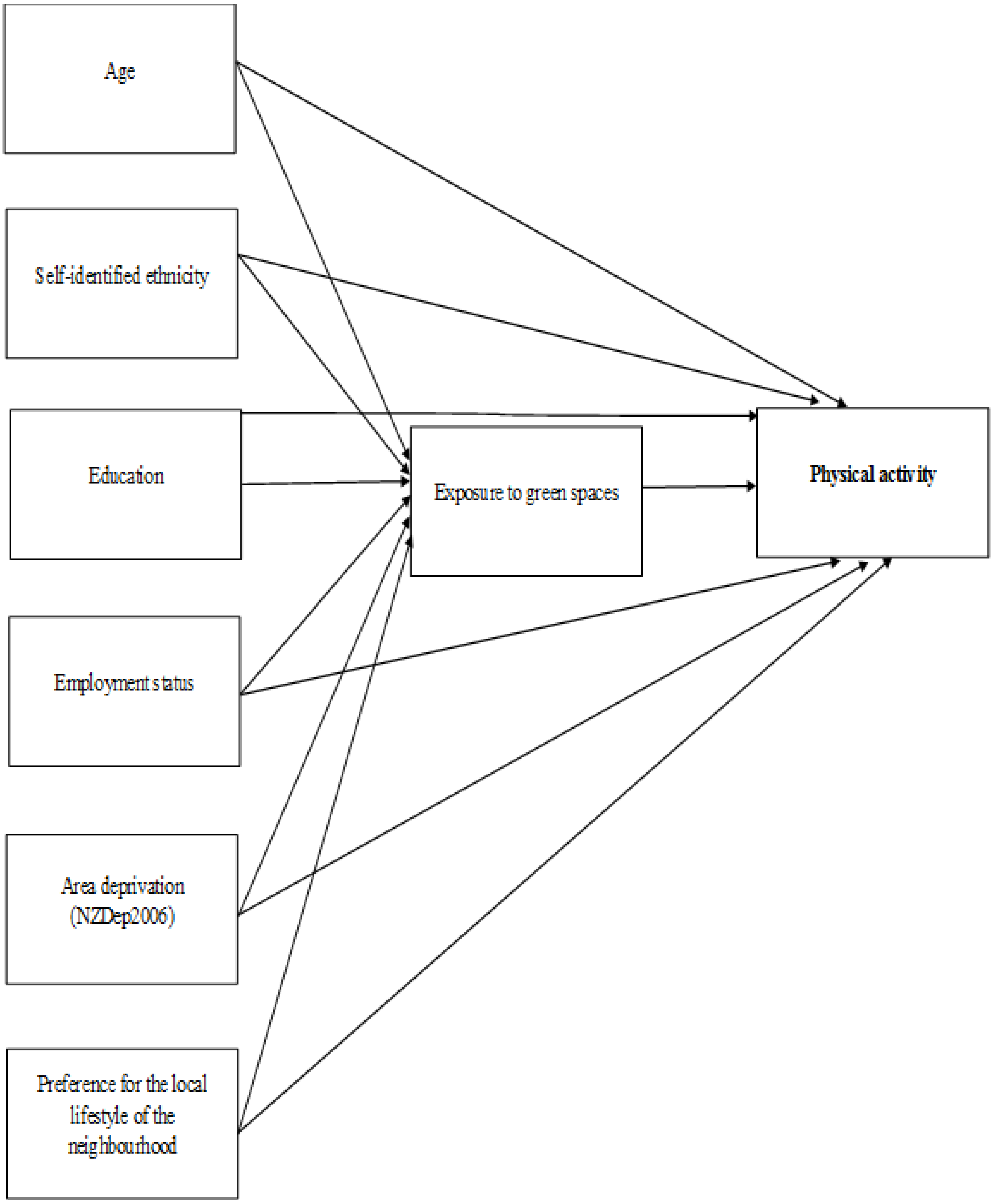


Figure 3-2: Directed acyclic graph describing the confounders of the association between green space and physical activity

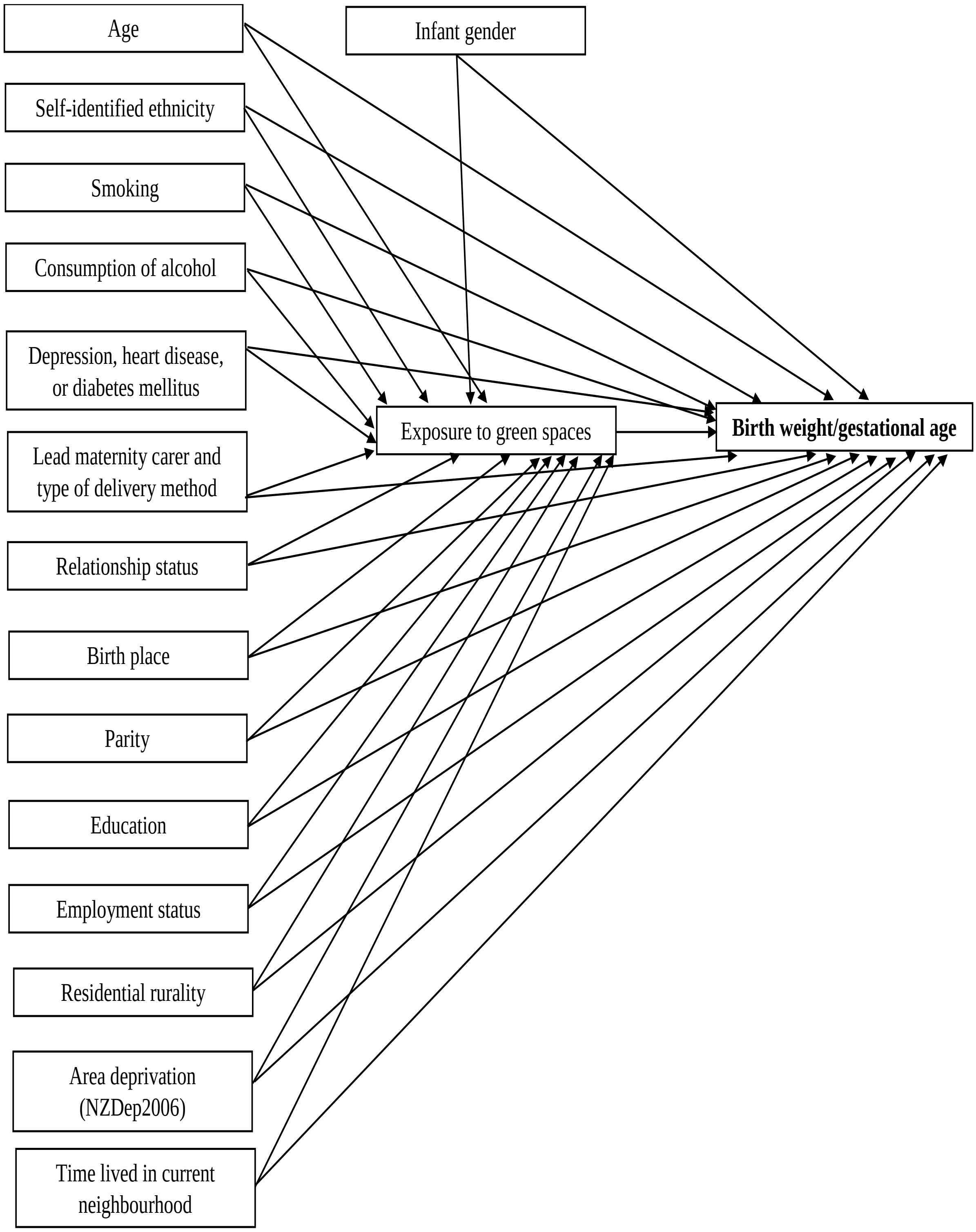


Figure 3-3: Directed acyclic graph describing the confounders of the associations between green space and pregnancy outcomes of birth weight and gestational age

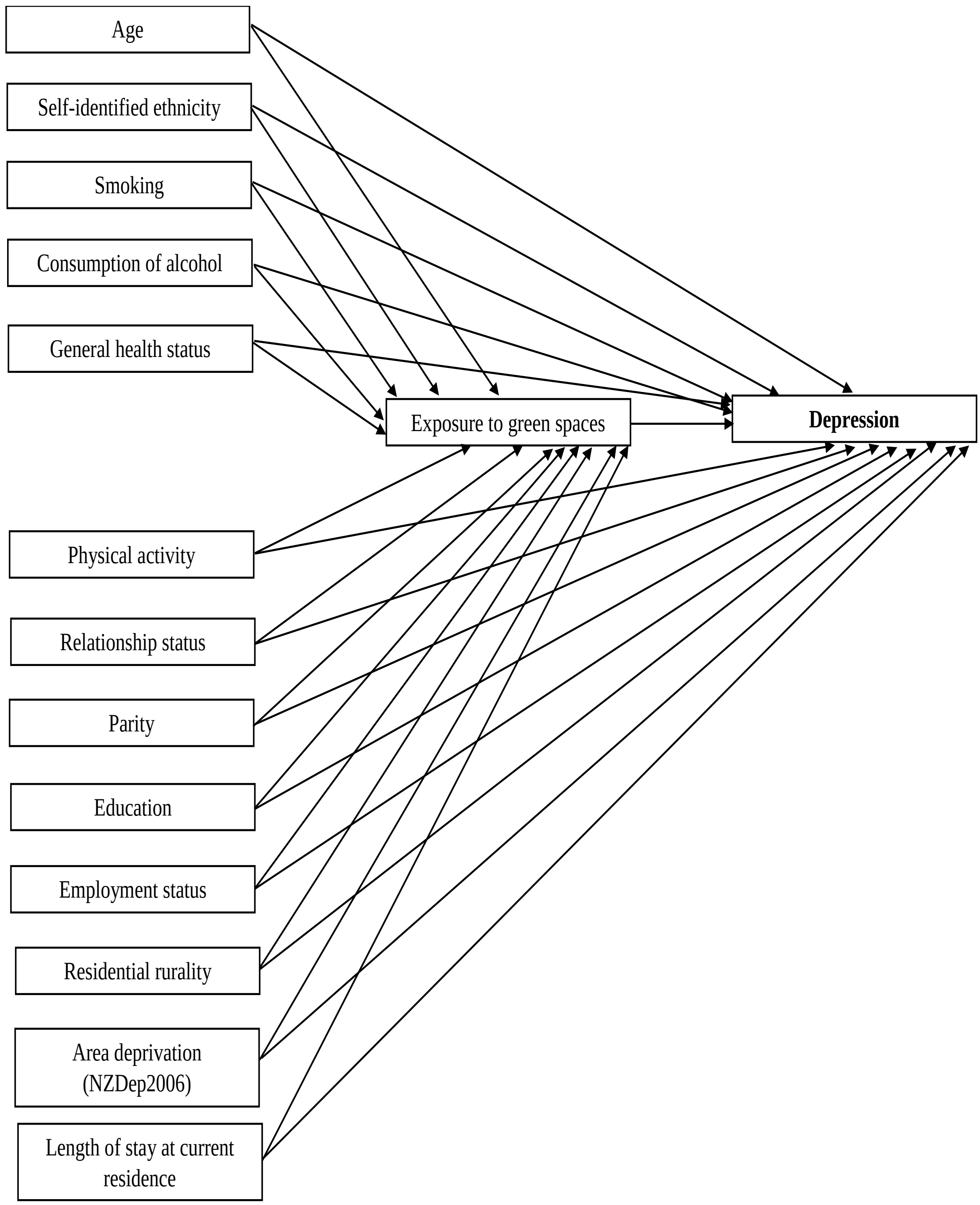


Figure 3-4: Directed acyclic graph describing the confounders of the association between green space and depression

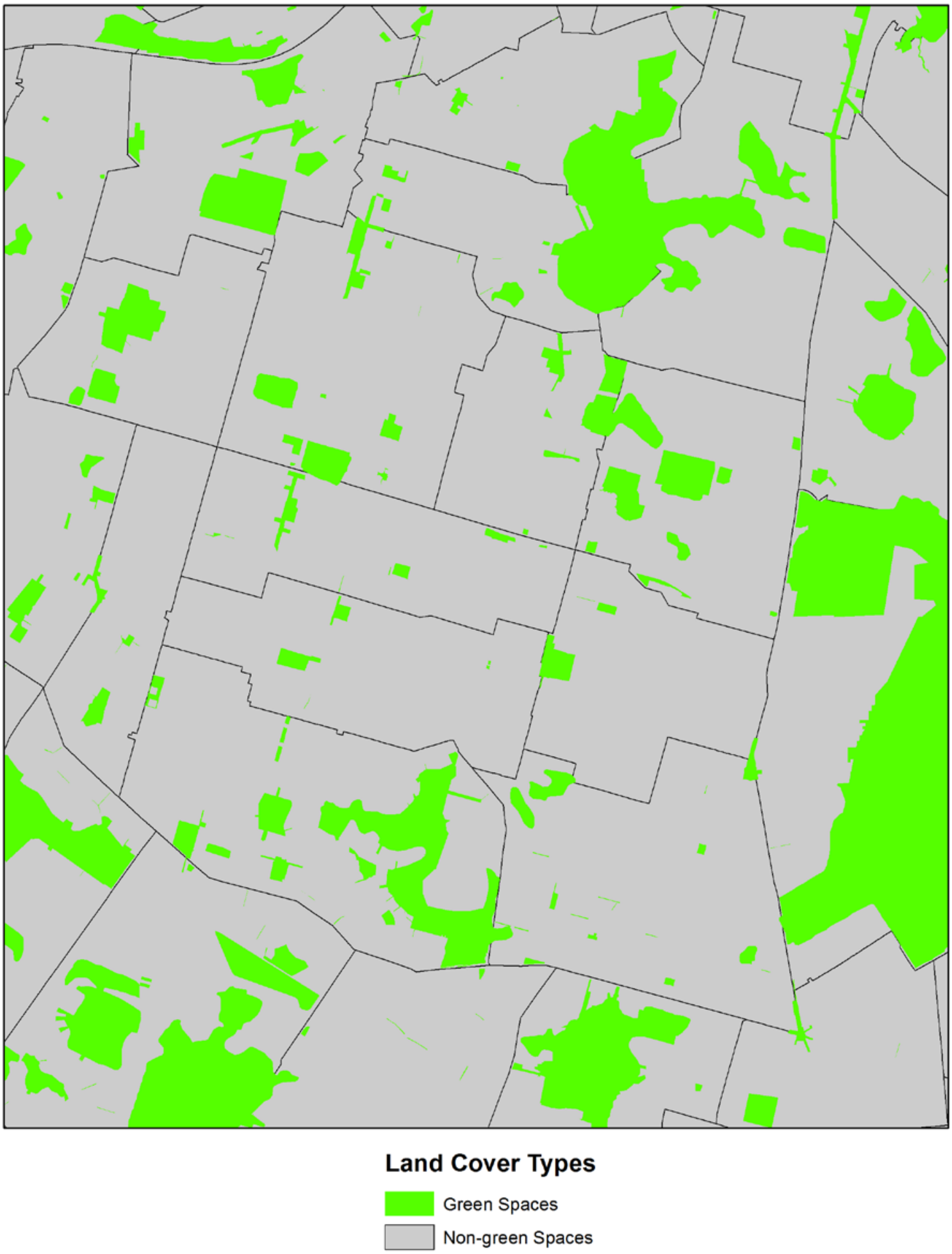


Figure 3-5: An example of green space classification for census area units of Auckland, Manukau, and Waikato regions of New Zealand using green space data from the Local Councils and the LCDB

Chapter 4. Results

This chapter describes the results for the three studies: 1) Green space and physical activity in pregnant women, 2) Green space and pregnancy outcomes in pregnant women, and 3) Green space and depression in pregnant women. More specifically, this chapter describes the results of green space exposure, the demographic and residential characteristics, the bivariate analyses, participation in physical activity, the interaction analyses, the main analyses, and the subgroup analyses.

4.1 Green space exposure for pregnant women

The CAUs of the Auckland and Counties-Manukau DHB regions (n=413) had a median area of 1.62 km^2 (range=0.20 to 592.46 km^2) while the CAUs of the Waikato DHB region (n=200) had a median area of 6.64 km^2 (range=0.14 to 1233.76 km^2). The mean (SD) percentage of green space in all CAUs of the Auckland and Counties-Manukau DHB regions (n=413) was 38% (32%) and for the Waikato DHB region (n=200) 65% (34%). A graphical representation of the proportion of green space in the CAUs of the study region is given in Figure 4-1.

The 25th, 50th, and 75th percentiles of green space exposure for the study participants were 12.32%, 21.46%, and 37.99%, respectively. Significant differences were identified between urban and rural areas in terms of exposure to green space (F=4217.30; *p-value*<0.0001) with the amount of green space being higher in rural areas than those in urban areas. The proportions of green space available to pregnant women residing in urban and rural areas were 26.31% (95% CI=25.76-26.87%) and 95.92% (95% CI=94.93-96.91%), respectively.

Exposure to green space differed between population subgroups defined by NZDep2006 decile groups ($F=172.79$; *p-value*<0.0001). Mothers residing in low deprivation areas (decile group one) were exposed to higher level of neighbourhood greenness in comparison to those residing in medium (decile group two) and high deprivation areas (decile group three). The difference in mean green space percentage between decile groups one and two was -8.08% (*p-value*=0.000). Simultaneously, the difference in mean green space percentage between decile groups one and three was -15.70 (*p-value*=0.000). The mean difference in green space percentage between decile groups two and three was statistically significant (mean difference= -7.62; *p-value*=0.000). A decrease of 2.12% (*p-value*<0.001) was observed in the percentage of green space with each decile increase in area deprivation score. The proportion of green space available to pregnant women residing in low, medium, and high deprivation areas was 39.93% (95% CI=38.33-41.53%), 31.85% (95% CI=30.68-33.02%), and 24.23% (95% CI=23.50-24.96%), respectively (Figure 4-2).

Significant differences were identified for education ($\chi^2=4.93$; *p-value*=0.0006) and self-identified ethnicity ($\chi^2=74.63$; *p-value*<0.0001) between population subgroups in terms of their exposure to green space. Pregnant women who had acquired diploma level education qualifications were exposed to higher surrounding greenness than those with other levels of educational qualification (diploma=32.65% [95% CI=31.42-33.88%], no secondary school=31.05% [95% CI=28.70-33.40%], secondary school=30.83% [95% CI=29.50-32.16%], bachelor's degrees=30.63% [95% CI=29.19-32.07%], and higher degrees=28.00% [95% CI=26.38-29.63%]). European pregnant women were exposed to higher surrounding greenness than non-European women (European=36.14% [95% CI=35.10-37.17%], Māori=31.08% [95% CI=29.43-32.73%], Pacific=21.90% [95% CI=20.93-22.86%], Asian=21.31% [95% CI=20.14-22.50%], Middle Eastern/Latin

American/African=26.58% [95% CI=23.12-30.05%], and Other or New Zealander=34.95% [95% CI=28.42-41.48%]).

Exposure to green space also differed between delivery methods (F=5.52; *p-value*<0.001). The proportions of green space available to pregnant women delivering by spontaneous vaginal, planned caesarean, emergency caesarean, and other assisted methods were 31.78% (95% CI=30.94-32.63%), 29.80% (95% CI=27.57-32.04%), 29.05% (95% CI=27.36-30.75%), and 27.90% (95% CI=25.90-29.90%), respectively. However, no significant differences were identified in exposure to green space between different maternal age groups (F=0.42; *p-value*=0.84). The proportions of green space available to pregnant women aged <20, 20-24, 25-29, 30-34, 35-39, ≥40 years were 28.94% (95% CI=26.36-31.51%), 31.15% (95% CI=29.45-32.85%), 31.15% (95% CI=29.82-32.48%), 30.99% (95% CI=29.77-32.21%), 30.65% (95% CI=29.19-32.11%) and 31.54% (95% CI=28.04-35.04%), respectively.

4.2 Demographics and residential characteristics of mothers and new born infants recruited in the Growing Up in New Zealand study

The mean (SD) maternal age was 30 (6) years. Ninety-two percent had attained some level of education and 54% were employed. Fifty-three percent of the pregnant women described their self-identified ethnicity as European. Fifty-nine percent of the pregnant women were in civil union or married to their partners, and 57% were multiparous. Seventy-one and 80% of mothers did not consume alcohol and smoke cigarettes during pregnancy, respectively. Only a small percentage of pregnant women, 10%, reported their pre-pregnancy general health status as poor or fair. The proportion of mothers who achieved the ACOG recommendations for physical activity during the first trimester and for the remainder of the pregnancy was 28% and 21%, respectively. Fifteen percent of mothers experienced depression during the antenatal period diagnosed through the administration of EPDS questionnaires with scores ≥13. The proportion of pregnant women experiencing depression who resided in areas of low, medium, high, and very high green space were 14.68%, 17.32%, 17.45%, and 15.22%, respectively. The mean (SD) duration of residence at the nominated address was 4 (6) years. Thirty-one percent of the pregnant women lived in their neighbourhood because they preferred its local lifestyle. Most mothers (93%) were residing in urban areas at the time of cohort recruitment. Consistent with the national data describing the deprivation of New Zealand households of families with young children, households in the most deprived three deciles were over represented (MOH, 2010). Sixty-five percent of mothers delivered by the spontaneous vaginal method. The mean (SD) of birth weight and gestational age of new born infants was 3458 (675) grams and 39 (5) weeks, respectively (Table 4-1).

4.3 Bivariate analyses

A two-way table with a measure of the association between preference of the local lifestyle of the neighbourhood and NZDep2006 showed that pregnant women who preferred the local lifestyle of the neighbourhood lived more frequently in low (38.8%) or medium deprivation areas (40.8%). Additionally, significant differences existed between population subgroups defined by NZDep2006 in their preference for the local lifestyle of the neighbourhood, confirming that these two variables were not independent (χ^2=523.56; *p-value*<0.0001). Preference for the local lifestyle of the neighbourhood was independently associated with green space (χ^2=166.34; p<0.0001), and with moderate or vigorous physical activity after the first trimester of pregnancy (χ^2=5.32; p=0.021), but not with moderate or vigorous physical activity during the first trimester of pregnancy (χ^2=2.91; *p-value*=0.09).

Significant differences were identified among population subgroups defined by NZDep2006 in terms of length of stay at the current residence (F=1.62; $p<0.0001$). The mean lengths of stay at the current residence for women residing in low, medium, and high deprivation areas were 3.89, 3.96, and 4.86 years, respectively. Additionally, the length of stay at the current residence was associated with gestational age (F=1.30; $p=0.01$). In contrast, the length of stay at the current residence was not associated with green space (F=1.15; $p=0.10$), residential rurality (F=0.95; $p=0.68$), physical activity during (F=1.15; $p=0.09$) and after the first trimester of pregnancy (F=0.93; $p=0.74$), depression (F=1.00; $p=0.50$), and birth weight (F=1.11; $p=0.17$) (Appendix 7).

4.4 Participation in physical activity by pregnant women

Moderate and vigorous physical activity decreased from the pre-pregnancy period (moderate 25%, vigorous 39%) to the first trimester (moderate 17%, vigorous 16%) and further to the remainder of the pregnancy based on the entire cohort (moderate 15%, vigorous 9%). Significant differences were present across the three-time intervals (before pregnancy, the first trimester, and during the remainder of the pregnancy) for both moderate and vigorous physical activity ($p<0.0001$ for all time interval comparisons of moderate and of vigorous physical activity). Significant differences persisted across the three-time intervals for both moderate and vigorous physical activity after stratification of analysis based on quartiles of green space (Table 4-2).

4.5 Interaction analyses

4.5.1 Interaction tests for physical activity during the first trimester and the remainder of the pregnancy

The p-value for interactions was taken as 0.05. No interaction was evident between green space and other variables (age, education, self-identified ethnicity, residential rurality, and NZDep2006), implying these did not modify the association between green space and physical activity independently during the first trimester ($p\text{-}value_{\text{residential rurality}}$=0.20; $p\text{-}value_{\text{area deprivation}}$=0.24; $p\text{-}value_{\text{age}}$=0.28; $p\text{-}value_{\text{self-identified ethnicity}}$=0.33; and $p\text{-}value_{\text{education}}$=0.90) and the remainder of the pregnancy ($p\text{-}value_{\text{area deprivation}}$=0.13; $p\text{-}value_{\text{residential rurality}}$=0.27; $p\text{-value}_{\text{age}}$=0.74; $p\text{-}value_{\text{self-identified ethnicity}}$=0.74; and $p\text{-}value_{\text{education}}$=0.98).

4.5.2 Interaction tests for birth weight and gestational age

Interaction terms for residential rurality (*p-value*=0.11), self-identified ethnicity (*p-value*=0.16), education (*p-value*=0.53), area deprivation (*p-value*=0.54), and age (*p-value*=0.79) were not significant for birth weight analyses at a *p-value* of 0.05 when considering the entire cohort. In contrast, there was an indication of effect modification for gestational age based on the residential rurality of the study participants. The interaction term for residential rurality was significant (*p-value*=0.01) for gestational age analyses when considering the entire cohort. No effect modifications on gestational age analyses were seen for age (*p-value*=0.08), self-identified ethnicity (*p-value*=0.16), education (*p-value*=0.60), and area deprivation (*p-value*=0.70).

4.5.3 Interaction tests for depression

Any interactions between green space and other variables of interest at *p-value* of 0.05 were not present while considering analyses for depression for the entire cohort (area deprivation [*p-value*=0.07], physical activity during the first trimester of pregnancy [*p-value* =0.07], age [*p-value*=0.09], physical activity after the first trimester of pregnancy [*p-value*=0.45], residential rurality [*p-value*=0.75], self-identified ethnicity [*p-value*=0.83], and education [*p-value*=0.94]). Consequently, subgroup analyses were not performed for depression after stratifying analyses according to area deprivation, age, and physical activity during and after the first trimester, residential rurality, self-identified ethnicity, and education of the cohort participants.

4.6 Main analyses

4.6.1 Associations of green space with physical activity during the first trimester and the remainder of pregnancy

The unadjusted regression analysis (Model 1) showed that exposure to medium (unadjusted $OR_{\text{medium green space}}$=0.98 [95% CI=0.84–1.15]) and high levels of green space (unadjusted $OR_{\text{high green space}}$=1.06 [95% CI=0.90–1.24]) was not associated with moderate or vigorous physical activity during the first trimester of pregnancy. However, exposure to very high levels of green space was associated with moderate or vigorous physical activity during the first trimester of pregnancy (unadjusted $OR_{\text{very high green space}}$=1.19 [95% CI=1.01–1.40]) (Model 1). After the first trimester of pregnancy, exposure to all levels of green space was not associated with moderate or vigorous physical activity (unadjusted $OR_{\text{medium green space}}$=0.87 [95% CI=0.73–1.04]; unadjusted $OR_{\text{high green space}}$=0.99 [95% CI=0.84–1.18]; and unadjusted $OR_{\text{very high green space}}$=1.08 [95% CI=0.90–1.28]) (Model 1) (Table 4-3 and Appendix 8).

The fully adjusted regression analysis (Model 4) showed that exposure to all levels of green space was not associated with moderate or vigorous physical activity either during the first trimester of pregnancy (adjusted $OR_{\text{medium green space}}$=0.94 [95% CI=0.79–1.10]; adjusted

OR $_{\text{high green space}}$=1.02 [95% CI=0.87–1.20]; and adjusted OR $_{\text{very high green space}}$=1.16 [95% CI=0.98–1.37]) or after the first trimester of pregnancy (adjusted OR $_{\text{medium green space}}$=0.85 [95% CI=0.72–1.02]; adjusted OR $_{\text{high green space}}$=0.98 [95% CI=0.83–1.17]; and adjusted OR $_{\text{very high green space}}$=1.04 [95% CI=0.88–1.24]) (Table 4-3 and Appendix 8).

4.6.2 Associations of green space with birth weight and gestational weight

In the univariate analysis for birth weight (Model 1), each IQR increase in green space in the CAU of the mother's residence (26% increase in green space percentage in CAU) was associated with an increase in infant birth weight by 13.18 grams (95% CI= -0.07-26.43), though the association was not statistically significant (Table 4-4 and Appendix 9). Similarly, in the fully adjusted regression analysis (Model 9), each IQR increase in green space in the CAU of the mother's residence was associated with an increase in infant birth weight by 11.73 grams (95% CI= -2.42-25.90), though the association again was not statistically significant (Table 4-4 and Appendix 9).

In the univariate analyses for gestational age (Model 1), each IQR increase in green space in the CAU of the mother's residence was associated with an increase in gestational age by 0.03 of a week (95% CI= -0.01-0.07), though the association was not statistical significant (Table 4-5 and Appendix 10). The fully adjusted regression analysis for gestational age (Model 9) indicated that each IQR increase in green space in the CAU of the mother's residence was associated with an increase in gestational age by 0.02 of a week (95% CI= -0.03-0.07), though the association again was not statistical significant (Table 4-5 and Appendix 10).

4.6.3 Association of green space with depression

Univariate regression analysis revealed that exposure to medium, high, or very high levels of green space was not associated with depression (unadjusted OR $_{\text{medium green space}}$=1.11 [95% CI=0.91–1.36]; unadjusted OR $_{\text{high green space}}$=1.12 [95% CI=0.92–1.36]; and unadjusted OR $_{\text{very high green space}}$=0.95 [95% CI=0.77–1.17]) (Model 1). Similarly, any association between exposure to green space and depression was not found after accounting for all confounders. That is, the fully adjusted regression analyses (Model 7) showed that exposure to medium, high, or very high levels of green space was not associated with depression (adjusted OR $_{\text{medium green space}}$=1.10 [95% CI=0.89–1.35]; adjusted OR $_{\text{high green space}}$=1.15 [95% CI=0.94–1.41]; and adjusted OR $_{\text{very high green space}}$=1.21 [95% CI=0.96–1.52]) (Table 4-8 and Appendix 13).

4.7 Subgroup analyses

4.7.1 Subgroup analyses based on residential rurality: Maternal exposure to green space and gestational age

I hypothesised that exposure to green space could be beneficial for pregnancy outcomes through increases in birth weight and gestational age for the entire cohort, and that these associations are likely to be stronger for specific population subgroups (e.g., women with low levels of education, or women residing in rural areas, or women residing in high deprived areas). The hypothesis is not supported for birth weight, but for gestational age. In the univariate model for pregnant women residing in urban CAUs (Model 1), each IQR increase in green space in the urban CAU of the mother's residence was associated with an increase in gestational age by 0.02 of a week (95% CI= -0.03-0.07), though this association was not statistical significant (Table 4-6 and Appendix 11). Similarly, this association was not significant in the fully adjusted multivariate model (Model 9). An increase in gestational age by 0.01 of a week (95% CI= -0.04-0.06) was observed in relation to an IQR increase in green space in the urban CAU of the mother's residence (Table 4-6 and Appendix 11).

In the univariate model for pregnant women residing in rural CAUs (Model 1), each IQR increase in green space in the CAU of the mother's residence was associated with an increase in gestational age by 0.52 of a week (95% CI=0.13-0.92) with this association being statistically significant (Table 4-7 and Appendix 12). This association remained significant in the fully adjusted multivariate model (Model 9). An increase in gestational age by 0.54 of a week (95% CI=0.12-0.97) was observed in relation to the IQR increase in green space in the rural CAU of the mother's residence (Table 4-7 and Appendix 12).

4.8 Summary of key findings

- The percentage of green space in CAUs decreased by 2.12% ($p<0.001$) with each decile increase in area deprivation score
- Exposure to green space for the entire cohort of pregnant women was not associated with physical activity during the first trimester (adjusted $OR_{\text{medium green space}}=0.94$ (95% CI=0.79-1.10); adjusted $OR_{\text{high green space}}=1.02$ (95% CI=0.87-1.20); and adjusted $OR_{\text{very high green space}}=1.16$ (95% CI=0.98-1.37)) or the remainder of the pregnancy (adjusted $OR_{\text{medium green space}}=0.85$ (95% CI=0.72-1.02); adjusted $OR_{\text{high green space}}=0.98$ (95% CI=0.83-1.17); and adjusted $OR_{\text{very high green space}}=1.04$ (95% CI=0.88-1.24))
- An IQR increase in green space for the entire cohort of pregnant women was associated with an increase in infant birth weight by 11.73 grams (95% CI= -2.42-25.90)
- An IQR increase in green space for the entire cohort of pregnant women was associated with an increase in infant gestational age by 0.02 of a week (95% CI= -0.03-0.07)

- Effect modification is seen for analyses of gestational age based on the residential rurality of pregnant women (interaction test *p*-value=0.01)
- An IQR increase in green space for pregnant women living in the urban areas resulted in an increase in infant gestational age by 0.01 of a week (95% CI= -0.04-0.06)
- An IQR increase in green space for pregnant women living in the rural areas resulted in an increase in infant gestational age by 0.54 of a week (95% CI=0.12-0.97)
- Exposure to green space was not associated with depression for entire cohort of pregnant women (adjusted $OR_{\text{medium green space}}$=1.10 (95% CI=0.89-1.35); adjusted $OR_{\text{high green space}}$=1.15 (95% CI=0.94-1.41); and adjusted $OR_{\text{very high green space}}$=1.21 (95% CI= 0.96-1.52))
- Effect modification was not observed for depression based on specific population subgroups

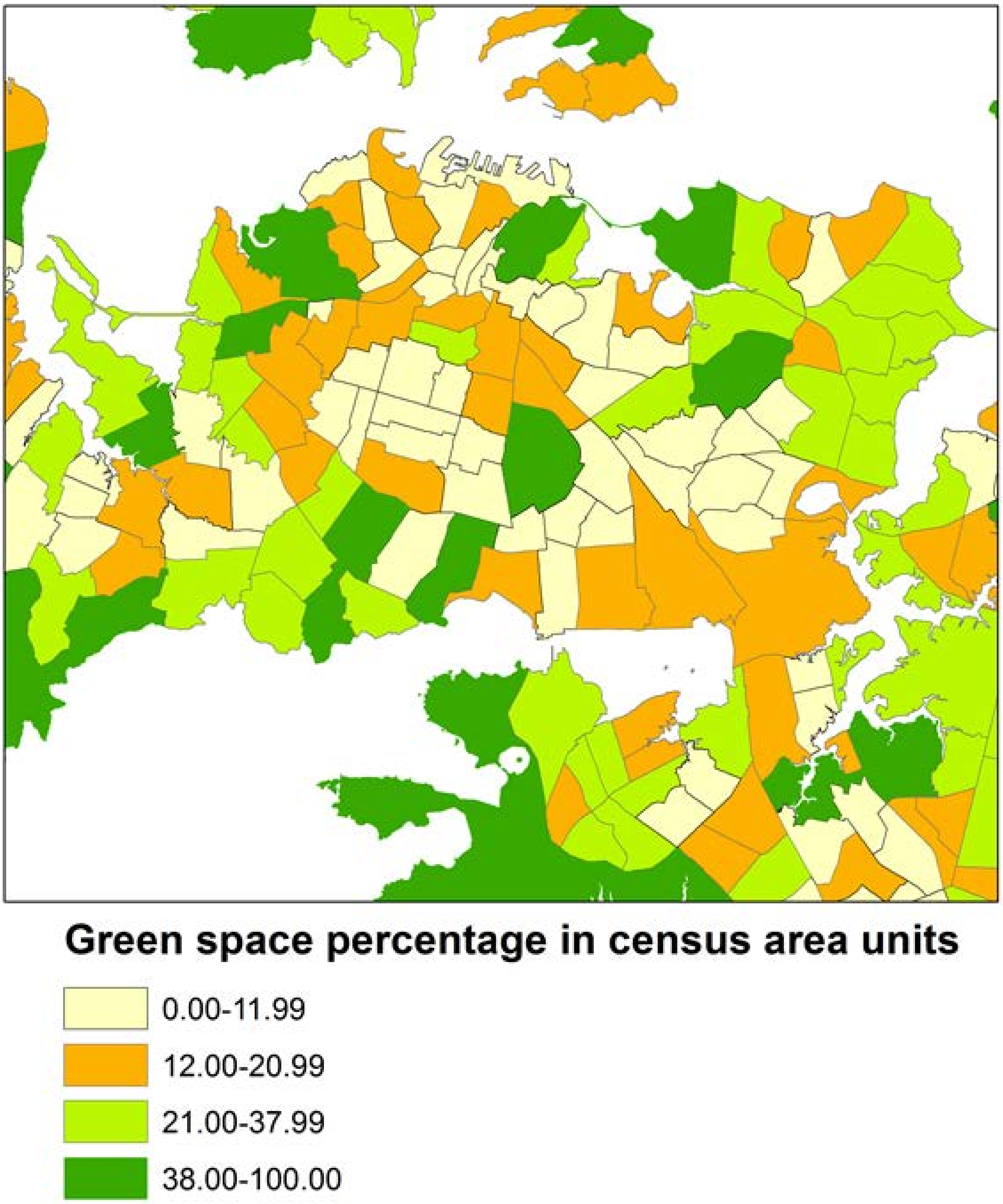


Figure 4-1: Proportion of green space in census area units of Auckland, Manukau, and Waikato regions of New Zealand

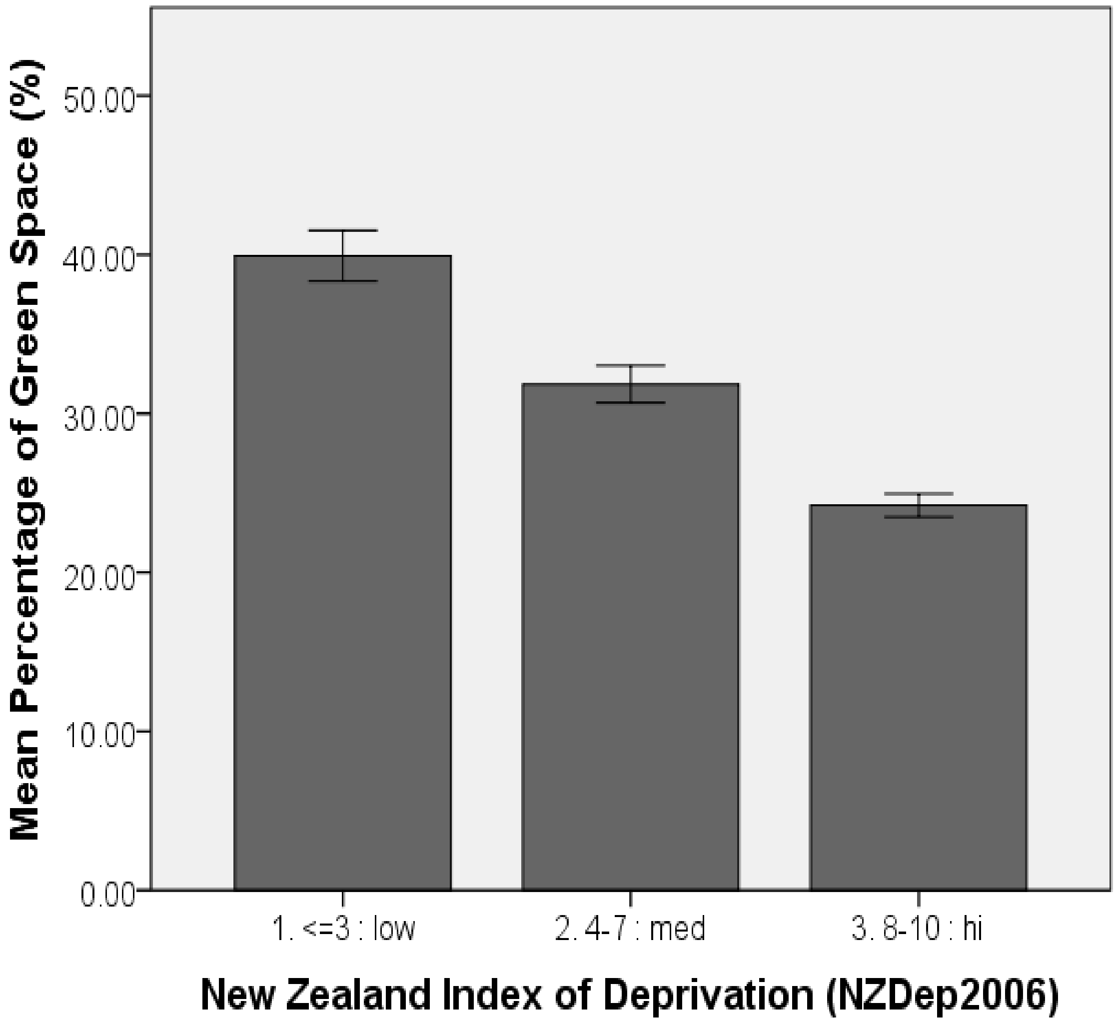


Figure 4-2: Green space availability by Area Deprivation (NZDep2006)

Table 4-1: Demographics and residential characteristics of mothers and new born infants recruited in the Growing Up in New Zealand study

Maternal variables	n=6772
Age groups, n (%)	
<20	325 (5)
20-24	992 (15)
25-29	1651 (24)
30-34	2108 (31)
35-39	1411 (21)
≥40	285 (4)
Missing	0 (0)
Highest education, n (%)	
No secondary school	485 (7)
Secondary school	1610 (24)
Diploma	2068 (30)
Bachelor’s degree	1532 (23)
Higher degree	1058 (15)
Missing	19 (1)
Employment status, n (%)	
Employed	3636 (54)
Unemployed	543 (8)
Student	455 (7)
Not in work force	1822 (27)
Missing	316 (4)
Self-identified ethnicity, n (%)	
European	3576 (53)
Māori	933 (13)
Pacific	1001 (15)
Asian	1002 (15)
Middle Eastern/Latin American/African	145 (2)
Other or New Zealander	96 (1)
Missing	19 (1)

Birth place, n (%)	
New Zealand	4331 (64)
Australia	120 (2)
Other Oceania	713 (10)
Asia	790 (11)
Europe	455 (6)
Africa	181 (3)
The Americas or Middle East or Other	175 (3)
Missing	7 (1)
Relationship with biological father, n (%)	
No relationship	125 (2)
Dating, but not cohabiting	278 (4)
Cohabiting	2312 (34)
Married or civil union	4038 (59)
Missing	19 (1)
Alcohol consumption during pregnancy (per week), n (%)	
No alcohol consumed during pregnancy	4851 (71)
Alcohol consumed during pregnancy	1904 (28)
Missing	17 (1)
Cigarette smoker during pregnancy, n (%)	
No	5473 (80)
Yes	656 (10)
Missing	643 (10)
Pre-existing doctor diagnosed depression, n (%)	
Never	5607 (82)
Before this pregnancy, but not during this pregnancy	819 (12)
Before and during this pregnancy	291 (4)
Only during this pregnancy	41 (1)
Missing	14 (1)
Pre-existing doctor diagnosed heart disease or high blood pressure, n (%)	
Never	6148 (91)
Before this pregnancy, but not during this pregnancy	331 (4)
Before and during this pregnancy	127 (2)
Only during this pregnancy	153 (2)
Missing	13 (1)

Pre-existing doctor diagnosed diabetes mellitus, n (%)	
Never	6463 (95)
Before this pregnancy, but not during this pregnancy	47 (1)
Before and during this pregnancy	80 (1)
Only during this pregnancy	162 (2)
Missing	20 (1)
Pre-pregnancy general health status, n (%)	
Poor or Fair	698 (10)
Good	2306 (34)
Very good	2382 (35)
Excellent	1372 (20)
Missing	14 (1)
Physical activity during the first trimester of pregnancy, n (%)	
No	4243 (63)
Yes	1890 (28)
Missing	639 (9)
Physical activity after the first trimester of pregnancy, n (%)	
No	4700 (69)
Yes	1433 (21)
Missing	639 (10)
Type of delivery method, n (%)	
Spontaneous vaginal	4426 (65)
Planned caesarean	653 (10)
Emergency caesarean	929 (14)
Other assisted	632 (9)
Missing	132 (2)
Parity, n (%)	
First born	2833 (42)
Subsequent	3932 (57)
Missing	7 (1)
Had a lead maternity carer during the pregnancy, n (%)	
No	147 (2)
Yes	6611 (97)
Missing	14 (1)

Antenatal depression, n (%)	
(diagnosed through EPDS questionnaires)	
No	5141 (76)
Yes	992 (15)
Missing	639 (9)
District health board of maternal domicile, n (%)	
Auckland	2421 (36)
Manukau	2526 (37)
Waikato	1825 (27)
Missing	0 (0)
Area-level deprivation index (NZDep2006), n (%)	
Low (decile 1-3)	1684 (25)
Medium (decile 4-7)	2471 (36)
High (decile 8-10)	2615 (38)
Missing	2 (1)
Residential rurality, n (%)	
Urban	6325 (93)
Rural	447 (7)
Missing	0 (0)
Time lived in current neighbourhood (years), mean (SD)	4 (6)
Preference for the local lifestyle of the neighbourhood	
No	4615 (68)
Yes	2135 (31)
Missing	22 (1)
Green space percentage in census area unit, mean (SD)	31 (28)
Green space percentage in census area unit, n (%)	
Low (0-<12%)	1672 (25)
Medium (12-<21%)	1652 (24)
High (21-<38%)	1764 (26)
Very high (38-100%)	1684 (25)
Missing	0 (0)
New born variables	**n=6772**
Gender, n (%)	
Male	3472 (51)
Female	3234 (48)
Missing	66 (1)

Birth weight (grams), mean (SD)	3458 (675)
Gestational Age (weeks), mean (SD)	39 (5)

Table 4-2: Participation in physical activity by pregnant women before and during pregnancy

Adherence to recommendations for frequency and duration of physical activity before and during pregnancy for pregnant women					
	Low green space	**Medium green space**	**High green space**	**Very high green space**	**Total Population (n=6772)**
Pre-pregnancy period	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
Met recommendations for:					
Moderate physical activity[1]	397 (26)	373 (25)	438 (28)	512 (33)	1720 (25)
Vigorous physical activity[2]	603 (40)	621 (42)	670 (42)	734 (47)	2628 (39)
Moderate or vigorous physical activity[3]	816 (54)	824 (56)	903 (57)	947 (61)	3490 (52)
First trimester of pregnancy					
Met recommendations for:					
Moderate physical activity[1]	269 (18)	237 (16)	298 (19)	334 (21)	1138 (17)
Vigorous physical activity[2]	244 (16)	249 (17)	274 (17)	319 (20)	1086 (16)
Moderate or vigorous physical activity[3]	437 (29)	429 (29)	491 (31)	533 (34)	1890 (28)
Remainder of pregnancy					
Met recommendations for:					
Moderate physical activity[1]	236 (16)	216 (15)	266 (17)	282 (18)	1000 (15)
Vigorous physical activity[2]	153 (10)	122 (8)	159 (10)	183 (12)	617 (9)
Moderate or vigorous physical activity[3]	351 (23)	312 (21)	375 (24)	395 (25)	1433 (21)

1=Moderate physical activity for 150 minutes per week; 2=Vigorous physical activity for 60 minutes per week; 3=Moderate physical activity for 150 minutes or vigorous physical activity for 60 minutes per week.

Table 4-3: Multilevel logistic regression analyses for associations between green space and physical activity for pregnant women during the first trimester and the remainder of pregnancy

Associations of green space with meeting recommendations for frequency and duration of moderate or vigorous physical activity (n=6772)				
Variable	**Model 1[a]**	**Model 2[b]**	**Model 3[c]**	**Model 4[d]**
Whether recommendations were met for moderate or vigorous physical activity during the first trimester of pregnancy[1]				
Green space percentage in census area unit	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Low	1.00	1.00	1.00	1.00
Medium	0.98 (0.84-1.15)	0.94 (0.80-1.11)	0.94 (0.79-1.10)	0.94 (0.79-1.10)
High	1.06 (0.90-1.24)	1.02 (0.87-1.19)	1.02 (0.87-1.20)	1.02 (0.87-1.20)
Very high	1.19 (1.01-1.40)	1.17 (0.99-1.38)	1.18 (0.99-1.39)	1.16 (0.98-1.37)
Whether recommendations were met for moderate or vigorous physical activity after the first trimester of pregnancy[1]				
Green space percentage in census area unit	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Low	1.00	1.00	1.00	1.00
Medium	0.87 (0.73-1.04)	0.85 (0.72-1.02)	0.85 (0.72-1.02)	0.85 (0.72-1.02)
High	0.99 (0.84-1.18)	0.98 (0.83-1.16)	0.98 (0.83-1.16)	0.98 (0.83-1.17)
Very high	1.08 (0.90-1.28)	1.06 (0.89-1.26)	1.07 (0.89-1.27)	1.04 (0.88-1.24)

a=unadjusted univariate (VPC for physical activity during the first trimester=0.004 and VPC for physical activity after the first trimester=0.002)
b=a + adjustment for age, ethnicity, education, and employment status (VPC for physical activity during the first trimester=0.002 and VPC for physical activity after the first trimester=0.0001)
c=b + adjustment for NZDep2006 (VPC for physical activity during the first trimester=0.002 and VPC for physical activity after the first trimester=0.0003)
d=c + adjustment for preference for the local lifestyle of the neighbourhood (VPC for physical activity during the first trimester=0.002 and VPC for physical activity after the first trimester=0.0003)
1=Moderate physical activity for 150 minutes per week or vigorous physical activity for 60 minutes per week

Table 4-4: Multilevel linear regression analysis for maternal exposure during pregnancy to green space and birth weight (grams) for the entire cohort

Association between maternal exposure to green space and birth weight (n=6615)				
Green space percentage in census area unit	**Model 1[a]** coefficient (95% CI)	**Model 2[b]** coefficient (95% CI)	**Model 3[c]** coefficient (95% CI)	**Model 4[d]** coefficient (95% CI)
Green space	13.18 (-0.07-26.43)	9.02 (-2.13-20.17)	2.61 (-8.53-13.74)	4.82 (-6.76-16.40)
Green space percentage in census area unit	**Model 5[e]** coefficient (95% CI)	**Model 6[f]** coefficient (95% CI)	**Model 7[g]** coefficient (95% CI)	**Model 8[h]** coefficient (95% CI)
Green space	5.31 (-6.26-16.88)	5.15 (-6.40-16.71)	4.21 (-7.13-15.55)	3.89 (-7.43-15.21)
Green space percentage in census area unit	**Model 9[i]** coefficient (95% CI)			
Green space	11.73 (-2.42-25.90)			

a=unadjusted univariate (VPC=0.002)
b=a + adjustment for gestational age and foetus gender (VPC=0.002)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=0.002)
d=c + adjustment for smoking and alcohol consumption (VPC=0.003)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=0.003)
f=e + adjustment for relationship status with biological father and birth place (VPC=0.003)
g=f + adjustment for lead maternity carer, type of delivery method, and parity (VPC=0.002)
h=g + adjustment for education and employment status (VPC=0.0013)
i=h + adjustment for residential rurality, time lived in current neighbourhood, and area deprivation (VPC=0.002)

Table 4-5: Multilevel linear regression analysis for maternal exposure during pregnancy to green space and gestational age (weeks) for the entire cohort

Association between maternal exposure to green space and gestational age (n=6615)				
Green space percentage in census area unit	**Model 1[a]** coefficient (95% CI)	**Model 2[b]** coefficient (95% CI)	**Model 3[c]** coefficient (95% CI)	**Model 4[d]** coefficient (95% CI)
Green space	0.03 (-0.01-0.07)	0.03 (-0.01-0.07)	0.02 (-0.02-0.06)	0.01 (-0.03-0.05)
Green space percentage in census area unit	**Model 5[e]** coefficient (95% CI)	**Model 6[f]** coefficient (95% CI)	**Model 7[g]** coefficient (95% CI)	**Model 8[h]** coefficient (95% CI)
Green space	0.01 (-0.03-0.05)	0.02 (-0.03-0.06)	0.02 (-0.03-0.05)	0.02 (-0.02-0.06)
Green space percentage in census area unit	**Model 9[i]** coefficient (95% CI)			
Green space	0.02 (-0.03-0.07)			

a=unadjusted univariate (VPC=3.97e-12)
b=a + adjustment for foetus gender (VPC=5.77e-12)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=3.93e-13)
d=c + adjustment for smoking and alcohol consumption (VPC=4.23e-13)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=2.94e-15)
f=e + adjustment for relationship status with biological father and birth place (VPC=1.15e-20)
g=f + adjustment for lead maternity carer, type of delivery method, and parity (VPC=1.18e-14)
h=g + adjustment for education and employment status (VPC=3.77e-09)
i=h + adjustment for residential rurality, time lived in current neighbourhood, and area deprivation **(**VPC=4.62e-10)

Table 4-6: Multilevel linear regression analysis for maternal exposure during pregnancy to green space and gestational age (weeks) for pregnant women residing in urban areas

Association between maternal exposure to green space and gestational age (n=6180)				
Green space percentage in census area unit	**Model 1[a]** coefficient (95% CI)	**Model 2[b]** coefficient (95% CI)	**Model 3[c]** coefficient (95% CI)	**Model 4[d]** coefficient (95% CI)
Green space	0.02 (-0.03-0.07)	0.02 (-0.03-0.07)	0.01 (-0.04-0.06)	0.01 (-0.05-0.06)
Green space percentage in census area unit	**Model 5[e]** coefficient (95% CI)	**Model 6[f]** coefficient (95% CI)	**Model 7[g]** coefficient (95% CI)	**Model 8[h]** coefficient (95% CI)
Green space	0.00 (-0.05-0.05)	0.01 (-0.04-0.06)	-0.00 (-0.05-0.05)	0.01 (-0.04-0.06)
Green space percentage in census area unit	**Model 9[i]** coefficient (95% CI)			
Green space	0.01 (-0.04-0.06)			

a=unadjusted univariate (VPC=4.19e-09)
b=a + adjustment for foetus gender (VPC=1.93e-13)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=4.26e-13)
d=c + adjustment for smoking and alcohol consumption (VPC=7.60e-13)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=1.46e-15)
f=e + adjustment for relationship status with biological father and birth place (VPC=2.41e-20)
g=f + adjustment for lead maternity carer, type of delivery method, and parity (VPC=9.46e-18)
h=g + adjustment for education and employment status (VPC=7.89e-13)
i=h + adjustment for time lived in current neighbourhood and area deprivation **(**VPC=1.21e-11)

Table 4-7: Multilevel linear regression analysis for maternal exposure during pregnancy to green space and gestational age (weeks) for pregnant women residing in rural areas

Association between maternal exposure to green space and gestational age (n=435)				
Green space percentage in census area unit	**Model 1[a]** coefficient (95% CI)	**Model 2[b]** coefficient (95% CI)	**Model 3[c]** coefficient (95% CI)	**Model 4[d]** coefficient (95% CI)
Green space	0.52 (0.13-0.92)	0.53 (0.13-0.92)	0.52 (0.11-0.94)	0.53 (0.11-0.95)
Green space percentage in census area unit	**Model 5[e]** coefficient (95% CI)	**Model 6[f]** coefficient (95% CI)	**Model 7[g]** coefficient (95% CI)	**Model 8[h]** coefficient (95% CI)
Green space	0.55 (0.14-0.97)	0.57 (0.15-0.98)	0.52 (0.11-0.92)	0.53 (0.12-0.93)
Green space percentage in census area unit	**Model 9[i]** coefficient (95% CI)			
Green space	0.54 (0.12-0.97)			

a=unadjusted univariate (VPC=3.20e-21)
b=a + adjustment for foetus gender (VPC=2.41e-21)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=7.56e-20)
d=c + adjustment for smoking and alcohol consumption (VPC=3.86e-20)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=5.09e-20)
f=e + adjustment for relationship status with biological father and birth place (VPC=3.23e-20)
g=f + adjustment for lead maternity carer, type of delivery method, and parity (VPC=4.55e-19)
h=g + adjustment for education and employment status (VPC=7.46e-21)
i=h + adjustment for time lived in current neighbourhood and area deprivation (VPC=2.55e-20)

Table 4-8: Multilevel logistic regression analyses for maternal exposure to green space during pregnancy and odds of depression for the entire cohort

Association between maternal exposure to green space and depression (n=6772)				
Green space percentage in census area unit	**Model 1[a]** OR (95% CI)	**Model 2[b]** OR (95% CI)	**Model 3[c]** OR (95% CI)	**Model 4[d]** OR (95% CI)
Low	1.00	1.00	1.00	1.00
Medium	1.11 (0.91-1.36)	1.13 (0.92-1.39)	1.12 (0.91-1.37)	1.10 (0.90-1.35)
High	1.12 (0.92-1.36)	1.13 (0.93-1.39)	1.13 (0.92-1.39)	1.12 (0.92-1.38)
Very high	0.95 (0.77-1.17)	1.20 (0.97-1.49)	1.20 (0.96-1.48)	1.22 (0.98-1.51)
Green space percentage in census area unit	**Model 5[e]** OR (95% CI)	**Model 6[f]** OR (95% CI)	**Model 7[g]** OR (95% CI)	
Low	1.00	1.00	1.00	
Medium	1.11 (0.90-1.36)	1.10 (0.90-1.36)	1.10 (0.89-1.35)	
High	1.14 (0.93-1.40)	1.14 (0.93-1.40)	1.15 (0.94-1.41)	
Very high	1.22 (0.98-1.51)	1.20 (0.97-1.49)	1.21 (0.96-1.52)	

a=unadjusted univariate (VPC=0.02)
b=a + adjustment for maternal age and self-identified ethnicity (VPC=0.002)
c=b + adjustment for smoking and alcohol consumption during pregnancy (VPC=0.002)
d=c + adjustment for pre-pregnancy general health status, physical activity during the first trimester and remainder of pregnancy (VPC=0.001)
e=d + adjustment for relationship status and parity (VPC=0.001)
f=e + adjustment for education and employment status (VPC=0.001)
g=f + adjustment for residential rurality, area deprivation, and length of stay at the current residence (VPC=0.001)

Chapter 5. Discussion

This chapter discusses the results of the three studies: 1) Green space and physical activity in pregnant women, 2) Green space and pregnancy outcomes in pregnant women, and 3) Green space and depression in pregnant women. In addition to presenting the main findings, this chapter provides a comparison of the thesis results with previous studies, presents the strengths and limitations, and provides possible mechanisms and conclusions.

5.1 Main Findings

In general, exposure to green space varied by New Zealand area-level deprivation, with green space decreasing as deprivation increased. This is in line with previous research on green space and socioeconomic status both within New Zealand (Richardson et al., 2010) and internationally (Dadvand et al., 2012a, Dadvand et al., 2014b, Astell-Burt et al., 2014d). In Spain and England, pregnant women living in the least deprived neighbourhoods experienced higher residential surrounding greenness (defined as the average of NDVI in a buffer of 100 m around each maternal address) than did women living in the most deprived neighbourhoods (Dadvand et al., 2014b, Dadvand et al., 2012a). In New Zealand, in a study of the association between green space and cause-specific mortality for adults aged 15 to 64 years, a socioeconomic gradient in exposure to green space was evident, with the percentage of green space decreasing by 11%, with each quintile increase in NZDep2001 deprivation score (Richardson et al., 2010). The amount of green space was higher in rural than in urban areas. This finding is consistent with those from a previous general population study conducted in the Netherlands (Maas et al., 2006).

Participation in moderate and vigorous physical activity for the entire cohort of pregnant women decreased from the pre-pregnancy period to the first trimester and further during the remainder of the pregnancy. This reduction in physical activity is consistent with previous pregnancy studies (Duncombe et al., 2009, Hayes et al., 2015). Contributing factors for reduction in physical activity that have been hypothesised include tiredness, lack of time, feeling unwell, and feeling uncomfortable (Duncombe et al., 2009). The decrease in physical activity was observed for all quartiles of green space.

Exposure to green space for pregnant women in general is not beneficial in increasing birth weight and gestational age. Previous research has shown that interaction and subgroup analyses can be performed in the presence of a non-significant overall effect (Abrahamowicz et al., 2013). Therefore, despite the null overall effects for birth weight and gestational age, interaction and subgroup analyses were performed for specific population subgroups. Subgroup analyses based on residential rurality of the study participants showed significant relationships between green space exposure and gestational age, but not between green space exposure and birth weight. Exposure to green space for pregnant women residing in rural areas was associated with gestational age, but for pregnant women residing in urban areas, it was not. As far as the association between green space and depression is concerned, exposure to green space for the entire cohort of pregnant women was not associated with depression. Additionally, the associations of exposure to green space with depression were not significant and stronger for specific population subgroups (e.g., women with low levels of education or women who were physically active during pregnancy).

5.2 Comparison of thesis results with previous studies with emphasis on self-selection bias

There are two sources of residential self-selection bias, namely socioeconomic status and attitudes (Mokhtarian and Cao, 2008). It is possible to eliminate self-selection bias due to socioeconomic status. This is by controlling for personal and area-level socioeconomic status in regression analyses. It is not easy to eliminate self-selection bias due to attitudes (Mokhtarian and Cao, 2008). The identification challenge that investigators have faced is how to select a variable that accurately represents self-selection bias. For socioeconomic status, it is easy to select variables that represent personal and area socioeconomic status. Some examples include education, employment status, and area deprivation. For attitudes, variables are not available which directly represent people's attitudes (Mokhtarian and Cao, 2008). The variables available for analysis from the *Growing Up in New Zealand* study were length of stay at the current residence and preference for the local lifestyle of the neighbourhood, which indirectly represented attitudinal self-selection bias (Morton et al., 2013). The statistical control of residential self-selection bias is a good method to account for self-selection bias, but not without limitations. The limitation of socioeconomic status is that it is not always available for analyses (e.g., income and value of assets are missing in most studies or if present have lot of missing values)(Mokhtarian and Cao, 2008). Attitudes cannot be measured in a straightforward manner; therefore, they are either missed or partially measured. Additionally, there is likelihood of a temporal mismatch if the attitudes at the time of data collection are not the same as those present prior to relocation (Mokhtarian and Cao, 2008).

This thesis adds to the already existing literature on green space and physical activity by exploring the issue of whether green space exposure does or does not increase the odds of participation in physical activity during pregnancy. Building on previous research on the green space-physical activity relationship in pregnant women from England (*Born in Bradford study*)(McEachan et al., 2015), this New Zealand-based research investigated the green space-physical activity association for a cohort (*Growing Up in New Zealand*)(Morton et al., 2013). The *Born in Bradford* study utilised a measure of green space (NDVI) which is different to the one used in the current thesis. The previous general population studies (Mytton et al., 2012, Richardson et al., 2013, Astell-Burt et al., 2014a, Ord et al., 2013, Maas et al., 2008, Astell-Burt et al., 2014b) used measures of classification and assessment of green space that are comparable to what the current thesis used, but in none of these studies was any measure of attitude-type self-selection bias used and only some of these studies considered area-level socioeconomic status. Overall, the trend in the general and pregnant population studies was that participants living in the greenest areas were more likely to perform five sessions of moderate or vigorous physical activity of at least 30 minutes duration in each week than were participants living in the least green areas (Mytton et al., 2012, Richardson et al., 2013, Astell-Burt et al., 2014a, Astell-Burt et al., 2014b, McMorris et al., 2015, McEachan et al., 2015). In contrast with both general adult (Mytton et al., 2012, Richardson et al., 2013, Astell-Burt et al., 2014a, Astell-Burt et al., 2014b, McMorris et al., 2015) and pregnant population studies (McEachan et al., 2015), findings of this thesis show that once neighbourhood self-selection bias (preference for the local lifestyle of the neighbourhood) is taken into consideration, green space exposure has no significant effect on the extent to which pregnant women engage in moderate or vigorous physical activity, irrespective of their socioeconomic background. It must be noted that self-selection bias due to socioeconomic status was taken into account in this thesis by controlling for socioeconomic status in the regression analyses.

The findings of this thesis with respect to a lack of association between exposure to green space and birth weight are consistent with the findings of one previous study, based in Barcelona, Spain (Dadvand et al., 2012a). Comparisons of thesis findings for birth weight with other green space-birth weight studies suggest that the effect size for birth weight observed in this current thesis was comparable to effect sizes for birth weight found in previous studies, though the associations were significant for other studies (Ebisu et al., 2016, Agay-Shay et al., 2014, Hystad et al., 2014, Markevych et al., 2014, Dadvand et al., 2012c, Dadvand et al., 2014b). The thesis findings are also in agreement with the two Spanish studies with respect to a lack of association between green space exposure and gestational age for the entire cohort (Dadvand et al., 2012a, Dadvand et al., 2012c). Direct comparisons of gestational age findings with other green space-gestational age studies is not possible as these other studies have dichotomised gestational age into a binary variable [preterm (gestational age <37 weeks) or term (gestational age ≥37 weeks)]. Mixed results have been obtained from these other green space-gestational age studies. Despite *not* including socioeconomic indicators as confounders in the regression analyses, some studies have shown exposure to green space to be associated with a lower likelihood of preterm birth (Laurent et al., 2013, Hystad et al., 2014, Casey et al., 2016). No association between green space exposure and preterm birth was found in one study, in which ward-based socioeconomic status ranking was included as a confounder in the regression analysis (Agay-Shay et al., 2014). It must be noted that most of previous pregnant population studies on green space and pregnancy outcomes had not accounted for self-selection bias (attitude-type or socioeconomic status-type) while determining the associations between green space and pregnancy outcomes (Ebisu et al., 2016, Agay-Shay et al., 2014, Hystad et al., 2014, Markevych et al., 2014, Dadvand et al., 2012c, Dadvand et al., 2014b, Dadvand et al., 2012a, Casey et al., 2016). In contrast, the study of green space and pregnancy outcomes presented in this thesis had accounted for self-selection bias by including the length of stay at the current residence (residential mobility) and socioeconomic status in regression modelling while determining the associations between green space and pregnancy outcomes. If residential mobility during pregnancy is not taken into account, then this results in exposure misclassification, low power, and biased risk estimates (Hodgson et al., 2015).

This thesis also adds new information to the currently limited body of literature on the relationship of green space exposure with birth weight and gestational age. The current thesis research has shown that effect modification occurs for gestational age among infants of pregnant women living in rural areas. In previous studies effect modification for birth weight but not gestational age has been shown based on socioeconomic status (Dadvand et al., 2012a, Dadvand et al., 2012c, Markevych et al., 2014, Agay-Shay et al., 2014, Dadvand et al., 2014b). None of these previous studies on pregnancy outcomes investigated the potential effect modification of residential rurality on the relationship of green space exposure with gestational age, probably due to a lack of interaction between green space and residential rurality. A growing body of evidence from the general population suggests that the associations between exposure to green space and health outcomes are dependent on the degree of residential rurality (de Vries et al., 2003, Maas et al., 2006). The thesis result of effect modification for pregnant women living in rural areas are consistent with these general population studies (de Vries et al., 2003, Maas et al., 2006) that have shown effect modifications for people living in rural areas, for general measures of health. Several potential reasons could explain why effect modifications are seen in rural but not urban populations. Numerous factors which can influence health vary with residential rurality. In addition to the amount of green space, differences in health between urban and rural residents can be attributed to differences in air pollution, noise pollution and lifestyle factors between urban and rural areas and to selective migration (e.g., migration from urban to rural areas and vice versa) (Maas et al., 2006). Adverse personal lifestyle habits (e.g., smoking, alcohol consumption, and substance abuse) are more common amongst urban than rural residents (Verheij, 1996). Air and noise pollution concentrations are higher in urban areas than rural areas (Verheij, 1996). Higher levels of social support are also seen in rural areas (Verheij, 1996). In the *Growing Up in New Zealand* cohort, about seven per cent of the pregnant women who resided in rural areas were exposed to high or very high levels of green space in the CAUs of their residence. It seems likely that exposure to high or very high levels of green space in CAUs for pregnant women living in rural areas, at least in part, will have contributed to the residential rurality effect modification observed within the cohort. It is hypothesised that both the availability of high or very high levels of green space and the use of this green space by rural pregnant women explain the effect modification on gestational age.

The thesis results with respect to the association between green space and depression can be compared to the results of a prior study on pregnant women carried out in England (Born in Bradford). The thesis findings are not in agreement with the English study which showed that pregnant women residing in the greenest areas had a lower likelihood of depression in comparison with those residing in the least green areas (McEachan et al., 2015). Some explanations can be given for the contrasting results between the current thesis and the Born in Bradford study. One possible explanation is the lack of environmental variation in green space in New Zealand. Another explanation for the differences in results is the inclusion of the neighbourhood self-selection variable in the regression analyses. The current thesis included the length of stay at the current residence variable as a surrogate for attitude-type neighbourhood self-selection in the regression models. This is in contrast with the Born in Bradford study that did not include a variable representing attitude-type self-selection bias in the regression analyses (McEachan et al., 2015). The thesis results can also be compared to the results of prior general population studies on green space-mental health carried out within and outside of New Zealand. The lack of association between exposure to green space and depression for the entire cohort of pregnant women found in this thesis is consistent with the results of a few general population studies on green space and mental health (Nutsford et al., 2016, Annerstedt et al., 2012, Bos et al., 2016), but not with others (Nutsford et al., 2013, Richardson et al., 2013, Astell-Burt et al., 2013b, Beyer et al., 2014). Consistent with previous pregnant population study on green space and depression (McEachan et al., 2015), most of previous general population studies on green space and mental health outcomes had not accounted for self-selection bias (attitude-type or socioeconomic status-type) while determining the associations between green space and mental health outcomes (Astell-Burt et al., 2013b, Nutsford et al., 2013, Mitchell, 2013, Bos et al., 2016, van den Berg et al., 2016, Nutsford et al., 2016).

5.3 Strengths and limitations

The studies presented within this thesis are the first of their kind in New Zealand that have investigated the associations between green space exposure and health outcomes among pregnant women. Adjustments were made for multiple potentially confounding factors including preference for the local lifestyle of the neighbourhood, the length of stay at the current residence, and socioeconomic status. It can therefore be expected that confounding factors were controlled for and represent real confounding rather than an artefact of residual confounding. Critical components of this thesis work were the inclusion of different types of green space, and using a sample of pregnant women residing in a diverse range of urban and rural areas as this allowed for an investigation into effect modification by residential rurality for the association between exposure to green space and gestational age. The green space data for the studies were also linked to health outcomes such as physical activity and depression. The sample size of the entire cohort of pregnant women utilised for this thesis was comparable to the sample size used in general and pregnant population studies performed in New Zealand and outside of New Zealand that have investigated the relationships between green space and health outcomes [442 (Nutsford et al., 2016); 1,064 (Alcock et al., 2014); 1,890 (Mitchell, 2013); 2,393 (Dadvand et al., 2012c); 2,479 (Beyer et al., 2014); 3,203 (Markevych et al., 2014); 3,292 (Grazuleviciene et al., 2015); 3,679 (Ord et al., 2013); 3,748 (van den Berg et al., 2016); 4,899 (Maas et al., 2008); 4,924 (Bos et al., 2016); 7,547 (McEachan et al., 2015); 7,552

(Nutsford et al., 2013); 8,157 (Richardson et al., 2013); 8,246 (Dadvand et al., 2012a); 9,230 (Annerstedt et al., 2012); 10,780 (Dadvand et al., 2014b); 12,529 (Witten et al., 2008); 12,821 (Casey et al., 2016); 31,409 (Mytton et al., 2012); 39,132 (Agay-Shay et al., 2014); 64,705 (Hystad et al., 2014); 65,407 (Astell-Burt et al., 2014e); 69,910 (McMorris et al., 2015); 81,186 (Laurent et al., 2013); 203,883 (Astell-Burt et al., 2014a); 239,811 (Ebisu et al., 2016); 246, 920 (Astell-Burt et al., 2014b) 260,061 (Astell-Burt et al., 2013b) and 345,143 (Maas et al., 2009b). Additionally, the sample size used to detect effect modification due to residential rurality in the study of green space and pregnancy outcomes was comparable to the sample size used in previous pregnant population studies for testing similar effect modifications [639 for primary school or no education group and 1,039 for secondary school education group (Dadvand et al., 2012c); 315 for low education group (Markevych et al., 2014); 164 for lowest education group (Dadvand et al., 2012a); 3,701 for most deprived group and 4,880 for five General Certificate of Secondary Education or A level equivalent group (Dadvand et al., 2014b)]. The *Growing Up in New Zealand* dataset, gave sufficient statistical power to identify effect modification for gestational age based on the residential rurality of mothers. Because of its cohort design, data obtained from the *Growing Up in New Zealand* study are subject to less sampling bias than would potentially be introduced in other sampling methodologies (e.g., postal questionnaires).

The three studies have some limitations. The measure of green space was based on calculating the proportion of green space in CAUs. As some CAUs had large areas, this could have led to green space exposure misclassification for the large-sized CAUs. The possibility of green space exposure misclassification for large-sized CAUs was reduced, at least in part, by performing multilevel analyses. A higher percentage of green space in CAUs might not necessarily translate into proximity to green space. Some confounders such as income, occupation, and

BMI were not included in the regression models due to a high proportion of missing observations for these variables. Both income and occupation are important components of personal-level socioeconomic status (Davis et al., 1997) and BMI has been shown to be an important determinant of physical activity (Lynch et al., 2012) and depression (Molyneaux et al., 2016). Objective measurements of physical activity and depression could have provided more precise estimates (Prince et al., 2008, Nutsford et al., 2013). The work of Ulrika Stigsdotter and Patrik Grahn in Sweden has shown that exposure to private gardens alone is linked to stress reduction in adults from the general population (Stigsdotter and Grahn, 2004). Similarly, a most recent Scottish general population study investigating the association of green space with mental health has shown that access to gardens alone in a residential environment is linked to stress reduction (Ward Thompson et al., 2016). Private gardens were not included in the classification of green spaces for the three studies as the national dataset such as the LCDB and the local council green space datasets do not capture data for private gardens. While it would have been helpful to investigate the role of access to green spaces by determining distances between home addresses and local green spaces, the data to do so were not available (e.g., the data on home addresses and the data on road/path networks were not available). Also, green space quality data were not available. The quality of green spaces (safety, aesthetics, amenities, and maintenance) has been shown to be an important determinant of the use of green spaces for physical activity (McCormack et al., 2010). Therefore, the inability to determine whether the green spaces were used for engagement in physical activity was a limitation. Preference for the local lifestyle of the neighbourhood is an imperfect measure of self-selection bias. Its limitation is that it also represents a participant's preference for living in a neighbourhood with better locational access to facilities other than green spaces and other recreational facilities (e.g., public transport, education, or health care facilities), not green space alone. The limitation in the length of stay at the current residence is that there is an assumption that women are not mobile, which may or may not be true. Over the last decade, there has been a housing shortage in Auckland, in particular. Therefore, the length of stay at the current residence may not be an ideal surrogate measure of attitude-type neighbourhood self-selection bias. As temporality cannot be established in cross-sectional studies, the result of this thesis may not represent a causal relationship for green space and gestational age for women residing in rural areas.

5.4 Possible mechanisms and conclusions

The current thesis findings suggest that, in New Zealand, exposure to green space in terms of having more green space in the residential neighbourhood is not associated with increased physical activity during pregnancy, irrespective of socioeconomic status and after adjustment for preference for the lifestyle of the neighbourhood. As the association between proximity to green space and physical activity was not determined, living in green space may or may not translate into better pregnancy health through increased participation in physical activity. Exposure to green space may not be an important determinant of either birth weight or gestational age when considering the entire population of this cohort. Conversely, exposure to green space may be an important determinant of gestational age for pregnant women living in rural areas only. Physical activity would not appear to be an important mediator of the association between exposure to green space and gestational age for pregnant women residing in rural areas. This means that other mechanisms, for example, social contacts, air and noise pollution, and environmental temperatures could potentially mediate the association between exposure to green space and gestational age for pregnant women residing in rural areas. Due to a lack of data on other mediating variables, the identification of the mediating pathways underlining the association between green space exposure and gestational age was not possible for pregnant women residing in rural areas. It must be noted that the associations between access to green space and pregnancy outcomes were not determined. The results of this thesis suggest that exposure to green space is not associated with depression across the cohort of pregnant women, after adjusting for socioeconomic status and length of stay at the current residence. This thesis did not estimate the association between access to green space and depression. Considering the limitations of the studies presented in this thesis, more studies on green space and maternal and child health outcomes in similar or different contexts are required to help overcome these limitations.

Chapter 6. Thesis summary, implications of thesis findings, and recommendations for future investigators and public health policy

In New Zealand, prior to this thesis being carried out, very little was known about the health effects of green space, and in particular the roles of socioeconomic status and self-selection bias on the associations between green space and health outcomes in pregnant women. The three studies presented investigated the associations between exposure to green space and health outcomes of New Zealand pregnant women and the role that socioeconomic status plays in these associations. This thesis combined green space data from the local councils and the LCDB, as well as socioeconomic and health data from the *Growing Up in New Zealand* study (Morton et al., 2013) to develop understanding of the role of green space for improving physical activity and reducing the prevalence rates of the adverse health outcomes of low birth weight, preterm birth, and depression. The proportion of green space within CAUs was used as a surrogate for exposure to green space. This thesis accounted for and controlled for socioeconomic status and self-selection bias whilst determining the associations of exposure to green space with physical activity, birth weight, gestational age, and depression. I hypothesised that exposure to green space for the cohort population would be associated with a higher likelihood of meeting the ACOG recommendations for physical activity, higher birth weight and gestational age, and a lower likelihood of depression. Additionally, exposure to green space could prove to be beneficial for specific population subgroups. However, the overall relationships were not in the predicted directions. The findings were suggestive of a lack of associations of green space with physical activity, birth weight, gestational age, and depression for the entire cohort, though there was an association with a higher gestational age for pregnant women residing in rural areas. That is, subgroup analysis was suggestive of a protective effect of green space on the length of gestation for pregnant women residing in rural areas. Considering the three studies, it can be concluded that green space, in general, is not an important determinant of physical activity, birth weight, gestational age, or depression for pregnant women of the *Growing Up in New Zealand* cohort. However, it is for gestational age for rural residence subgroups. This thesis could not determine through mediation analyses, whether mediating mechanisms such as air pollution, noise pollution, environmental temperatures, or social ties mediated the relationships between exposure to green space and gestational age for rural residence subgroups. It is thought that the study setting has a huge effect on the health of population subgroups. In New Zealand, cities generally provide a high amount of green space (Richardson et al., 2010, Witten et al., 2008, Dekrout et al., 2014, Freeman and Buck, 2003). As a result, the amount of green space does not seem to be important for improving health outcomes.

Future researchers should use objective measurements of physical activity (data from acceloremeters and heart rate monitors) and depression (e.g., recording number of anxiety/mood disorder treatment counts). Estimates of accessibility to green space could be created. This could be achieved by determining distances to local green spaces through road networks. The green space exposure measure should be choosen in such a way that private gardens are captured. Quality characteristics of green space could also be considered as they likely alter the extent to which green space is sought out for physical activity. Future studies on pregnant women are warranted to confirm the research finding on the effect modification of residential rurality on the relationship of green space exposure with gestational age and test for the effect modification of residential rurality on the relationship of green space exposure with birth weight. Data on the socioeconomic (income and occupation) and BMI variables should be collected from all participants so that they can be utilised as confounders in the regression models. Future studies in pregnant women should acquire information on visits to green spaces and times spend in leisure activities in green spaces. Gathering such information is crucial for the determination of the mediators of the associations between green space and health outcomes. Future investigators could ask direct questions to the study participants on self-selection bias. Insights into the causal relationships between exposure to green space and health outcomes could be gained in longitudinal studies by analysing a subset of pregnant women migrating from less to more green areas or vice versa.

Many urban planners appreciate the importance of establishing and maintaining green spaces in public policy for general health and lifestyle factors while considering the general population as a target group (Barbosa et al., 2007). Currently, urban planning has not taken into account pregnant women specifically (Greed, 2016); therefore, the results of this thesis are important for urban policy makers who should target pregnant women while preparing policies on the construction of new residential areas. The finding of lower levels of green space in more highly deprived areas points to discrepancies in government policy regarding the socioeconomic distribution of green spaces. Therefore, urban planners should ensure a more equal distribution of green spaces for pregnant women residing in low, medium, and high deprivation areas. Urban planners could ensure there is enough exposure to green spaces so that pregnant women who want to live in them can do so (a supply and demand issue) and be physically active. The provision of new residential areas in greener environments through urban planning might prove beneficial in terms of increasing gestational age for pregnant women residing in rural areas. It remains unclear as to whether the provision of new residential areas in greener environments through urban planning could prove beneficial to the mental health of pregnant women, irrespective of residential rurality.

Appendix

Appendix 1: Land use categories obtained from the LCDB and their inclusion or exclusion into classifications of green spaces in this thesis

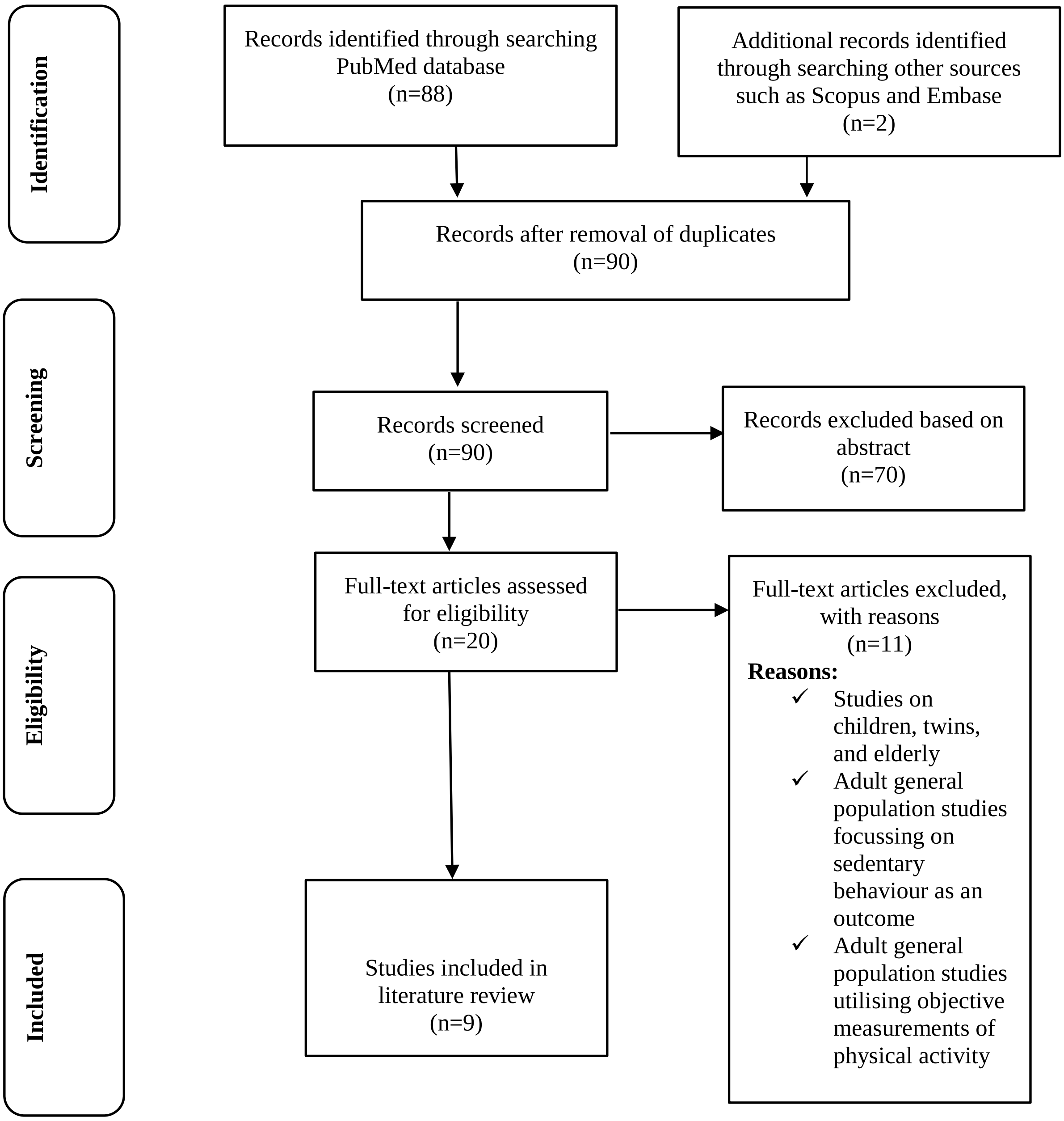
Land use categories derived from the LCDB	Inclusion into classification of green spaces in this thesis (Yes/No)
Urban Parkland/Open Space	Yes
Flax Land	Yes
Broadleaved Indigenous Hardwood	Yes
Deciduous Hardwood	Yes
Exotic Forest	Yes
Fern Land	Yes
Forest – Harvested	Yes
Gorse and/or Broom	Yes
Herbaceous Freshwater Vegetation	Yes
Herbaceous Saline Vegetation	Yes
High Producing Exotic Grassland	Yes
Indigenous Forest	Yes
Landslide	Yes
Low Producing Grassland	Yes
Mangrove	Yes
Manuka and/or Kanuka	Yes
Matagouri or Grey Scrub	Yes
Mixed Exotic Shrub Land	Yes
Orchard, Vineyard or Other Perennial Crop	Yes
Short-rotation Cropland	Yes
Sand or Gravel	Yes
Built-up Area (settlement)	No
Estuarine Open Water	No
Gravel or Rock	No
Lake or Pond	No
River	No
Surface Mine or Dump	No
Transport Infrastructure	No

Appendix 2: Comparison of demographics and residential characteristics for pregnant woman who were interviewed before birth vs pregnant women interviewed after birth of new born infants

Maternal variable 1 vs Maternal variable 2	Test statistic (chi square or t-test)	*p-value*
Age	19.90	0.75
Self-identified ethnicity	22.53	0.61
Education	14.74	0.54
Employment status	5.26	0.81
Birth place	35.11	0.51
Relationship with biological father	10.53	0.31
Alcohol consumption during pregnancy	0.64	0.43
Cigarette smoker during pregnancy	5.05	0.03
Pre-existing doctor diagnosed depression	9.30	0.41
Pre-existing doctor diagnosed heart disease or high blood pressure	11.46	0.25
Pre-existing doctor diagnosed diabetes mellitus	17.63	0.04
Pre-pregnancy general health status	9.97	0.35
Physical activity during the first trimester of pregnancy	0.08	0.78
Physical activity after the first trimester of pregnancy	0.01	0.93
Antenatal depression (diagnosed through EPDS questionnaires)	0.05	0.81
Type of delivery method	13.92	0.13
Parity	0.18	0.67
Had a lead maternity carer during pregnancy	0.08	0.78
District health board of maternal domicile	4.86	0.30
Residential rurality	1.73	0.19
Area-level deprivation index (NZDep2006)	0.89	0.93
Time lived in current neighbourhood	-3.29	0.00
Preference for the local lifestyle of the neighbourhood	0.02	0.88
Green space percentage in census area unit	5.68	0.77
New born variable 1 vs New born variable 2	**Test statistic (chi square or t-test)**	***p-value***
Gender	4.94	0.29
Birth weight	1.21	0.23
Gestational age	2.62	0.01

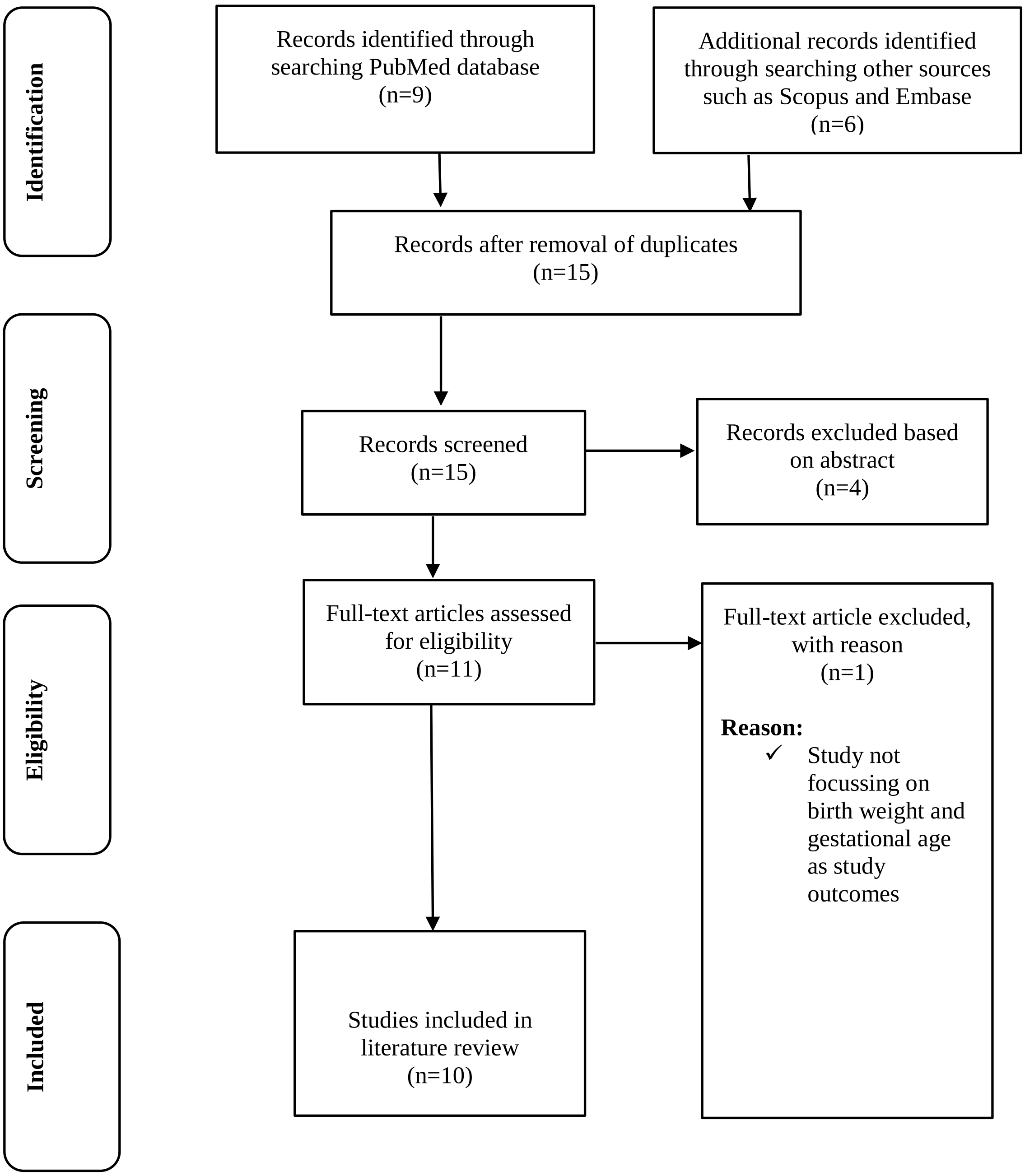
1=pregnant women interviewed before birth; 2=pregnant women interviewed after birth

Appendix 3: Criteria for selection of general population and pregnant population studies on green space and physical activity from the literature and inclusion into this thesis



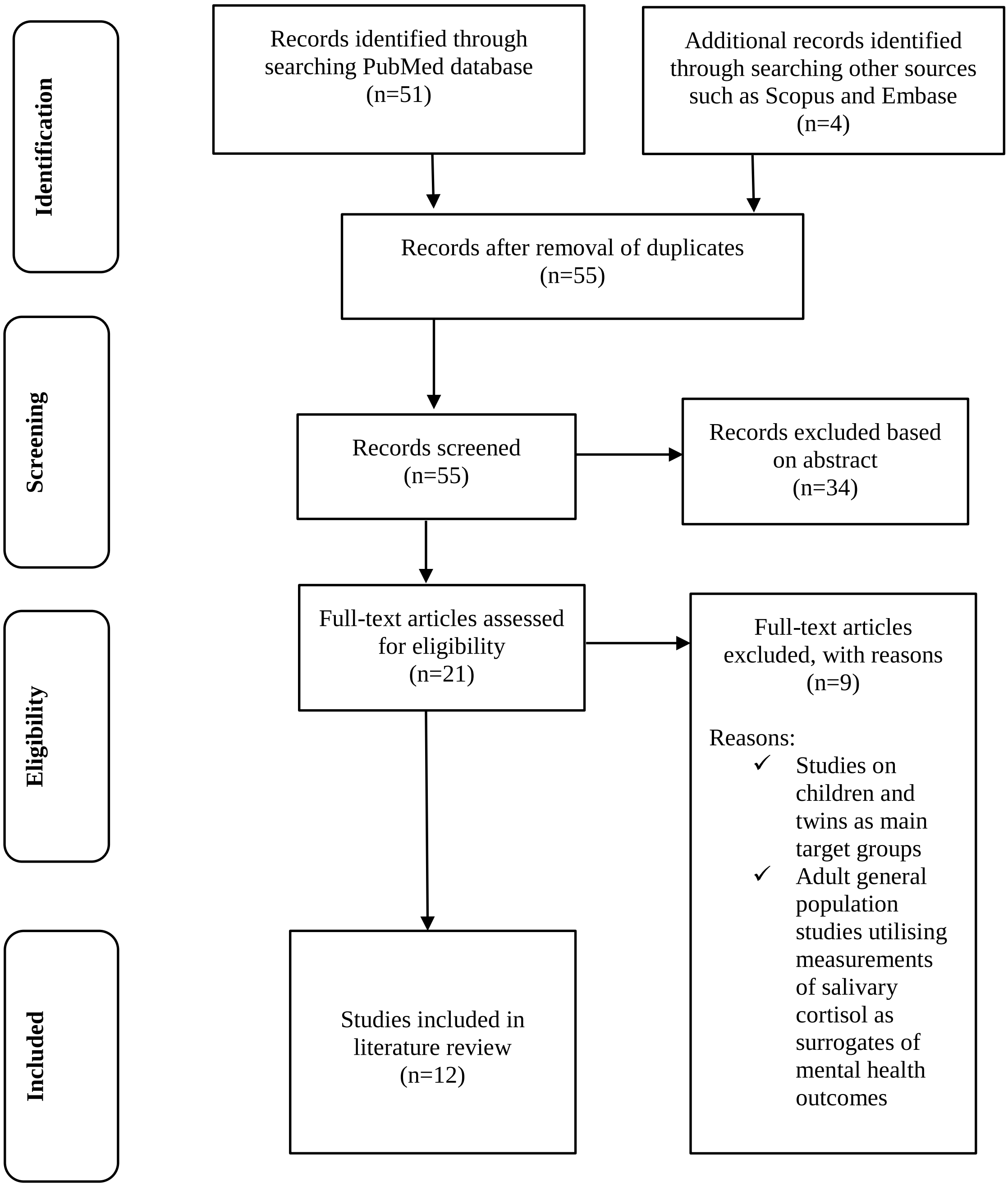
From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal. pmed1000097

Appendix 4: Criteria for selection of pregnant population studies on green space and birth weight and/or gestational age from the literature and inclusion into this thesis



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal. pmed1000097

Appendix 5: Criteria for selection of general population and pregnant population studies on green space and mental health disorders from the literature and inclusion into this thesis



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal. pmed1000097

Appendix 6: Summary of studies included in literature review in this thesis

Authors, year, country	Sample size	Age group	Assessment of green space	Dependent variables	Mediating variables	Covariates	Summary of results	Strengths of study	Limitations of study
General population studies showing associations between green space and physical activity									
Mytton et. al. 2012 England	31,409	≥16 years	Percentage of green space within a MSOA	Overall physical activity, sports, green space leisure, walking, occupational physical activity, domestic physical activity (e.g., housework, gardening and do-it-yourself)	-	Age, sex, social class, income, car ownership, ethnicity, social capital factors (e.g., vandalism, ease of access to local shops, quality of leisure facilities), and area deprivation	Participants residing in the greenest areas were more likely to meet recommendations for overall physical activity in comparison to those residing in the least green areas. Associations were significant for occupational and do-it-yourself types of physical activities	Used large sample size and objective measures of green space exposure, identified different types of physical activity, and controlled for multiple confounders in regression analyses	Cross-sectional design, self-reported measures of physical activity, lack of control for self-selection bias and lack of explanation for mechanisms of the associations between physical activity and exposure to green space
Richardson et al. 2013 New Zealand	8,157	≥15 years	Percentage of green space within a CAU	Obesity, poor general health, poor mental health, cardiovascular disease	Weekly duration of moderate and vigorous physical activity	Age, sex, and smoking	Exposure to green space was associated with lowered risks of poor mental health and cardiovascular disease. Additionally, participants	Included different types of green spaces in classification of green spaces, covariates were obtained through a	Did not evaluate other mediating mechanisms (e.g., stress reduction and social support), and could not control for

							residing in the greener areas were more likely to be physically active in comparison to those residing in the least green areas	national survey, and use of multi-level modelling to determine associations of green space exposure with health outcomes	area-level deprivation and self-selection bias in regression models
Astell-Burt et al. 2014 Australia	203,883	≥45 years	Percentage of green space within a buffer of 1 km around the PWC of a CCD	Time consumed in walking, moderate physical activity, and vigorous physical activity	-	Age, gender, annual household income, employment status, couple status, mental health status, ethnicity, country of birth, language spoken at home, time spend outdoors, social interactions, local affluence and geographical remoteness	Participants residing in greener areas were more likely to participate in walking, moderate, and vigorous physical activity in comparison to participants residing in the least green areas	Utilised large sample size, objective measures of green space exposure, and valid and reliable instrument for measuring physical activity	Low response rate of 18%, cross-sectional design, recall period of 1 week for measuring physical activity, and lack of control for self-selection bias
Astell-Burt et al. 2014 Australia	246,920	45-106 years	Percentage of green space within a buffer of 1 km around the PWC of a CCD	BMI	Moderate physical activity, vigorous physical activity, and sedentary behaviour	Age, weekly sessions of moderate to vigorous physical activity, daily sitting time, consumption of fruits/vegetable/ red meat/cheese, annual household income, education, employment status, psychological	Women residing in the greenest areas were less likely to be overweight and obese than those residing in the least green areas. Additionally, higher participation in moderate and vigorous physical	Utilised objective measures of green space exposure, a validated measure of BMI, and included moderate physical activity, vigorous	Cross-sectional design, lack of data on types and quality of green space and lack of control for self-selection bias in regression analyses

						distress, ethnicity, country of birth, language spoken at home, alcohol consumption, smoking status, sleep duration, social interactions, local affluence and geographical remoteness	activity and lower sedentary behaviour was seen in men and women who were residents of the greenest areas in comparison to residents of the least green areas	physical activity, and sedentary behaviour as mediators in regression analyses	
McMorris et al. 2015 Canada	69,910	≥20 years	NDVI within circular buffers of 500 m around centroids of post codes of the study participants	Level of physical activity for a usual day, participation in leisure time physical activity, monthly frequency of physical activity with each session of physical activity of at least 15 minutes duration, overall frequency of physical activity, daily energy expenditure, and physical activity index	-	Age, sex, income adequacy, smoking status, and marital status	Participants living in the greener areas were more likely to meet recommendations for leisure time physical activity than those living in the least green areas. The associations for leisure time physical activity were evident in all income groups. Additionally, the association of greenness with monthly frequency of physical activity was statistically significant	Used multiple measures of physical activity and tested for effect modification based on income of the study participants	Utilised self-reported measurements of physical activity and did not account for self-selection bias

General population studies not showing associations between green space and physical activity									
Witten et al. 2008 New Zealand	12,529	≥15 years	Access to nearest park and beach by measuring travel times to nearest park and beach	BMI, sedentary and non-sedentary behaviours	-	Age, sex, number of respondents in the mesh block, ethnicity, number of adults in the household, education, social class, receipt of benefits, employment status, household income, residential rurality, and area-level deprivation	Access to parks was not associated with BMI, sedentary behaviour, and physical activity. Conversely, access to beach was weakly associated with BMI and physical activity	Used national data for measurements of physical activity, park access, and beach access, and controlled for personal-level and area-level covariates in regression analyses	Lack of consideration of different types of physical activity (e.g., leisure, transport, or sports)
Maas et al. 2008 Netherlands	4,899	≥12 years	Percentage of land area covered by green space within buffers of 1 km and 3 km radii around residences of the study participants	General health status	Physical activity and specific types of physical activities (e.g., walking, bicycling, gardening, and sports)	Age, gender, education, income and urbanity	Exposure to green space was hardly related to physical activity and the relationship between green space and general health could not be explained on basis of physical activity in green space	Utilised objective measures of green space exposure, health and green space data derived from different sources eliminating single source bias, and investigated whether physical activity was a mediator of the association between green space and general health	Cross-sectional design, lack of data on use of green spaces by the study participants, and lack of control for density of sports facilities, dog ownership, and self-selection bias in regression analyses

Ord et al. 2013 Scotland	3,679	≥16 years	Percentage of green space in a CAS	Overall physical activity, walking, and green physical activity	-	Age, sex, and household income	Exposure to green space was not associated with participation in overall physical activity, walking, and physical activity occurring specifically in green space	Used large sample size, objective measures of green space exposure, and determined green physical activity	Lack of inclusion of green space quality, neighbourhood safety, neighbourhood density, and self-selection bias in regression modelling
Pregnant population study showing association between green space and physical activity									
McEachan et al. 2015 UK	7,547	<21 to ≥35 years	NDVI in buffers of 100 m, 300 m, and 500 m around maternal addresses, and access to nearest green space by measuring Euclidean distance	Depression	Physical activity	Age, parity, ethno-language grouping, marital status, education, financial status, household size, index of multiple deprivation, smoking, alcohol consumption, and physical activity	Participants living in the greener areas or within 300 m of major green spaces were independently less likely to report depression in comparison to those living in the least green areas or living further away from green spaces. Additionally, the	Utilised large size sample, objective measures of green space exposure, tested for mediating effect of physical activity, and controlled for multitude of covariates	Lack of inclusion of green space quality and residential mobility in regression modelling, and did not measure distance to nearest green space through road network

							associations were robust for physically active or those with low educational qualifications. Physical activity was thought to partially mediate the association between exposure to green space and depression		
Pregnant population studies showing associations between green space and birth weight and/or gestational age									
Dadvand et al. 2012 Spain	8,246	Mean age=30 years	NDVI within buffers of 100 m around the residences of the study participants and presence of residential addresses within buffers of 500 m of a major green space	Birth weight and gestational age	-	Gestational age, area-level socioeconomic status, residential rurality, distance to major roads, maternal weight, ethnicity, education, occupation, smoking, alcohol consumption, parity, history of gynaecology and obstetrics diseases, diabetes mellitus, assisted reproduction techniques, and infant sex	Exposure to green space was not associated with birth weight or gestational age for the entire cohort. Conversely, exposure to green space was associated with birth weight for population subgroups not acquiring any level of education	Used objective measures of green space exposure and adjusted for large number of covariates in regression analyses	Did not control for household income, paternal occupation and education, and residential mobility in the regression analyses
Dadvand et al. 2012 Spain	2,393	≥16 years	NDVI in buffers of 100 m, 250 m,	Birth weight, gestational age,	-	Maternal age, ethnicity, education,	Exposure to green space was associated with	Used health and green space data	Did not control for area-level

			and 500 m around the residences of the study participants	and head circumference		smoking, alcohol consumption, parity, infant sex, season of conception, gestational age, maternal BMI, weight gain during pregnancy, socioeconomic status, and paternal BMI	birth weight and head circumference for the entire cohort. Additionally, associations for birth weight and head circumference were stronger for pregnant women with lower educational qualifications	from two different biographic regions of Spain	socioeconomic status, residential mobility, and use of green space by the study participants in regression analyses
Laurent et al. 2013 US	81,186	<20 to ≥40 years	NDVI within buffers of 50 m, 100 m, and 150 m around the residences of the study participants	Birth weight, preterm birth, and preeclampsia	Air pollution	Maternal age, ethnicity, insurance status, parity, pyelonephritis, and diabetes mellitus, poverty, infant's gender, and gestational age	Exposure to green space was associated with increased term birth weight and lowered risk of preterm birth for the entire cohort. Additionally, air pollution was not a mediator of the association between green space exposure and term birth weight and preterm birth	Utilised objective measures of green space exposure	Could not control for maternal smoking and BMI in regression analyses

Dadvand et al. 2014 UK	10,780	<20 to >40 years	NDVI in buffers of 50 m, 100 m, 250 m, 500 m, or 1000 m around the residences of the study participants and living within 300 m of a major green space	Birth weight	-	Gestational age, BMI, active smoking, passive smoking, parity, alcohol consumption, conception year, conception season, education, area-level deprivation, ethnicity, and maternal age	Exposure to green space was associated with birth weight for the entire cohort. Additionally, associations for birth weight were stronger for pregnant women describing their ethnicity as 'White British' or those residing in most deprived areas	Investigated effect modifications for birth weight based on ethnicity and socioeconomic status of the cohort participants	Did not control for self-selection bias, use of green space and green space quality in regression modelling
Hystad et al. 2014 Canada	64,705	≤19 to ≥40 years	NDVI in buffers of 100 m around the residences of the study participants	Birth weight, moderately preterm birth, very preterm birth, and small for gestational age	Air pollution, noise pollution, neighbourhood walkability, and park proximity	Infant sex, gestational age, month and year of birth of infant, first nations status, parity, smoking, education, income, and maternal age	Exposure to green space was associated with birth weight and risk of moderately preterm birth for the entire cohort. Results for birth weight and moderately preterm birth did not change after adjustment of mediators	Adjustment for large number of covariates in regression modelling	Did not control for maternal diabetes and residential mobility in regression modelling

Markevych et al. 2014 Germany	3,203	Mean age=32 years	NDVI in buffers of 100 m, 250 m, 500 m, or 800 m and amount of neighbourhood green spaces in buffers of 500 m around the residences of the study participants	Birth weight	Air pollution, noise pollution, distance to major roads, and population density	Year of birth, season of birth, infant sex, maternal age, education, and smoking during pregnancy	Exposure to green space was associated with birth weight for the entire cohort. Additionally, associations for birth weight were stronger for pregnant women with lower educational qualifications. Associations between green space and birth weight were mostly strong after adjustment of mediators	Utilised large sample size, controlled for covariates in regression modelling, and performed sensitivity analyses	Did not account for self-selection bias and area-level socioeconomic status, and could not determine the mediating mechanisms underlining green space-birth weight associations
Agay-Shay et al. 2015 Israel	39,132	<20 to ≤41 years	NDVI within a buffer of 250 m around street center point of each maternal address and access to green space defined as presence of residential address within 300 m of a major green space	Birth weight, gestational age, low birth weight, very low birth weight, preterm birth, and very preterm birth	Air pollution	Maternal birth place, marital status, season of conception, maternal age, year of infant birth, ward-based socioeconomic status, gestational age, infant sex, and infant religion	Exposure to green space was associated with birth weight and low birth weight for the entire cohort. Additionally, associations for birth weight and low birth weight were stronger for pregnant women living in most deprived areas	Information on birth was obtained from birth certificates; thereby, reducing the likelihood of selection bias	Did not control for confounders such as maternal health status, smoking, alcohol intake during pregnancy, and self-selection bias in regression analyses

Grazuleviciene et al. 2015 Lithuania	3,292	20-45 years	NDVI within buffers of 100 m, 300 m, and 500 m around residences of the study participants and access to green space defined as Euclidean distance from maternal address to the nearest park	Birth weight, low birth weight, term low birth weight, gestational age, preterm birth, and small for gestational age	-	Marital status, height, education, smoking, blood pressure, BMI, parity, chronic diseases such as diabetes and stress, history of preterm birth, alcohol consumption, infant sex, gestational age, paternal height, and paternal smoking	Increased distance to green space was associated with decreased gestational age and increased risk of preterm birth. Exposure to lower surrounding greenness was associated with lower term birth weight. Additionally, increased distance to green space and lower surrounding greenness were associated with low birth weight, term low birth weight, and preterm birth	Controlled for multitude of covariates in regression modelling, including self-selection bias	Lack of any data on use of green spaces by the study participants
Casey et al. 2016 US	12,821	Not mentioned	NDVI within buffers of 250 m and 1250 m around residences of the study participants who lived in cities, towns, or boroughs	Birth weight, small for gestational age, preterm birth, and 5-minute Apgar score	-	Year and season of birth, infant sex, gestational age, maternal age, ethnicity, primary care patient status, smoking, pre-pregnancy BMI, parity, antibiotics treatment during pregnancy, receipt of medical assistance, delivery	Exposure to green space was associated with lowered risks of preterm birth and small for gestational age for pregnant women residing in cities. No such associations were seen for pregnant women residing	Controlled for large number of confounders in regression analyses	Did not control for indicators of personal-level socioeconomic status such as maternal occupation, income, and education and residential mobility in

						at hospital, source of drinking water, distance to nearest major road, proximity to swine livestock operations, number of unconventional natural gas wells within 20 km, community socioeconomic deprivation, and community walkability	in boroughs or townships		regression modelling
Ebisu et al. 2016 US	239,811	<20 to ≥40 years	Proportion of land covered by green space, urban space, and urban open space in buffers of 250 m around the residences of the study participants	Birth weight, low birth weight, and small for gestational age	$PM_{2.5}$, and traffic density	Infant sex, gestational age, maternal age, ethnicity, education, marital status, trimester care, alcohol consumption, smoking during pregnancy, birth order, birth season, birth year, area-level socioeconomic status, and average temperature during each trimester of pregnancy	Exposure to green space was associated with higher birth weight and a lower risk of low birth weight for the entire cohort. Associations for birth weight were slightly weakened, but stronger for low birth weight after inclusion of mediators in regression models	First study that has demonstrated associations between exposure to green space and pregnancy outcomes in the Eastern US	Did not control for residential mobility in regression modelling

General population studies showing associations between green space and mental health disorders									
Maas et al. 2009 Netherlands	345,143	≤12 to >65 years	Proportion of green space within 1 km and 3 km radii around the postal code coordinates of the study participants	Morbidity outcomes (cardiovascular, musculo-skeletal, mental, respiratory, neurological, digestive, and miscellaneous)	-	Age, gender, education, health insurance, employment status, and urbanity	Exposure to green space within 1 km and 3 km radii for the entire cohort was associated with morbidity outcomes, though strongest associations were seen for depression and anxiety disorder. Additionally, effect modifications were seen for some of morbidity outcomes in children and those with low levels of education	First study that has investigated the relationship between green space and morbidity outcomes, and collected accurate morbidity data from electronic medical records within Dutch practices in the Netherlands. Additionally, it accounted for self-selection bias	Did not control for income and area-level socioeconomic status in regression modelling. Additionally, small-sized green spaces such as gardens, street trees, and green verges were not included in classification of green spaces

Astell-Burt et al. 2013 Australia	260,061	45-106 years	Percentage of land area covered by green space within buffers of 1 km radius around residences of the study participants	Psychological distress	Physical activity	Age, gender, ancestry, country of birth, language spoken at home, annual household income, highest educational qualification, employment, couple status, smoking, alcohol consumption, BMI, social interactions, history of falls within last 12 months, and neighbourhood affluence	Participants living in the greenest areas who were physically active were less likely to develop psychological distress in comparison to physically active participants living in the least green areas	Utilised large sample size; objective measures of green space exposure, physical activity, and social interactions; and a validated measure of mental health	Did not account for use of green spaces by the study participants and self-selection bias
Nutsford et al. 2013 New Zealand	7,552	≥15 years	Proportion of land area covered by useable and total green space within buffers of 300 m and 3 km of population-weighted mesh block centroids and distances from centroids to nearest useable and total green space	Anxiety/mood disorder treatment count	-	Area deprivation	Exposure to green space in terms of decreased distance to useable green space and proportion of land covered by useable and total green space within broader environment was associated with better mental health	Used objectively measured mental health construct, and determined role of useable green space in improving mental health	Did not include private gardens in the classification of green spaces and did not control for length of stay at the current residence, gender, and ethnicity in regression analyses

Mitchell et al. 2013 Scotland	1,890	≥16 years	Proportion of land covered by green space within a CAS ward	The 12-Item GHQ Score (used to measure minor psychiatric morbidity) and WEMWBS Score (used to measure well-being)	-	Age, sex, equalised household income, average hours of physical activity per week, residential rurality, and quantity of green space in residential neighbourhood	Participants utilising parks and forests for physical activity at least once a week were less likely to develop minor psychiatric morbidity in comparison to participants not using parks and forests for physical activity. Additionally, use of parks for less than once a week, sports pitches for at least once a week, and gymnasiums for at least once a week were significantly associated with better well-being	Utilised large sample size and objective measures of mental health and well-being. Additionally, all types of environments were included into analyses (e.g., green and non-green environments)	Did not control for duration of physical activity and self-selection bias in regression modelling
Beyer et al. 2014 US	2,479	21-74 years	NDVI within a census block group, or percent tree canopy coverage, or NDVI and percent tree canopy within a census block group	DASS	-	Age, gender, ethnicity, marital status, education, annual household income, occupational status, type of residence, type of health insurance, residential rurality, population density,	Exposure to green space within each census block group was associated with decreased depression, anxiety, and stress	Used population-based sample, objective measures of green space exposure, and validated measures of mental health constructs. Controlled for	Did not acquire data on mental health and green space indicators in the same year

						and socioeconomic status		range of covariates in regression modelling, including residential mobility	
Astell-Burt et al. 2014 UK	65,407	≥15 years	Proportion of land covered by green space within a ward	Minor psychiatric morbidity	-	Age, gender, household income, employment status, marital status, education, household tenure, and smoking	The association of green space with mental health differed across the life course for men and women. In men, the association of green space with mental health appeared in early to mid-adulthood that persisted till age of 60 years. In women, the association of green space with mental health appeared in mid-adulthood and persisted till old age	Measured the association of green space with mental health across life course of the study participants and controlled for residential mobility in the regression analyses	Did not determine mediating mechanisms (e.g., physical activity and social contacts) underlying the associations between green space and minor psychiatric morbidity
Alcock et al. 2014 England	1,064	≥16 years	Proportion of land covered by green space within a LSOA for people moving from less green to	The 12-Item GHQ score (used to measure mental health)	-	Income deprivation, employment deprivation, education deprivation, crime rate index, age, education, marital status, living with	People moving from less green to greener areas had better mental health after moving in comparison to their mental health before	Measured the association of green space with mental health for people moving from less green to	Did not control for stress and stress reducing life events in regression modelling. Additionally, mediators of

			greener areas and vice versa			children, household income, work-limiting illness, labour market status, residence type, and commuting time	moving. Conversely, people moving from greener to less green areas showed no change in mental health following move in comparison to their mental health before moving	greener areas and vice versa	the association between exposure to green space and mental health were not examined
Bos et al. 2016 Netherlands	4,924	18-87 years	Proportion of land covered by green space within buffers of 1 km and 3 km radii around 4-digit postal code centroid of home addresses	DASS and MANSA	-	Age, gender, education, partner status, employment status, birth place, and income	Exposure to green space was associated with better mental health for certain age and gender subgroups. Moderating effects of age and gender could be explained based on differential use of green spaces by different age and gender subgroups	Used personal-level data on income, and validated measures of mental health	Cross-sectional design, green space exposure mis-classification, lack of diverse socio-demographic sample and lack of control for self-selection bias
Magdalena van den Berg et al. 2016 Europe	3,748	18-75 years	Total duration of visits to green space (expressed in hours/month)	Perceived mental health and vitality	-	Age, gender, education, income, employment and household with and without children aged <12 years	Exposure to green space was associated with better perceived mental health and vitality. Additionally, the association between visits to green space and	Utilised large sample size and controlled for variety of confounders in regression analyses	Used self-reported measures of access to green space, perceived mental health and vitality and did not control for

							perceived mental health was stronger for participants with little childhood nature experience in comparison to participants with high childhood nature experience. On the other hand, participants with low level of education had higher vitality scores in comparison to participants with medium or high levels of education		self-selection bias
General population studies not showing associations between green space and mental health disorders									
Annerstedt et al. 2012 Sweden	9,230	18-80 years	Amount and access to green space qualities (Serenity, Space, Wild, Culture, and Lush)	The 12-Item GHQ score (used to measure poor mental health)	Financial stress, living conditions, and physical activity	Age, gender, economy, marital status, ethnicity, and education	In men and women, the associations of green space qualities with mental health were not significant with respect to quantity or access. Conversely, women who were physically active and had access to	Utilised large sample size and objective measures of green space exposure, and controlled for variety of confounders in regression analyses	Used non-validated measures of physical activity and stress as mediators

							Serenity or Space had a lower risk of poor mental health in comparison to women who were physically inactive		
Nutsford et al. 2016 New Zealand	442	≥15 years	VVI (used to measure degrees of visibility for green and blue spaces)	Psychological distress	-	Age, sex, personal income, neighbourhood population density, housing quality, crime, and area deprivation	Green space visibility was not associated with psychological distress. Conversely, blue space visibility was associated with psychological distress.	Used quantitative measurements of visibility of blue and green spaces, and separately accessed the effects of green and blue spaces on psychological distress	Lack of inclusion of private gardens in classification of green spaces and lack of control for length of residence in the neighbourhood in regression analyses
Gascon et al. 2015, a systematic review which included European and non-European studies	100 to 345,143	3-10 years and 12-84 years	Percentege land covered by green space in buffers of 300 m to 3 km or CAU NDVI in buffers of 100 m to 800 m around residences of the study participants or in CAU	Emotional and behavioural problems in children. In adults, mental health was assessed in general by measuring general mental health status and specifically by measuring presence of anxiety, stress, depression, or mood disorders	-	Different confounders for different studies included in the systematic review	In adults, there was limited evidence of the associations between exposure to green space and mental health outcomes. For children, there was inadequate evidence of the associations between exposure (access and exposure to green spaces,	Objective measurements of exposure and outcome variables	The review included limited number of mental health studies which measured exposure variables in different ways

			Access to green space Amount of blue spaces in buffers of 1 km and 3 km or estimating whether participants lived within 5 km of coastal margins				quality of green spaces, and exposure and access to blue spaces) and outcome variables. Similarly, in adults, there was inadequate evidence of the associations between other exposures of interest (access to green spaces, quality of green spaces, and exposure and access to blue spaces) and outcome variables.		

Appendix 7: Bivariate analyses for associations of green space with physical activity, birth weight, gestational age, and depression

Maternal variables	Test statistic 1 (*p-value*)	Test statistic 2 (*p-value*)	Test statistic 3 (*p-value*)	Test statistic 4 (*p-value*)	Test statistic 5 (*p-value*)
Age	6.90 (0.23)	5.60 (0.35)	3.02 (0.01)	12.13 (0.00)	147.30 (0.00)
Self-identified ethnicity	85.48 (0.00)	27.68 (0.00)	59.43 (0.00)	2.45 (0.03)	202.76 (0.00)
Education	23.74 (0.00)	4.11 (0.39)	1.13 (0.34)	0.80 (0.52)	123.47 (0.00)
Employment status	14.33 (0.00)	11.40 (0.01)	6.57 (0.00)	1.01 (0.39)	93.83 (0.00)
Birth place	56.94 (0.00)	18.51 (0.01)	25.54 (0.00)	2.41 (0.03)	60.51 (0.00)
Relationship with biological father	43.63 (0.00)	29.52 (0.00)	1.80 (0.15)	1.04 (0.37)	115.04 (0.00)
Alcohol consumption during pregnancy	32.03 (0.00)	2.81 (0.09)	0.25 (0.61)	7.82 (0.01)	9.12 (0.00)
Cigarette smoker during pregnancy	10.99 (0.00)	15.99 (0.00)	51.97 (0.00)	5.61 (0.02)	101.53 (0.00)
Pre-existing doctor diagnosed depression	9.12 (0.03)	4.46 (0.22)	4.43 (0.00)	9.69 (0.00)	224.34 (0.00)
Pre-existing doctor diagnosed heart disease or high blood pressure	2.22 (0.53)	0.97 (0.81)	9.17 (0.00)	22.80 (0.00)	18.52 (0.00)
Pre-existing doctor diagnosed diabetes mellitus	4.83 (0.19)	11.55 (0.01)	4.73 (0.00)	44.54 (0.00)	21.38 (0.00)
Pre-pregnancy general health status	53.12 (0.00)	32.28 (0.00)	1.36 (0.25)	1.63 (0.18)	168.79 (0.00)
Physical activity during the first trimester of pregnancy	-	1900 (0.00)	0.23 (0.63)	0.42 (0.52)	2.91 (0.09)
Physical activity after the first trimester of pregnancy	1900 (0.00)	-	0.96 (0.33)	2.32 (0.13)	0.64 (0.42)
Antenatal depression (diagnosed through EPDS questionnaires)	2.91 (0.09)	0.64 (0.42)	2.13 (0.15)	9.89 (0.00)	-

Type of delivery method	1.19 (0.76)	7.20 (0.07)	5.10 (0.00)	65.23 (0.00)	6.53 (0.09)
Parity	4.50 (0.03)	3.58 (0.06)	111.33 (0.00)	16.96 (0.00)	0.68 (0.41)
Had a lead maternity carer during pregnancy	0.03 (0.86)	0.0630 (0.80)	2.20 (0.14)	0.11 (0.74)	18.05 (0.00)
District health board of maternal domicile	24.46 (0.00)	12.25 (0.002)	9.84 (0.00)	2.21 (0.11)	53.70 (0.00)
Residential rurality	20.95 (0.00)	9.3233 (0.00)	1.46 (0.23)	1.66 (0.20)	3.52 (0.06)
Area-level deprivation index (NZDep2006)	0.73 (0.70)	0.8685 (0.65)	0.28 (0.76)	1.17 (0.31)	90.83 (0.00)
Time lived in current neighbourhood	1.15 (0.09)	0.93 (0.74)	1.11 (0.17)	1.30 (0.01)	1.00 (0.50)
Preference for the local lifestyle of the neighbourhood	2.91 (0.09)	5.32 (0.021)	0.79 (0.38)	0.03 (0.86)	26.81 (0.00)
Green space percentage in census area unit (categorical)	13.00 (0.01)	8.06 (0.05)	4.43 (0.00)	0.51 (0.68)	6.87 (0.08)
Green space percentage in census area unit (continuous)	20.30 (0.00)	7.76 (0.01)	0.02 (0.90)	0.84 (0.36)	0.77 (0.38)
New born variables					
Gender	1.73 (0.42)	4.34 (0.11)	53.09 (0.00)	3.59 (0.06)	0.44 (0.80)
Birth weight	0.56 (0.45)	1.80 (0.18)	-	1229.63 (0.00)	0.25 (0.61)
Gestational age	0.11 (0.74)	0.27 (0.60)	1229.63 (0.00)	-	0.16 (0.69)

Test statistic 1 (chi square or F-test)=bivariate analyses for the association of green space with physical activity during the first trimester of pregnancy

Test statistic 2 (chi square or F-test)=bivariate analyses for the association of green space with physical activity after the first trimester of pregnancy

Test statistic 3 (chi square or F-test)=bivariate analyses for the association of green space with birth weight

Test statistic 4 (chi square or F-test)=bivariate analyses for the association of green space with gestational age

Test statistic 5 (chi square or F-test)=bivariate analyses for the association of green space with depression

Appendix 8: Multilevel logistic regression analyses for associations between green space and physical activity for pregnant women during the first trimester and the remainder of pregnancy

Associations of green space with meeting recommendations for frequency and duration of moderate or vigorous physical activity (n=6772)				
Variables	**Model 1[a]**	**Model 2[b]**	**Model 3[c]**	**Model 4[d]**
Whether recommendations were met for moderate or vigorous physical activity during the first trimester of pregnancy[1]				
Green space percentage in census area unit	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Low	1.00	1.00	1.00	1.00
Medium	0.98 (0.84-1.15)	0.94 (0.80-1.11)	0.94 (0.79-1.10)	0.94 (0.79-1.10)
High	1.06 (0.90-1.24)	1.02 (0.87-1.19)	1.02 (0.87-1.20)	1.02 (0.87-1.20)
Very high	1.19 (1.01-1.40)	1.17 (0.99-1.38)	1.18 (0.99-1.39)	1.16 (0.98-1.37)
Age groups		OR (95% CI)	OR (95% CI)	OR (95% CI)
<20		1.00	1.00	1.00
20-24		0.94 (0.71-1.26)	0.95 (0.71-1.26)	0.94 (0.71-1.25)
25-29		0.94 (0.71-1.24)	0.94 (0.71-1.24)	0.93 (0.70-1.23)
30-34		0.85 (0.64-1.13)	0.86 (0.65-1.14)	0.84 (0.64-1.12)
35-39		0.81 (0.60-1.08)	0.81 (0.60-1.08)	0.79 (0.60-1.07)
≥40		0.82 (0.56-1.20)	0.82 (0.56-1.21)	0.81 (0.55-1.20)
Self-identified ethnicity		OR (95% CI)	OR (95% CI)	OR (95% CI)
European		1.00	1.00	1.00
Māori		1.68 (1.42-1.99)	1.67 (1.40-1.99)	1.67 (1.40-1.99)
Pacific		1.08 (0.90-1.30)	1.07 (0.88-1.31)	1.08 (0.89-1.31)
Asian		0.66 (0.55-0.79)	0.66 (0.55-0.79)	0.67 (0.55-0.80)
Middle Eastern/Latin American/African		0.92 (0.62-1.35)	0.91 (0.62-1.35)	0.89 (0.60-1.33)
Other or New Zealander		1.71 (1.11-2.62)	1.70 (1.11-2.62)	1.73 (1.12-2.67)

Education		OR (95% CI)	OR (95% CI)	OR (95% CI)
No secondary school		1.00	1.00	1.00
Secondary school		1.39 (1.08-1.79)	1.39 (1.08-1.79)	1.39 (1.08-1.79)
Diploma		1.66 (1.29-2.13)	1.66 (1.30-2.14)	1.65 (1.29-2.13)
Bachelor's		1.41 (1.07-1.85)	1.41 (1.07-1.85)	1.39 (1.06-1.83)
Higher degree		1.29 (0.97-1.72)	1.30 (0.97-1.73)	1.28 (0.96-1.72)
Employment status		OR (95% CI)	OR (95% CI)	OR (95% CI)
Employed		1.00	1.00	1.00
Unemployed		0.92 (0.75-1.14)	0.92 (0.75-1.14)	0.93 (0.75-1.14)
Student		1.06 (0.86-1.31)	1.06 (0.86-1.31)	1.06 (0.86-1.31)
Not in work force		0.80 (0.70-0.91)	0.79 (0.70-0.91)	0.80 (0.70-0.91)
Area deprivation			OR (95% CI)	OR (95% CI)
Low (decile 1-3)			1.00	1.00
Medium (decile 4-7)			1.03 (0.89-1.20)	1.04 (0.90-1.21)
High (decile 8-10)			1.03 (0.88-1.22)	1.05 (0.89-1.24)
Preference for the local lifestyle of the neighbourhood				OR (95% CI)
No				1.00
Yes				1.09 (0.96-1.24)
Whether recommendations were met for moderate or vigorous physical activity after the first trimester of pregnancy[1]				
Green space percentage in census area unit	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Low	1.00	1.00	1.00	1.00
Medium	0.87 (0.73-1.04)	0.85 (0.72-1.02)	0.85 (0.72-1.02)	0.85 (0.72-1.02)
High	0.99 (0.84-1.18)	0.98 (0.83-1.16)	0.98 (0.83-1.16)	0.98 (0.83-1.17)
Very high	1.08 (0.90-1.28)	1.06 (0.89-1.26)	1.07 (0.89-1.27)	1.04 (0.88-1.24)

Age groups	OR (95% CI)	OR (95% CI)	OR (95% CI)
<20	1.00	1.00	1.00
20-24	0.96 (0.71-1.30)	0.96 (0.70-1.30)	0.95 (0.70-1.30)
25-29	0.82 (0.61-1.11)	0.82 (0.61-1.11)	0.81 (0.60-1.09)
30-34	0.81 (0.60-1.10)	0.81 (0.60-1.10)	0.79 (0.58-1.08)
35-39	0.76 (0.56-1.04)	0.76 (0.56-1.04)	0.74 (0.54-1.02)
≥40	0.73 (0.48-1.12)	0.73 (0.48-1.12)	0.72 (0.47-1.09)
Self-identified ethnicity	OR (95% CI)	OR (95% CI)	OR (95% CI)
European	1.00	1.00	1.00
Māori	1.30 (1.08-1.56)	1.28 (1.06-1.55)	1.27 (1.05-1.54)
Pacific	0.90 (0.73-1.11)	0.88 (0.71-1.09)	0.88 (0.71-1.10)
Asian	0.81 (0.66-0.98)	0.81 (0.66-0.98)	0.82 (0.67-0.99)
Middle Eastern/Latin American/African	0.91 (0.59-1.39)	0.90 (0.59-1.38)	0.92 (0.60-1.41)
Other or New Zealander	1.68 (1.07-2.63)	1.67 (1.07-2.62)	1.70 (1.08-2.67)
Education	OR (95% CI)	OR (95% CI)	OR (95% CI)
No secondary school	1.00	1.00	1.00
Secondary school	1.14 (0.87-1.50)	1.15 (0.87-1.50)	1.13 (0.86-1.50)
Diploma	1.30 (0.99-1.70)	1.31 (0.99-1.71)	1.30 (0.99-1.70)
Bachelor’s	1.23 (0.92-1.65)	1.25 (0.93-1.67)	1.23 (0.92-1.66)
Higher degree	1.31 (0.97-1.79)	1.33 (0.98-1.81)	1.31 (0.96-1.79)
Employment status	OR (95% CI)	OR (95% CI)	OR (95% CI)
Employed	1.00	1.00	1.00
Unemployed	1.02 (0.82-1.28)	1.01 (0.81-1.27)	1.02 (0.81-1.28)
Student	1.13 (0.91-1.42)	1.13 (0.90-1.42)	1.14 (0.91-1.43)
Not in work force	0.84 (0.73-0.97)	0.84 (0.72-0.97)	0.84 (0.72-0.97)
Area deprivation		OR (95% CI)	OR (95% CI)
Low (decile 1-3)		1.00	1.00
Medium (decile 4-7)		0.95 (0.81-1.11)	0.97 (0.82-1.13)
High (decile 8-10)		1.04 (0.88-1.24)	1.08 (0.90-1.29)

Preference for the local lifestyle of the neighbourhood	OR (95% CI)
No	1.00
Yes	1.14 (1.00-1.31)

a=unadjusted univariate (VPC for physical activity during the first trimester=0.004 and VPC for physical activity after the first trimester=0.002)

b=a + adjustment for age, ethnicity, education, and employment status (VPC for physical activity during the first trimester=0.002 and VPC for physical activity after the first trimester=0.0001)

c=b + adjustment for NZDep2006 (VPC for physical activity during the first trimester=0.002 and VPC for physical activity after the first trimester=0.0003)

d=c + adjustment for preference for the local lifestyle of the neighbourhood (VPC for physical activity during the first trimester=0.002 and VPC for physical activity after the first trimester=0.0003)

1=Moderate physical activity for 150 minutes per week or vigorous physical activity for 60 minutes per week

Appendix 9: Multilevel regression analyses for maternal exposure to green space and birth weight (grams) for the entire cohort

	Association between maternal exposure to green space and birth weight (n=6615)				
	Model 1[a]	**Model 2[b]**	**Model 3[c]**	**Model 4[d]**	**Model 5[e]**
Green space percentage in census area unit					
Green space	13.18 (-0.07-26.43)	9.02 (-2.13-20.17)	2.61 (-8.53-13.74)	4.82 (-6.76-16.40)	5.31 (-6.26-16.88)
Gestational age		174.29 (167.64-180.94)	173.40 (166.90-179.91)	171.38 (164.56-178.19)	172.33 (165.41-179.25)
Gender					
Male		Reference	Reference	Reference	Reference
Female		-113.28 (-135.69- -90.87)	-111.60 (-133.40- -89.80)	-105.90 (-128.70- -83.10)	-106.37 (-129.17- -83.56)
Age groups					
<20			Reference	Reference	Reference
20-24			77.10 (19.63-134.55)	68.25 (8.50-128.01)	66.08 (6.28-125.89)
25-29			126.09 (70.84-181.33)	104.43 (46.80-162.05)	102.43 (44.80-160.07)
30-34			169.53 (114.69-224.37)	147.33 (90.11-204.54)	144.25 (86.98-201.52)
35-39			167.37 (110.66-224.08)	139.09 (79.75-198.41)	132.55 (73.07-192.02)
≥40			128.56 (54.73-202.40)	91.26 (12.66-169.85)	86.93 (8.14-165.72)
Self-identified ethnicity					
European			Reference	Reference	Reference
Māori			-21.79 (-56.13-12.56)	24.74 (-12.31-61.79)	23.66 (-13.52-60.85)
Pacific			141.08 (106.80-175.37)	151.69 (115.12-188.26)	146.85 (109.79-183.90)
Asian			-241.69 (-274.87- -208.51)	-252.91 (-288.48- -217.35)	-258.13 (-294.07- -222.18)
Middle Eastern/Latin American/African			-59.16 (-135.32-16.99)	-68.76 (-147.55-10.04)	-74.23 (-153.00-4.55)
Other/ New Zealander			-68.61 (-161.50-24.26)	-75.65 (-172.26-20.95)	-74.63 (-171.07-21.81)

Smoking during pregnancy		
No	Reference	Reference
Yes	-173.48 (-213.59- -133.37)	-172.34 (-212.63- -132.04)
Alcohol consumption during pregnancy		
No	Reference	Reference
Yes	-32.32 (-58.50- -6.15)	-33.41 (-59.63- -7.20)
Doctor diagnosed depression		
Never		Reference
Before this pregnancy		12.25 (-22.95-47.46)
Before and during this pregnancy		2.31 (-54.05-58.67)
Only during this pregnancy		-64.00 (-217.74-89.74)
Doctor diagnosed high blood pressure or heart disease		
Never		Reference
Before this pregnancy		-11.68 (-64.06-40.70)
Before and during this pregnancy		-99.19 (-185.93- -12.45)
Only during this pregnancy		-73.05 (-156.93-10.82)
Doctor diagnosed diabetes mellitus		
Never		Reference
Before this pregnancy		246.74 (117.09-376.38)
Before and during this pregnancy		121.82 (19.36-224.28)
Only during this pregnancy		99.17 (19.62-178.72)

Association between maternal exposure to green space and birth weight (n=6615)				
	Model 6[f]	**Model 7[g]**	**Model 8[h]**	**Model 9[i]**
Green space percentage in census area unit				
Green space	5.15 (-6.40-16.71)	4.21 (-7.13-15.55)	3.89 (-7.43-15.21)	11.73 (-2.42-25.90)
Gestational age	172.39 (165.48-179.30)	175.76 (168.84-182.69)	175.85 (168.92-182.78)	175.95 (169.01-182.89)
Gender				
Male	Reference	Reference	Reference	Reference
Female	-106.22 (-128.99- -83.44)	-104.92 (-127.50- -82.33)	-105.23 (-127.81- -82.64)	-105.34 (-127.94 - -82.75)
Age groups				
<20	Reference	Reference	Reference	Reference
20-24	66.27 (5.98-126.56)	16.54 (-44.02-77.11)	12.14 (-49.43-73.70)	16.41 (-45.35-78.17)
25-29	93.37 (33.98-152.75)	19.94 (-40.14-80.02)	14.32 (-47.89-76.52)	20.39 (-42.06-82.84)
30-34	134.58 (74.88-194.29)	43.90 (-17.05-104.84)	42.02 (-21.99-106.03)	48.02 (-16.27-112.31)
35-39	122.90 (61.15-184.65)	8.86 (-54.92-72.62)	6.65 (-60.27-73.58)	11.35 (-55.80-78.51)
≥40	80.37 (-0.026-160.77)	-27.31 (-108.85-54.22)	-31.38 (-115.18-52.41)	-27.68 (-111.71-56.35)
Self-identified ethnicity				
European	Reference	Reference	Reference	Reference
Māori	25.06 (-12.99-63.12)	1.99 (-36.06-40.05)	-1.96 (-40.34-36.42)	-2.72 (-41.83-36.40)
Pacific	141.48 (94.22-188.74)	109.45 (62.13-156.76)	108.71 (61.05-156.37)	109.32 (60.13-158.51)
Asian	-337.85 (-409.30- -226.40)	-341.35 (-412.13- -270.57)	-343.74 (-414.59- -272.90)	-344.30 (-415.40- -273.21)
Middle Eastern/Latin American/African	-66.96 (-166.66-32.74)	-81.84 (-180.15-16.46)	-89.68 (-188.19-8.83)	-95.20 (-194.09-3.70)
Other/ New Zealander	-76.72 (-173.37-19.93)	-71.46 (-167.84-24.92)	-75.62 (-171.97-20.74)	-75.24 (-171.60-21.12)

Smoking during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	-163.77 (-204.85- -122.69)	-184.92 (-226.00- -143.83)	-178.72 (-220.65- -136.79)	-177.42 (-219.41- -135.43)
Alcohol consumption during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	-30.36 (-56.76- -3.96)	-27.84 (-53.96- -1.71)	-26.50 (-52.64- -0.35)	-26.68 (-52.83- 0.52)
Doctor diagnosed depression				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	14.03 (-21.19-49.26)	5.99 (-28.93-40.90)	4.81 (-30.10-39.72)	4.80 (-30.14-39.74)
Before and during this pregnancy	7.49 (-49.10-64.09)	-0.65 (-56.94-55.65)	-1.70 (-58.10-54.70)	0.59 (-55.92-57.09)
Only during this pregnancy	-55.63 (-209.44-98.16)	-94.96 (-248.84-58.92)	-88.81 (-242.62-65.00)	-89.26 (-243.00-64.49)
Doctor diagnosed high blood pressure or heart disease				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-14.78 (-67.18-37.62)	-48.99 (-100.99-3.01)	-49.23 (-101.24-2.78)	-48.77 (-100.78-3.23)
Before and during this pregnancy	-104.66 (-191.36- -17.97)	-115.16 (-200.65- -29.66)	-112.61 (-198.04 - -27.19)	-111.52 (-197.76- -25.28)
Only during this pregnancy	-69.38 (-153.20-14.44)	-68.40 (-152.34-15.55)	-71.60 (-155.86-12.66)	-67.85 (-152.52-16.82)
Doctor diagnosed diabetes mellitus				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	248.88 (119.36-378.40)	203.15 (75.22-331.08)	200.02 (72.19-327.86)	195.18 (67.32-323.04)
Before and during this pregnancy	115.85 (13.39-218.31)	95.11 (-6.05-196.27)	98.16 (-2.97-199.28)	96.54 (-4.54-197.63)
Only during this pregnancy	99.97 (20.34-179.59)	111.16 (32.29-190.02)	111.91 (33.12-190.71)	113.41 (34.34-192.48)

Relationship status				
No relationship	Reference	Reference	Reference	Reference
Dating, but not cohabiting	110.55 (6.26-214.84)	117.69 (12.25-223.13)	107.16 (0.85-213.46)	109.10 (2.41-215.78)
Cohabiting	106.17 (17.15-195.20)	103.76 (13.07-194.45)	92.44 (0.84-184.04)	97.12 (4.98-189.26)
Married or civil union	125.60 (35.50-215.71)	105.66 (13.84-197.49)	94.41 (1.64-187.19)	99.03 (5.68-192.38)
Birth place				
New Zealand	Reference	Reference	Reference	Reference
Australia	42.88 (-43.70-129.47)	38.65 (-47.49-124.80)	31.38 (-54.76-117.52)	32.01 (-54.14-118.15)
Other Oceania	4.95 (-49.55-59.45)	15.31 (-38.87-69.49)	15.41 (-39.08-69.90)	18.64 (-36.42-73.70)
Asia	90.87 (14.73-167.01)	104.66 (29.20-180.11)	110.43 (34.66-186.20)	113.02 (37.01-189.03)
Europe	-32.69 (-79.77-14.40)	-18.98 (-65.51-27.55)	-16.76 (-63.55-30.02)	-16.86 (-63.78-30.07)
Africa	-34.70 (-111.57-42.17)	-39.59 (-115.39-36.21)	-40.53 (-116.26-35.20)	-41.36 (-117.28-34.56)
The Americas or Middle East or Other	1.04 (-87.30-89.38)	1.63 (-85.45-88.71)	4.14 (-83.05-91.33)	8.95 (-78.44-96.33)
Access to health care during pregnancy				
No		Reference	Reference	Reference
Yes		-66.03 (-144.62-12.56)	-56.87 (-136.16-22.42)	-54.42 (-133.71-24.88)
Parity				
First born		Reference	Reference	Reference
Subsequent		154.37 (128.21-180.53)	153.70 (126.68-180.71)	152.56 (125.50-179.62)
Type of delivery method				
Spontaneous vaginal		Reference	Reference	Reference
Planned caesarean		76.10 (35.65-116.54)	75.82 (35.41-116.22)	77.99 (37.47-118.51)
Emergency caesarean		65.38 (31.04-99.73)	65.76 (31.41-100.10)	65.77 (31.42-100.12)
Other assisted		0.79 (-39.91-41.48)	1.97 (-38.69-42.64)	1.36 (-39.33-42.04)
Education				
No secondary school			Reference	Reference
Secondary school			36.05 (-16.24-88.34)	34.55 (-17.84-86.94)
Diploma			46.08 (-5.78-97.94)	44.28 (-7.70-96.26)
Bachelor’s degree			31.37 (-25.44-88.18)	29.26 (-27.80-86.32)

Higher degree	16.74 (-43.11-76.59)	16.39 (-43.76-76.54)
Employment status		
Employed	Reference	Reference
Unemployed	-31.50 (-75.53-12.53)	-27.75 (-71.90-16.41)
Student	56.06 (11.43-100.68)	58.61 (13.93-103.29)
Not in work force	16.45 (-11.66-44.55)	17.57 (-10.60-45.73)
Residential rurality		
Urban		Reference
Rural		-56.17 (-113.23-0.89)
Area-level deprivation index		
Low		Reference
Medium		13.26 (-16.65-43.17)
High		-2.62 (-36.72-31.48)
Time lived in current neighbourhood		1.31 (-0.79-3.42)

a=unadjusted univariate (VPC=0.002)
b=a + adjustment for gestational age and foetus gender (VPC=0.002)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=0.002)
d=c + adjustment for smoking and alcohol consumption (VPC=0.003)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=0.003)
f=e + adjustment for relationship status with biological father and birth place (VPC=0.003)
g=f + adjustment for lead maternity carer, type of delivery, and parity (VPC=0.002)
h=g + adjustment for education and employment status (VPC=0.0013)
i=h + adjustment for residential rurality, time lived in current neighbourhood, and area deprivation (VPC=0.002)

Appendix 10: Multilevel regression analyses for maternal exposure to green space and gestational age (weeks) for the entire cohort

	Association between maternal exposure to green space and gestational age (n=6615)				
	Model 1[a]	**Model 2[b]**	**Model 3[c]**	**Model 4[d]**	**Model 5[e]**
Green space percentage in census area unit					
Green space	0.03 (-0.01-0.07)	0.03 (-0.01-0.07)	0.02 (-0.02-0.06)	0.01 (-0.03-0.05)	0.01 (-0.03-0 .05)
Gender					
Male	-	Reference	Reference	Reference	Reference
Female		0.08 (-0.003-0.16)	0.07 (-0.01-0.15)	0.08 (-0.008-0.16)	0.08 (0.0005-0.17)
Age groups					
<20			Reference	Reference	Reference
20-24			-0.18 (-0.39-0.037)	-0.18 (-0.4-0.05)	-0.13 (-0.35-0.09)
25-29			-0.12 (-0.33-0.083)	-0.14 (-0.4-0.07)	-0.12 (-0.33-0.09)
30-34			-0.24 (-0.44 - - 0.036)	-0.25 (-0.5- -0.04)	-0.21 (-0.42-0.004)
35-39			-0.46 (-0.67- -0.25)	-0.47 (-0.7- -0.26)	-0.39 (-0.61- -0.17)
≥40			-0.78 (-1.05- -0.51)	-0.83 (-1.1- -0.54)	-0.70 (-0.98- -0.41)
Self-identified ethnicity					
European			Reference	Reference	Reference
Māori			-0.1 (-0.23-0.03)	-0.08 (-0.21-0.06)	-0.05 (-0.18-0.10)
Pacific			-0.08 (-0.21-0.04)	-0.03 (-0.16-0.10)	0.005 (-0.13-0.14)
Asian			-0.24 (-0.36- -0.12)	-0.24 (-0.37- -0.11)	-0.23 (-0.36- -0.10)
Middle Eastern/Latin American/African			-0.04 (-0.32-0.24)	-0.07 (-0.37-0.22)	-0.05 (-0.34-0.24)
Other/ New Zealander			-0.17 (-0.51-0.17)	-0.17 (-0.53-0.19)	-0.17 (-0.52-0.19)

Smoking during pregnancy		
No	Reference	Reference
Yes	-0.28 (-0.43- -0.13)	-0.24 (-0.39- -0.09)
Alcohol consumption during pregnancy		
No	Reference	Reference
Yes	0.12 (0.03-0.22)	0.11 (0.01-0.20)
Doctor diagnosed depression		
Never		Reference
Before this pregnancy		-0.14 (-0.27- -0.01)
Before and during this pregnancy		-0.18 (-0.38-0.03)
Only during this pregnancy		-0.96 (-1.52- -0.39)
Doctor diagnosed high blood pressure or heart disease		
Never		Reference
Before this pregnancy		-0.31 (-0.50- -0.12)
Before and during this pregnancy		-0.74 (-1.06- -0.42)
Only during this pregnancy		-0.69 (-1.00- -0.39)
Doctor diagnosed diabetes mellitus		
Never		Reference
Before this pregnancy		-0.43 (-0.90-0.05)
Before and during this pregnancy		-1.50 (-1.83- -1.09)
Only during this pregnancy		-0.73 (-1.02- -0.44)

Association between maternal exposure to green space and gestational age (n=6615)				
	Model 6[f]	**Model 7[g]**	**Model 8[h]**	**Model 9[i]**
Green space percentage in census area unit				
Green space	0.02 (-0.03-0.06)	0.02 (-0.03-0.05)	0.02 (-0.02-0.06)	0.02 (-0.03-0.07)
Gender				
Male	Reference	Reference	Reference	Reference
Female	0.08 (-0.002-0.17)	0.07 (-0.02-0.15)	0.07 (-0.02-0.15)	0.07 (-0.02-0.15)
Age groups				
<20	Reference	Reference	Reference	Reference
20-24	-0.13 (-0.35-0.10)	-0.10 (-0.32-0.13)	-0.11 (-0.34-0.12)	-0.11 (-0.34-0.12)
25-29	-0.11 (-0.32-0.11)	-0.02 (-0.25-0.20)	-0.06 (-0.29-0.17)	-0.06 (-0.29-0.17)
30-34	-0.19 (-0.41-0.03)	-0.10 (-0.32-0.13)	-0.15 (-0.39-0.09)	-0.14 (-0.38-0.10)
35-39	-0.38 (-0.61- -0.16)	-0.22 (-0.45-0.02)	-0.27 (-0.52- -0.03)	-0.26 (-0.50 - - 0.01)
≥40	-0.70 (-0.98- -0.39)	-0.52 (-0.82- -0.22)	-0.57 (-0.87- -0.26)	-0.54 (-0.85- -0.23)
Self-identified ethnicity				
European	Reference	Reference	Reference	Reference
Māori	-0.07 (-0.21-0.07)	-0.09 (-0.22-0.06)	-0.07 (-0.22-0.07)	-0.08 (-0.23-0.06)
Pacific	-0.01 (-0.18-0.16)	-0.05 (-0.22-0.12)	-0.02 (-0.20-0.15)	-0.03 (-0.21-0.15)
Asian	-0.27 (-0.53- -0.004)	-0.27 (-0.53- -0.01)	-0.26 (-0.52-0.002)	-0.27 (-0.53- -0.005)
Middle Eastern/Latin American/African	0.10 (-0.26-0.47)	0.13 (-0.23-0.49)	0.14 (-0.22-0.50)	0.11 (-0.25-0.47)
Other/ New Zealander	-0.15 (-0.51-0.21)	-0.11 (-0.46-0.25)	-0.09 (-0.45-0.26)	-0.10 (-0.46-0.25)
Smoking during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	-0.25 (-0.40- -0.10)	-0.24 (-0.39- -0.10)	-0.23 (-0.38- -0.07)	-0.23 (-0.38- -0.08)

Alcohol consumption during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	0.10 (0.003-0.2)	0.09 (-0.002-0.19)	0.09 (-0.002-0.19)	0.09 (-0.006-0.19)
Doctor diagnosed depression				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.14 (-0.27- -0.01)	-0.14 (-0.27- -0.01)	-0.14 (-0.27- -0.01)	-0.13 (-0.26- -0.003)
Before and during this pregnancy	-0.18 (-0.39-0.03)	-0.18 (-0.38-0.03)	-0.17 (-0.37-0.04)	-0.17 (-0.38-0.04)
Only during this pregnancy	-0.96 (-1.52- -0.39)	-0.87 (-1.44- -0.30)	-0.85 (-1.42- -0.29)	-0.85 (-1.41- -0.28)
Doctor diagnosed high blood pressure or heart disease				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.31 (-0.51- -0.12)	-0.27 (-0.46- -0.07)	-0.27 (-0.46- -0.07)	-0.27 (-0.46- -0.08)
Before and during this pregnancy	-0.74 (-1.06- -0.43)	-0.73 (-1.05- -0.42)	-0.73 (-1.04- -0.41)	-0.73 (-1.10- -0.42)
Only during this pregnancy	-0.69 (-1.00- -0.38)	-0.70 (-1.01- -0.39)	-0.70 (-1.09- -0.39)	-0.71 (-1.03- -0.40)
Doctor diagnosed diabetes mellitus				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.41 (-0.89-0.06)	-0.32 (-0.79-0.15)	-0.31 (-0.79-0.15)	-0.30 (-0.78-0.17)
Before and during this pregnancy	-1.46 (-1.84- -1.10)	-1.31 (-1.69- -0.94)	-1.30 (-1.67- -0.93)	-1.30 (-1.67- -0.92)
Only during this pregnancy	-0.72 (-1.02- -0.43)	-0.70 (-0.98- -0.39)	-0.68 (-0.97- -0.39)	-0.67 (-0.96- -0.38)

Relationship status	Reference	Reference	Reference	Reference
No relationship	-0.01 (-0.40-0.37)	-0.05 (-0.44-0.34)	-0.06 (-0.45-0.33)	-0.09 (-0.48-0.31)
Dating	0.01 (-0.31-0.34)	-0.03 (-0.37-0.30)	-0.06 (-0.39-0.28)	-0.10 (-0.44-0.25)
Cohabiting	-0.02 (-0.36-0.31)	-0.08 (-0.42-0.26)	-0.12 (-0.46-0.22)	-0.15 (-0.50-0.19)
Married or civil union				
Birth place				
New Zealand	Reference	Reference	Reference	Reference
Australia	-0.01 (-0.33-0.31)	-0.03 (-0.35-0.29)	-0.04 (-0.36-0.28)	-0.05 (-0.36-0.27)
Other Oceania	0.00 (-0.20-0.20)	0.01 (-0.20-0.21)	0.03 (-0.17-0.23)	-0.01 (-0.22-0.19)
Asia	0.04 (-0.24-0.32)	0.01 (-0.27-0.29)	-0.01 (-0.29-0.27)	-0.03 (-0.31-0.25)
Europe	-0.02 (-0.19-0.16)	-0.03 (-0.20-0.14)	-0.04 (-0.21-0.14)	-0.05 (-0.22-0.12)
Africa	-0.31 (-0.60- -0.03)	-0.29 (-0.57- -0.01)	-0.28 (-0.56- -0.01)	-0.31 (-0.59- -0.03)
The Americas or Middle East or Other	-0.10 (-0.42-0.23)	-0.08 (-0.40-0.24)	-0.10 (-0.42-0.22)	-0.11 (-0.43-0.22)
Access to health care during pregnancy				
No		Reference	Reference	Reference
Yes		0.08 (-0.21-0.37)	0.10 (-0.19-0.39)	0.09 (-0.20-0.38)
Parity				
First born		Reference	Reference	Reference
Subsequent		-0.04 (-0.14-0.06)	-0.02 (-0.12-0.10)	-0.02 (-0.12-0.08)
Type of delivery method				
Spontaneous vaginal		Reference	Reference	Reference
Planned caesarean		-0.77 (-0.91- -0.62)	-0.76 (-0.91- -0.62)	-0.76 (-0.91- -0.61)
Emergency caesarean		-0.27 (-0.40- -0.14)	-0.27 (-0.39- -0.14)	-0.27 (-0.39- -0.14)
Other assisted		0.16 (0.01-0.31)	0.16 (0.01-0.31)	0.17 (0.02-0.32)
Education				
No secondary school			Reference	Reference
Secondary school			0.02 (-0.18-0.21)	0.02 (-0.18-0.21)
Diploma			0.05 (-0.15-0.24)	0.05 (-0.15-0.24)
Bachelor’s degree			0.13 (-0.08-0.34)	0.14 (-0.07-0.35)

Higher degree	0.15 (-0.07-0.37)	0.16 (-0.07-0.38)
Employment status		
Employed	Reference	Reference
Unemployed	-0.03 (-0.19-0.13)	-0.05 (-0.21-0.12)
Student	0.04 (-0.13-0.20)	0.04 (-0.13-0.20)
Not in work force	0.00 (-0.10-0.11)	-0.01 (-0.11-0.10)
Residential rurality		
Urban		Reference
Rural		0.01 (-0.20-0.22)
Area-level deprivation index		
Low		Reference
Medium		0.00 (-0.11-0.11)
High		0.10 (-0.04-0.22)
Time lived in current neighbourhood		-0.01 (-0.02- -0.001)

a=unadjusted univariate (VPC=3.97e-12)
b=a + adjustment for foetus gender (VPC=5.77e-12)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=3.93e-13)
d=c + adjustment for smoking and alcohol consumption (VPC=4.23e-13)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=2.94e-15)
f=e + adjustment for relationship status with biological father and birth place (VPC=1.15e-20)
g=f + adjustment for lead maternity carer, type of delivery, and parity (VPC=1.18e-14)
h=g + adjustment for education and employment status (VPC=3.77e-09)
i=h + adjustment for residential rurality, time lived in current neighbourhood, and area deprivation **(**VPC=4.62e-10)

Appendix 11: Multilevel regression analyses for maternal exposure to green space and gestational age (weeks) for pregnant women residing in urban areas

	Association between maternal exposure to green space and gestational age (n=6180)				
	Model 1[a]	**Model 2[b]**	**Model 3[c]**	**Model 4[d]**	**Model 5[e]**
Green space percentage in census area unit					
Green space	0.02 (-0.03-0.07)	0.02 (-0.03-0.07)	0.01 (-0.04-0.06)	0.01 (-0.05-0.06)	0.00 (-0.05-0.05)
Gender					
Male	-	Reference	Reference	Reference	Reference
Female		0.08 (-0.002-0.17)	0.07 (-0.02-0.15)	0.07 (-0.01-0.16)	0.08 (-0.01-0.16)
Age groups					
<20			Reference	Reference	Reference
20-24			-0.15 (-0.37-0.06)	-0.15 (-0.38-0.08)	-0.10 (-0.33-0.12)
25-29			-0.10 (-0.31-0.11)	-0.11 (-0.33-0.11)	-0.10 (-0.31-0.12)
30-34			-0.21 (-0.41- -0.001)	-0.21 (-0.43-0.003)	-0.18 (-0.39-0.04)
35-39			-0.44 (-0.65 - -0.23)	-0.45 (-0.68- -0.23)	-0.37 (-0.59 - -0.15)
≥40			-0.81 (-1.10 - -0.53)	-0.86 (-1.15 - -0.56)	-0.73 (-1.03 - -0.44)
Self-identified ethnicity					
European			Reference	Reference	Reference
Māori			-0.09 (-0.22-0.04)	-0.06 (-0.20-0.08)	-0.03 (-0.18-0.11)
Pacific			-0.08 (-0.20-0.05)	-0.02 (-0.16-0.11)	0.01 (-0.12-0.14)
Asian			-0.24 (-0.36- -0.12)	-0.24 (-0.38 - -0.11)	-0.23 (-0.37 - -0.10)
Middle Eastern/Latin American/African			-0.02 (-0.31-0.26)	-0.06 (-0.35-0.24)	-0.04 (-0.33-0.25)
Other/ New Zealander			-0.21 (-0.57-0.15)	-0.22 (-0.59-0.16)	-0.21 (-0.58-0.16)

Smoking during pregnancy		
No	Reference	Reference
Yes	-0.30 (-0.45 - -0.14)	-0.26 (-0.42 - -0.11)
Alcohol consumption during pregnancy		
No	Reference	Reference
Yes	0.11 (0.01-0.21)	0.10 (-0.004-0.19)
Doctor diagnosed depression		
Never		Reference
Before this pregnancy		-0.12 (-0.26-0.01)
Before and during this pregnancy		-0.11 (-0.32-0.11)
Only during this pregnancy		-0.76 (-1.35 - -0.18)
Doctor diagnosed high blood pressure or heart disease		
Never		Reference
Before this pregnancy		-0.36 (-0.56 - -0.16)
Before and during this pregnancy		-0.81 (-1.14 - -0.47)
Only during this pregnancy		-0.71 (-1.03 - -0.39)
Doctor diagnosed diabetes mellitus		
Never		
Before this pregnancy		Reference
Before and during this		-0.37 (-0.85-0.12)
pregnancy		-1.43 (-1.81 - -1.05)
Only during this		
pregnancy		-0.73 (-1.02 - -0.43)

Association between maternal exposure to green space and gestational age (n=6180)				
	Model 6[f]	**Model 7[g]**	**Model 8[h]**	**Model 9[i]**
Green space percentage in census area unit				
Green space	0.01 (-0.04-0.06)	-0.00 (-0.05-0.05)	0.01 (-0.04-0.06)	0.01 (-0.04-0.06)
Gender				
Male	Reference	Reference	Reference	Reference
Female	0.07 (-0.01-0.16)	0.06 (-0.02-0.15)	0.06 (-0.02-0.15)	0.06 (-0.02-0.15)
Age groups				
<20	Reference	Reference	Reference	Reference
20-24	-0.09 (-0.32-0.13)	-0.06 (-0.29-0.17)	-0.07 (-0.30-0.16)	-0.07 (-0.30-0.16)
25-29	-0.07 (-0.29-0.15)	0.02 (-0.21-0.25)	-0.02 (-0.25-0.22)	-0.02 (-0.25-0.22)
30-34	-0.15 (-0.37-0.08)	-0.04 (-0.27-0.19)	-0.10 (-0.34-0.14)	-0.09 (-0.33-0.15)
35-39	-0.35 (-0.58 - -0.12)	-0.17 (-0.41-0.07)	-0.23 (-0.48-0.02)	-0.21 (-0.46-0.04)
≥40	-0.71 (-1.02 - -0.41)	-0.54 (-0.85- -0.23)	-0.59 (-0.90 - -0.27)	-0.55 (-0.87 - -0.24)
Self-identified ethnicity				
European	Reference	Reference	Reference	Reference
Māori	-0.06 (-0.21-0.08)	-0.08 (-0.22-0.07)	-0.07 (-0.22-0.08)	-0.08 (-0.23-0.07)
Pacific	-0.01 (-0.18-0.17)	-0.04 (-0.22-0.13)	-0.02 (-0.19-0.16)	-0.02 (-0.20-0.16)
Asian	-0.26 (-0.52-0.003)	-0.27 (-0.53 - -0.01)	-0.26 (-0.52-0.01)	-0.27 (-0.53 - -0.003)
Middle Eastern/Latin American/African	0.17 (-0.20-0.54)	0.20 (-0.17-0.56)	0.20 (-0.16-0.57)	0.17 (-0.20-0.54)
Other/ New Zealander	-0.19 (-0.56-0.19)	-0.16 (-0.53-0.22)	-0.14 (-0.51-0.24)	-0.15 (-0.52-0.23)
Smoking during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	-0.28 (-0.44 - -0.12)	-0.26 (-0.42- -0.11)	-0.25 (-0.41 - -0.09)	-0.26 (-0.42 - -0.10)

Alcohol consumption during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	0.09 (-0.02-0.19)	0.08 (-0.02-0.18)	0.08 (-0.02-0.18)	0.08 (-0.02-0.18)
Doctor diagnosed depression				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.13 (-0.26-0.01)	-0.14 (-0.27- -0.004)	-0.13 (-0.27-0.001)	-0.13 (-0.26-0.007)
Before and during this pregnancy	-0.11 (-0.33-0.10)	-0.12 (-0.33-0.10)	-0.11 (-0.32-0.11)	-0.11 (-0.33-0.10)
Only during this pregnancy	-0.77 (-1.4 - -0.19)	-0.67 (-1.25- -0.09)	-0.65 (-1.23- -0.07)	-0.64 (-1.22 - -0.06)
Doctor diagnosed high blood pressure or heart disease				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.36 (-0.56 - -0.16)	-0.32 (-0.51 - -0.12)	-0.32 (-0.52 - -0.12)	-0.32 (-0.52 - -0.12)
Before and during this pregnancy	-0.81 (-1.14 - -0.47)	-0.80 (-1.12 - -0.50)	-0.78 (-1.11 - -0.45)	-0.79 (-1.13 - -0.45)
Only during this pregnancy	-0.71 (-1.03- -0.39)	-0.75 (-1.06 - -0.43)	-0.75 (-1.07 - -0.43)	-0.76 (-1.08 - -0.44)
Doctor diagnosed diabetes mellitus				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.35 (-0.83-0.14)	-0.23 (-0.72-0.25)	-0.23 (-0.71-0.25)	-0.22 (-0.70-0.26)
Before and during this pregnancy	-1.42 (-1.80 - -1.04)	-1.27 (-1.65 - -0.90)	-1.26 (-1.64 - -0.88)	-1.26 (-1.64 - -0.88)
Only during this pregnancy	-0.72 (-1.01 - -0.42)	-0.68 (-0.97 - -0.39)	-0.67 (-0.97 - -0.38)	-0.67 (-0.96 - -0.38)

Relationship status	Reference	Reference	Reference	Reference
No relationship	-0.02 (-0.40-0.37)	-0.05 (-0.44-0.34)	-0.07 (-0.46-0.32)	-0.10 (-0.49-0.30)
Dating	0.03 (-0.30-0.36)	-0.02 (-0.36-0.31)	-0.04 (-0.38-0.30)	-0.08 (-0.42-0.26)
Cohabiting	-0.04 (-0.37-0.29)	-0.10 (-0.44-0.24)	-0.14 (-0.48-0.21)	-0.17 (-0.51-0.18)
Married or civil union				
Birth place				
New Zealand	Reference	Reference	Reference	Reference
Australia	-0.04 (-0.37-0.29)	-0.06 (-0.39-0.28)	-0.07 (-0.40-0.27)	-0.08 (-0.41-0.26)
Other Oceania	-0.003 (-0.20-0.19)	-0.001 (-0.20-0.20)	0.02 (-0.18-0.22)	-0.03 (-0.23-0.18)
Asia	0.04 (-0.25-0.32)	0.008 (-0.27-0.29)	-0.01 (-0.29-0.27)	-0.04 (-0.32-0.24)
Europe	-0.01 (-0.19-0.16)	-0.02 (-0.20-0.15)	-0.04 (-0.22-0.14)	-0.05 (-0.23-0.13)
Africa	-0.36 (-0.65 - -0.07)	-0.34 (-0.63 - -0.05)	-0.33 (-0.62- -0.04)	-0.36 (-0.65 - -0.07)
The Americas or Middle East or Other	-0.17 (-0.50-0.16)	-0.15 (-0.48-0.18)	-0.17 (-0.50-0.16)	-0.18 (-0.51-0.15)
Access to health care during pregnancy				
No		Reference	Reference	Reference
Yes		0.10 (-0.20-0.39)	0.11 (-0.19-0.40)	0.10 (-0.20-0.39)
Parity				
First born		Reference	Reference	Reference
Subsequent		-0.06 (-0.16-0.04)	-0.04 (-0.14-0.07)	-0.03 (-0.14-0.07)
Type of delivery method				
Spontaneous vaginal		Reference	Reference	Reference
Planned caesarean		-0.77 (-0.93- -0.62)	-0.77 (-0.92 - -0.62)	-0.76 (-0.92 - -0.61)
Emergency caesarean		-0.23 (-0.36 - -0.10)	-0.22 (-0.35 - -0.09)	-0.22 (-0.35 - -0.09)
Other assisted		0.11 (-0.04-0.26)	0.11 (-0.04-0.26)	0.12 (-0.04-0.27)
Education				
No secondary school			Reference	Reference
Secondary school			0.02 (-0.18-0.22)	0.02 (-0.18-0.22)
Diploma			0.05 (-0.15-0.24)	0.05 (-0.15-0.25)
Bachelor's degree			0.12 (-0.10-0.33)	0.12 (-0.09-0.34)

Higher degree	0.19 (-0.04-0.41)	0.19 (-0.04-0.42)
Employment status		
Employed	Reference	Reference
Unemployed	-0.004 (-0.17-0.16)	-0.02 (-0.19-0.14)
Student	0.08 (-0.10-0.25)	0.07 (-0.10-0.25)
Not in work force	-0.003 (-0.11-0.10)	-0.01 (-0.12-0.09)
Residential rurality		
Urban		Reference
Rural		-
Area-level deprivation index		
Low		Reference
Medium		0.04 (-0.08-0.15)
High		0.11 (-0.02-0.24)
Time lived in current neighbourhood		-0.01 (-0.02- -0.002)

a=unadjusted univariate (VPC=4.19e-09)
b=a + adjustment for foetus gender (VPC=1.93e-13)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=4.26e-13)
d=c + adjustment for smoking and alcohol consumption (VPC=7.60e-13)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=1.46e-15)
f=e + adjustment for relationship status with biological father and birth place (VPC=2.41e-20)
g=f + adjustment for lead maternity carer, type of delivery, and parity (VPC=9.46e-18)
h=g + adjustment for education and employment status (VPC=7.89e-13)
i=h + adjustment for time lived in current neighbourhood and area deprivation **(**VPC**=**1.21e-11)

Appendix 12: Multilevel regression analyses for maternal exposure to green space and gestational age (weeks) for pregnant women residing in rural areas

	Association between maternal exposure to green space and gestational age (n=435)				
	Model 1[a]	**Model 2[b]**	**Model 3[c]**	**Model 4[d]**	**Model 5[e]**
Green space percentage in census area unit					
Green space	0.52 (0.13-0.92)	0.53 (0.13-0.92)	0.52 (0.11-0.94)	0.53 (0.11-0.95)	0.55 (0.14-0.97)
Gender					
Male	-	Reference	Reference	Reference	Reference
Female		0.02 (-0.31-0.35)	0.01 (-0.32-0.34)	0.08 (-0.27-0.42)	0.18 (-0.16-0.51)
Age groups					
<20			Reference	Reference	Reference
20-24			-0.83 (-1.92-0.25)	-1.03 (-2.17-0.12)	-1.16 (-2.31 - -0.01)
25-29			-0.76 (-1.80-0.26)	-0.93 (-2.03-0.17)	-1.06 (-2.17-0.05)
30-34			-0.96 (-2.00-0.07)	-1.15 (-2.25 - -0.06)	-1.15 (-2.26 - -0.04)
35-39			-0.94 (-2.01-0.14)	-1.06 (-2.20-0.08)	-1.23 (-2.38 - -0.09)
≥40			-0.75 (-2.01-0.51)	-0.91 (-2.25-0.42)	-0.84 (-2.20-0.51)
Self-identified ethnicity					
European			Reference	Reference	Reference
Māori			-0.04 (-0.58-0.50)	-0.05 (-0.61-0.52)	0.02 (-0.56-0.59)
Pacific			-0.60 (-2.03-0.82)	-1.05 (-2.81-0.71)	-1.17 (-2.89-0.55)
Asian			-0.52 (-1.93-0.89)	-0.49 (-1.90-0.93)	-0.58 (-1.95-0.79)
Middle Eastern/Latin American/African			-2.25 (-5.68-1.19)	-2.18 (-5.63-1.27)	3.30 (-1.42-8.01)
Other/ New Zealander			0.25 (-0.91-1.40)	0.19 (-0.97-1.35)	0.28 (-0.85-1.41)

Smoking during pregnancy		
No	Reference	Reference
Yes	0.002 (-0.56-0.56)	0.19 (-0.37-0.74)
Alcohol consumption during pregnancy		
No	Reference	Reference
Yes	0.25 (-0.11-0.61)	0.20 (-0.15-0.55)
Doctor diagnosed		
depression		Reference
Never		-0.29 (-0.75-0.16)
Before this pregnancy		-1.10 (-1.88 - -0.32)
Before and during this		
pregnancy		-5.48 (-8.81 - -2.15)
Only during this pregnancy		
Doctor diagnosed high blood pressure or heart disease		
Never		Reference
Before this pregnancy		0.26 (-0.43-0.96)
Before and during this pregnancy		-0.35 (-1.37-0.67)
Only during this pregnancy		-0.71 (-2.04-0.63)
Doctor diagnosed diabetes mellitus		
Never		Reference
Before this pregnancy		-0.73 (-3.16-1.69)
Before and during this pregnancy		-2.60 (-4.60 - -0.59)
Only during this pregnancy		-0.60 (-2.36-1.156)

Association between maternal exposure to green space and gestational age (n=435)				
	Model 6[f]	**Model 7[g]**	**Model 8[h]**	**Model 9[i]**
Green space percentage in census area unit				
Green space	0.57 (0.15-0.98)	0.52 (0.11-0.92)	0.53 (0.12-0.93)	0.54 (0.12-0.97)
Gender				
Male	Reference	Reference	Reference	Reference
Female	0.16 (-0.18-0.50)	0.12 (-0.21-0.45)	0.12 (-0.21-0.45)	0.14 (-0.18-0.47)
Age groups				
<20	Reference	Reference	Reference	Reference
20-24	-1.18 (-2.37-0.01)	-1.19 (-2.35 - -0.03)	-1.07 (-2.22-0.09)	-1.05 (-2.20-0.10)
25-29	-1.09 (-2.26-0.07)	-1.18 (-2.32 - -0.03)	-1.13 (-2.28-0.01)	-1.10 (-2.24-0.05)
30-34	-1.23 (-2.41 - -0.05)	-1.35 (-2.53 - -0.17)	-1.30 (-2.48 - -0.10)	-1.30 (-2.48 - -0.12)
35-39	-1.27 (-2.48 - -0.07)	-1.30 (-2.51 - -0.10)	-1.24 (-2.46 - -0.02)	-1.24 (-2.45 - -0.02)
≥40	-0.92 (-2.35-0.50)	-1.07 (-2.49-0.34)	-0.87 (-2.29-0.55)	-0.99 (-2.42-0.42)
Self-identified ethnicity				
European	Reference	Reference	Reference	Reference
Māori	0.10 (-0.50-0.69)	0.02 (-0.56-0.60)	0.10 (-0.48-0.68)	0.10 (-0.49-0.68)
Pacific	-1.06 (-3.00-0.89)	-0.29 (-2.22-1.63)	-0.26 (-2.18-1.67)	-0.30 (-2.22-1.62)
Asian	0.15 (-2.37-2.66)	0.31 (-2.27-2.88)	0.22 (-2.40-2.79)	0.49 (-2.07-3.05)
Middle Eastern/Latin American/African	3.12 (-1.72-7.97)	3.18 (-1.48-7.84)	2.70 (-1.99-7.37)	2.32 (-2.35-6.99)
Other/ New Zealander	0.27 (-0.85-1.40)	0.38 (-0.70-1.47)	0.55 (-0.54-1.64)	0.65 (-0.44-1.75)

Smoking during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	0.26 (-0.31-0.82)	0.16 (-0.39-0.71)	0.25 (-0.33-0.82)	0.23 (-0.34-0.81)
Alcohol consumption during pregnancy				
No	Reference	Reference	Reference	Reference
Yes	0.22 (-0.13-0.57)	0.23 (-0.10-0.57)	0.26 (-0.08-0.60)	0.29 (-0.05-0.62)
Doctor diagnosed depression				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.26 (-0.72-0.19)	-0.15 (-0.60-0.30)	-0.18 (-0.63-0.27)	-0.20 (-0.64-0.25)
Before and during this pregnancy	-1.04 (-1.82 - -0.26)	-0.75 (-1.51-0.006)	-0.72 (-1.49-0.05)	-0.70 (-1.46-0.07)
Only during this pregnancy	-5.24 (-8.57 - -1.91)	-5.31 (-8.51 - -2.10)	-4.95 (-8.16 - -1.74)	-4.67 (-7.87 - -1.48)
Doctor diagnosed high blood pressure or heart disease				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	0.20 (-0.50-0.91)	0.18 (-0.50-0.87)	0.19 (-0.48-0.87)	0.22 (-0.45-0.90)
Before and during this pregnancy	-0.29 (-1.31-0.73)	-0.43 (-1.41-0.56)	-0.36 (-1.34-0.63)	-0.34 (-1.32-0.63)
Only during this pregnancy	-0.72 (-2.06-0.61)	-0.35 (-1.65-0.95)	-0.35 (-1.65-0.95)	-0.33 (-1.63-0.96)
Doctor diagnosed diabetes mellitus				
Never	Reference	Reference	Reference	Reference
Before this pregnancy	-0.67 (-3.10-1.75)	-0.91 (-3.25-1.43)	-0.66 (-3.00-1.69)	-0.57 (-2.90-1.77)
Before and during this pregnancy	-2.50 (-4.50 - -0.50)	-2.20 (-4.13 - -0.27)	-2.22 (-4.15 - -0.30)	-2.55 (-4.52 - -0.58)
Only during this pregnancy	-0.59 (-2.34-1.16)	-0.67 (-2.36-1.02)	-0.64 (-2.33-1.05)	-0.62 (-2.30-1.07)

Relationship status				
No relationship	Reference	Reference	Reference	Reference
Dating	0.34 (-3.36-4.04)	0.18 (-3.40-3.80)	-0.07 (-3.65-3.51)	-0.06 (-3.65-3.52)
Cohabiting	-0.13 (-3.49-3.23)	-0.10 (-3.33-3.15)	-0.42 (-3.69-2.85)	-0.23 (-3.48-3.03)
Married or civil union	0.11 (-3.26-3.48)	0.25 (-3.00-3.50)	-0.08 (-3.35-3.20)	0.10 (-3.16-3.35)
Birth place				
New Zealand	Reference	Reference	Reference	Reference
Australia	0.08 (-0.90-1.07)	0.25 (-0.71-1.21)	0.29 (-0.67-1.26)	0.25 (-0.70-1.21)
Other Oceania	-0.13 (-1.93-1.67)	-0.37 (-2.14-1.40)	-0.47 (-2.23-1.29)	-0.54 (-2.30-1.22)
Asia	-1.06 (-4.09-1.96)	-0.90 (-3.93-2.14)	-0.83 (-3.85-2.20)	-1.24 (-4.28-1.79)
Europe	0.11 (-0.51-0.74)	0.10 (-0.50-0.71)	0.14 (-0.47-0.75)	0.13 (-0.49-0.74)
Africa	0.12 (-1.03-1.26)	-0.08 (-1.18-1.03)	0.11 (-0.99-1.22)	0.12 (-0.99-1.23)
The Americas or Middle East or Other	0.94 (-0.73-2.62)	1.20 (-0.43-2.84)	1.08 (-0.55-2.71)	1.06 (-0.58-2.69)
Access to health care during pregnancy				
No		Reference	Reference	Reference
Yes		-0.28 (-2.35-1.80)	-0.20 (-2.28-1.87)	-0.19 (-2.30-1.88)
Parity				
First born		Reference	Reference	Reference
Subsequent		0.29 (-0.09-0.67)	0.24 (-0.15-0.63)	0.19 (-0.20-0.59)
Type of delivery method				
Spontaneous vaginal		Reference	Reference	Reference
Planned caesarean		-0.78 (-1.33 - -0.23)	-0.79 (-1.34- -0.24)	-0.79 (-1.33- -0.24)
Emergency caesarean		-0.96 (-1.51 - -0.41)	-0.96 (-1.51- -0.42)	-0.95 (-1.49- -0.40)
Other assisted		0.97 (0.33-1.62)	0.93 (0.29-1.57)	0.99 (0.35-1.63)

Education		
No secondary school	Reference	Reference
Secondary school	0.12 (-0.71-0.94)	0.04 (-0.78-0.87)
Diploma	0.15 (-0.67-0.98)	0.07 (-0.76-0.89)
Bachelor’s degree	0.36 (-0.52-1.24)	0.32 (-0.56-1.19)
Higher degree	-0.19 (-1.14-0.75)	-0.28 (-1.22-0.66)
Employment status		
Employed	Reference	Reference
Unemployed	-0.35 (-1.03-0.32)	-0.34 (-1.01-0.33)
Student	-0.39 (-0.93-0.15)	-0.37 (-0.91-0.16)
Not in work force	0.11 (-0.29-0.51)	0.10 (-0.30-0.50)
Residential rurality		
Urban		Reference
Rural		-
Area-level deprivation index		
Low		Reference
Medium		-0.35 (-0.70- -0.01)
High		-0.09 (-0.78-0.61)
Time lived in current neighbourhood		0.02 (-0.02-0.05)

a=unadjusted univariate (VPC=3.20e-21)
b=a + adjustment for foetus gender (VPC=2.41e-21)
c=b + adjustment for maternal age and self-identified ethnicity (VPC=7.56e-20)
d=c + adjustment for smoking and alcohol consumption (VPC=3.86e-20)
e=d + adjustment for depression, heart disease or high blood pressure, and diabetes mellitus (VPC=5.09e-20)
f=e + adjustment for relationship status with biological father and birth place (VPC=3.23e-20)
g=f + adjustment for lead maternity carer, type of delivery, and parity (VPC=4.55e-19)
h=g + adjustment for education and employment status (VPC=7.46e-21)
i=h + adjustment for time lived in current neighbourhood and area deprivation (VPC=2.55e-20)

Appendix 13: Multilevel logistic regression analyses for maternal exposure to green space during pregnancy and odds of depression for the entire cohort

	Association between maternal exposure to green space and depression (n=6772)						
Variables	**Model 1[a]**	**Model 2[b]**	**Model 3[c]**	**Model 4[d]**	**Model 5[e]**	**Model 6[f]**	**Model 7[g]**
Green space percentage in census area unit	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Low	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Medium	1.11 (0.91-1.36)	1.13 (0.92-1.39)	1.12 (0.91-1.37)	1.10 (0.90-1.35)	1.11 (0.90-1.36)	1.10 (0.90-1.36)	1.10 (0.89-1.35)
High	1.12 (0.92-1.36)	1.13 (0.93-1.39)	1.13 (0.92-1.39)	1.12 (0.92-1.38)	1.14 (0.93-1.40)	1.14 (0.93-1.40)	1.15 (0.94-1.41)
Very high	0.95 (0.77-1.17)	1.20 (0.97-1.49)	1.20 (0.96-1.48)	1.22 (0.98-1.51)	1.22 (0.98-1.51)	1.20 (0.97-1.49)	1.21 (0.96-1.52)
Age groups		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
<20		1.00	1.00	1.00	1.00	1.00	1.00
20-24		1.31 (0.96-1.79)	1.38 (1.00-1.89)	1.40 (1.02-1.92)	1.44 (1.05-1.99)	1.52 (1.10-2.12)	1.50 (1.08-2.10)
25-29		0.83 (0.61-1.12)	0.91 (0.67-1.24)	0.99 (0.72-1.36)	1.10 (0.79-1.53)	1.21 (0.86-1.71)	1.19 (0.84-1.67)
30-34		0.60 (0.44-0.82)	0.67 (0.50-0.92)	0.75 (0.55-1.03)	0.85 (0.60-1.20)	0.98 (0.68-1.40)	0.96 (0.67-1.38)
35-39		0.57 (0.41-0.79)	0.64 (0.46-0.90)	0.73 (0.52-1.02)	0.81 (0.57-1.17)	0.95 (0.64-1.39)	0.94 (0.64-1.38)
≥40		0.61 (0.38-0.98)	0.69 (0.43-1.10)	0.80 (0.50-1.29)	0.88 (0.53-1.44)	0.99 (0.60-1.65)	0.99 (0.60-1.66)
Self-identified ethnicity		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
European		1.00	1.00	1.00	1.00	1.00	1.00
Māori		1.94 (1.58-2.38)	1.64 (1.33-2.03)	1.50 (1.21-1.87)	1.40 (1.12-1.74)	1.32 (1.06-1.65)	1.31 (1.04-1.64)
Pacific		2.78 (2.27-3.40)	2.81 (2.29-3.45)	2.55 (2.06-3.14)	2.46 (1.99-3.04)	2.32 (1.86-2.88)	2.28 (1.81-2.88)
Asian		1.56 (1.25-1.94)	1.76 (1.41-2.20)	1.61 (1.28-2.02)	1.77 (1.41-2.23)	1.75 (1.39-2.21)	1.70 (1.34-2.15)
Middle Eastern/Latin American/African		1.56 (0.97-2.50)	1.71 (1.06-2.75)	1.67 (1.04-2.70)	1.73 (1.07-2.79)	1.68 (1.04-2.71)	1.64 (1.01-2.65)
Other/ New Zealander		1.12 (0.59-2.14)	1.14 (0.60-2.17)	1.09 (0.57-2.10)	1.07 (0.56-2.05)	1.04 (0.54-1.99)	1.03 (0.53-1.98)

Smoking during pregnancy	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
No	1.00	1.00	1.00	1.00	1.00
Yes	1.77 (1.44-2.18)	1.64 (1.34-2.02)	1.48 (1.20-1.83)	1.40 (1.13-1.74)	1.40 (1.12-1.74)
Alcohol consumption during pregnancy	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
No	1.00	1.00	1.00	1.00	1.00
Yes	1.30 (1.11-1.53)	1.31 (1.11-1.53)	1.24 (1.06-1.46)	1.25 (1.06-1.47)	1.25 (1.06-1.48)
Pre-pregnancy general health status		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Poor or Fair		1.00	1.00	1.00	1.00
Good		0.70 (0.57-0.86)	0.71 (0.58-0.88)	0.73 (0.59-0.90)	0.72 (0.58-0.90)
Very good		0.53 (0.42-0.66)	0.55 (0.44-0.70)	0.57 (0.46-0.72)	0.57 (0.45-0.72)
Excellent		0.43 (0.33-0.57)	0.45 (0.35-0.60)	0.47 (0.36-0.62)	0.47 (0.35-0.61)
Physical activity during the first trimester of pregnancy		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
No		1.00	1.00	1.00	1.00
Yes		0.86 (0.71-1.04)	0.85 (0.70-1.03)	0.85 (0.70-1.03)	0.85 (0.70-1.03)
Physical activity after the first trimester of pregnancy		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
No		1.00	1.00	1.00	1.00
Yes		1.03 (0.84-1.26)	1.03 (0.84-1.26)	1.04 (0.85-1.28)	1.04 (0.85-1.27)

Relationship status with biological father	OR (95% CI)	OR (95% CI)	OR (95% CI)
No relationship	1.00	1.00	1.00
Dating, but not cohabiting	0.69 (0.41-1.14)	0.66 (0.40-1.11)	0.70 (0.41-1.17)
Cohabiting	0.60 (0.38-0.91)	0.58 (0.37-0.90)	0.60 (0.38-0.92)
Married or civil union	0.43 (0.28-0.68)	0.44 (0.28-0.69)	0.45 (0.29-0.71)
Parity	OR (95% CI)	OR (95% CI)	OR (95% CI)
First born	1.00	1.00	1.00
Subsequent	1.10 (0.94-1.30)	1.05 (0.89-1.23)	1.05 (0.90-1.24)
Education		OR (95% CI)	OR (95% CI)
No secondary school		1.00	1.00
Secondary school		0.83 (0.63-1.08)	0.84 (0.64-1.10)
Diploma		0.95 (0.72-1.24)	0.96 (0.73-1.26)
Bachelor’s		0.74 (0.54-1.03)	0.76 (0.55-1.05)
Higher degree		0.76 (0.54-1.09)	0.78 (0.54-1.10)
Employment status		OR (95% CI)	OR (95% CI)
Employed		1.00	1.00
Unemployed		1.34 (1.06-1.71)	1.34 (1.05-1.70)
Student		1.38 (1.06-1.81)	1.39 (1.06-1.81)
Not in work force		1.15 (0.97-1.38)	1.15 (0.96-1.37)
Residential rurality			OR (95% CI)
Urban			1.00
Rural			0.97 (0.69-1.36)

Area deprivation index	OR (95% CI)
Low	1.00
Medium	1.04 (0.84-1.28)
High	1.06 (0.84-1.32)
Length of stay at the current residence	OR (95% CI)
	0.99 (0.98-1.00)

a=unadjusted univariate (VPC=0.02)
b=a + adjustment for maternal age and self-identified ethnicity (VPC=0.002)
c=b + adjustment for smoking and alcohol consumption during pregnancy (VPC=0.002)
d=c + adjustment for pre-pregnancy general health status, physical activity during the first trimester and remainder of pregnancy (VPC=0.001)
e=d + adjustment for relationship status and parity (VPC=0.001)
f=e + adjustment for education and employment status (VPC=0.001)
g=f + adjustment for residential rurality, area deprivation, and length of stay at the current residence (VPC=0.001)

References

Abrahamowicz, M., Beauchamp, M.-E., Fournier, P. & Dumont, A. 2013. Evidence of subgroup-specific treatment effect in the absence of an overall effect: is there really a contradiction? *Pharmacoepidemiology and Drug Safety,* 22**,** 1178-1188.

Accortt, E. E., Cheadle, A. C. D. & Schetter, C. D. 2015. Prenatal Depression and Adverse Birth Outcomes: An Updated Systematic Review. *Maternal and child health journal,* 19**,** 1306-1337.

ACOG. 2002. ACOG Committee Opinion No. 267: Exercise During Pregnancy and the Postpartum Period. *Obstetrics & Gynaecology,* 99**,** 171-173.

Agay-Shay, K., Peled, A., Crespo, A. V., Peretz, C., Amitai, Y., Linn, S., Friger, M. & Nieuwenhuijsen, M. J. 2014. Green spaces and adverse pregnancy outcomes. *Occupational and Environmental Medicine,* 71**,** 562-569.

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E. & Depledge, M. H. 2014. Longitudinal Effects on Mental Health of Moving to Greener and Less Green Urban Areas. *Environmental Science & Technology,* 48**,** 1247-1255.

Andrews, G. 2001. Should depression be managed as a chronic disease? *BMJ : British Medical Journal,* 322**,** 419-421.

Annerstedt, M., Östergren, P.-O., Björk, J., Grahn, P., Skärbäck, E. & Währborg, P. 2012. Green qualities in the neighbourhood and mental health–results from a longitudinal cohort study in Southern Sweden. *BMC Public Health,* 12**,** 1-13.

Arroyo, V., Díaz, J., Ortiz, C., Carmona, R., Sáez, M. & Linares, C. 2016. Short term effect of air pollution, noise and heat waves on preterm births in Madrid (Spain). *Environmental Research,* 145**,** 162-168.

Artal, R. & O'toole, M. 2003. Guidelines of the American College of Obstetricians and Gynaecologists for exercise during pregnancy and the postpartum period. *British Journal of Sports Medicine,* 37**,** 6-12.

Astell-Burt, T., Feng, X. & Kolt, G. S. 2013a. Does access to neighbourhood green space promote a healthy duration of sleep? Novel findings from a cross-sectional study of 259 319 Australians. *BMJ Open,* 3, e003094.

Astell-Burt, T., Feng, X. & Kolt, G. S. 2013b. Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: Evidence from 260,061 Australians. *Preventive Medicine,* 57**,** 601-606.

Astell-Burt, T., Feng, X. & Kolt, G. S. 2014a. Green space is associated with walking and moderate-to-vigorous physical activity (MVPA) in middle-to-older-aged adults: findings from 203 883 Australians in the 45 and Up Study. *British Journal of Sports Medicine,* 48**,** 404-406.

Astell-Burt, T., Feng, X. & Kolt, G. S. 2014b. Greener neighbourhoods, slimmer people? Evidence from 246 920 Australians. *International Journal of Obesity,* 38**,** 156-159.

Astell-Burt, T., Feng, X. & Kolt, G. S. 2014c. Is Neighbourhood Green Space Associated With a Lower Risk of Type 2 Diabetes? Evidence From 267,072 Australians. *Diabetes Care,* 37**,** 197-201.

Astell-Burt, T., Feng, X., Mavoa, S., Badland, H. M. & Giles-Corti, B. 2014d. Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health*, 14**,** 292.

Astell-Burt, T., Mitchell, R. & Hartig, T. 2014e. The association between green space and mental health varies across the lifecourse. A longitudinal study. *Journal of Epidemiology and Community Health*, 68, 578–583.

Ayele, T. A., Azale, T., Alemu, K., Abdissa, Z., Mulat, H. & Fekadu, A. 2016. Prevalence and Associated Factors of Antenatal Depression among Women Attending Antenatal Care Service at Gondar University Hospital, Northwest Ethiopia. *PLoS ONE,* 11**,** e0155125.

Barbosa, O., Tratalos, J. A., Armsworth, P. R., Davies, R. G., Fuller, R. A., Johnson, P. & Gaston, K. J. 2007. Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning,* 83**,** 187-195.

Barton, J. & Pretty, J. 2010. What is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis. *Environmental Science & Technology,* 44**,** 3947-3955.

Basu, R., Sarovar, V. & Malig, B. J. 2016. Association Between High Ambient Temperature and Risk of Stillbirth in California. *American Journal of Epidemiology,* 183**,** 894-901.

Bedimo-Rung, A. L., Mowen, A. J. & Cohen, D. A. 2005. The significance of parks to physical activity and public health. *American Journal of Preventive Medicine,* 28**,** 159-168.

Bertolotto, A., Volpe, L., Calianno, A., Pugliese, M. C., Lencioni, C., Resi, V., Ghio, A., Corfini, M., Benzi, L., Del Prato, S. & Di Cianni, G. 2010. Physical activity and dietary habits during pregnancy: effects on glucose tolerance. *The Journal of Maternal-Foetal & Neonatal Medicine,* 23**,** 1310-1314.

Beyer, K., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F. & Malecki, K. 2014. Exposure to Neighbourhood Green Space and Mental Health: Evidence from the Survey of the Health of Wisconsin. *International Journal of Environmental Research and Public Health,* 11**,** 3453.

Bhaskar, R. K., Deo, K. K., Neupane, U., Chaudhary Bhaskar, S., Yadav, B. K., Pokharel, H. P. & Pokharel, P. K. 2015. A Case Control Study on Risk Factors Associated with Low Birth Weight Babies in Eastern Nepal. *International Journal of Paediatrics,* 7.

Biaggi, A., Conroy, S., Pawlby, S. & Pariante, C. M. 2016. Identifying the women at risk of antenatal anxiety and depression: A systematic review. *Journal of Affective Disorders,* 191**,** 62-77.

Bisetegn, T. A., Mihretie, G. & Muche, T. 2016. Prevalence and Predictors of Depression among Pregnant Women in Debretabor Town, Northwest Ethiopia. *PLoS ONE,* 11**,** e0161108.

Bixby, H., Hodgson, S., Fortunato, L., Hansell, A. & Fecht, D. 2015. Associations between Green Space and Health in English Cities: An Ecological, Cross-Sectional Study. *PLoS ONE,* 10**,** e0119495.

Blakely, T. A. & Woodward, A. J. 2000. Ecological effects in multi-level studies. *Journal of Epidemiology and Community Health,* 54**,** 367-374.

Bogar, S. & Beyer, K. M. 2015. Green Space, Violence, and Crime: A Systematic Review. *Trauma, Violence, & Abuse* [Online]. Available: http://tva.sagepub.com/content/early/2015/03/27/1524838015576412.abstract [Accessed 29 March 2015].

Boone-Heinonen, J., Guilkey, D. K., Evenson, K. R. & Gordon-Larsen, P. 2010. Residential self-selection bias in the estimation of built environment effects on physical activity between adolescence and young adulthood. *International Journal of Behavioural Nutrition and Physical Activity,* 7**,** 70.

Bos, E., Van Der Meulen, L., Wichers, M. & Jeronimus, B. 2016. A Primrose Path? Moderating Effects of Age and Gender in the Association between Green Space and Mental Health. *International Journal of Environmental Research and Public Health,* 13**,** 492.

Boscoe, F. P., Henry, K. A. & Zdeb, M. S. 2012. A Nationwide Comparison of Driving Distance Versus Straight-Line Distance to Hospitals. *The Professional Geographer,* 64**,** 188-196.

Bromet, E., Andrade, L. H., Hwang, I., Sampson, N. A., Alonso, J., De Girolamo, G., De Graaf, R., Demyttenaere, K., Hu, C., Iwata, N., Karam, A. N., Kaur, J., Kostyuchenko, S., Lépine, J.-P., Levinson, D., Matschinger, H., Mora, M. E. M., Browne, M. O., Posada-Villa, J., Viana, M. C., Williams, D. R. & Kessler, R. C. 2011. Cross-national epidemiology of DSM-IV major depressive episode. *BMC Medicine*, 9**,** 90.

Carter, M. & Horwitz, P. 2014. Beyond Proximity: The Importance of Green Space Useability to Self-Reported Health. *EcoHealth*, 11**,** 322-332.

Casey, J., James, P., Rudolph, K., Wu, C.-D. & Schwartz, B. 2016. Greenness and Birth Outcomes in a Range of Pennsylvania Communities. *International Journal of Environmental Research and Public Health*, 13**,** 311.

CDC. 2015. *Physical Activity and Health: The Benefits of Physical Activity* [Online]. Available: https://www.cdc.gov/physicalactivity/basics/pa-health/ [Accessed 29 August 2016].

Clapp Iii, J. F., Kim, H., Burciu, B. & Lopez, B. 2000. Beginning regular exercise in early pregnancy: Effect on fetoplacental growth. *American Journal of Obstetrics and Gynaecology*, 183**,** 1484-1488.

Clark, W. A. V. & Ledwith, V. 2006. Mobility, Housing Stress, and Neighbourhood Contexts: Evidence from Los Angeles. *Environment and Planning A*, 38**,** 1077-1093.

Coll, C. D. V. N., Da Silveira, M. F., Bassani, D. G., Netsi, E., Wehrmeister, F. C., Barros, F. C. & Stein, A. 2017a. Antenatal depressive symptoms among pregnant women: Evidence from a Southern Brazilian population-based cohort study. *Journal of Affective Disorders*, 209**,** 140-146.

Coll, C. D. V. N., Domingues, M. R., Hallal, P. C., Da Silva, I. C. M., Bassani, D. G., Matijasevich, A., Barros, A., Santos, I. S. & Bertoldi, A. D. 2017b. Changes in leisure-time physical activity among Brazilian pregnant women: comparison between two birth cohort studies (2004–2015). *BMC Public Health,* 17**,** 119.

Coutinho, P. R., Cecatti, J. G., Surita, F. G., Souza, J. P. D. & Morais, S. S. D. 2009. Factors associated with low birth weight in a historical series of deliveries in Campinas, Brazil. *Revista da Associação Médica Brasileira,* 55**,** 692-699.

Cox, J. L., Holden, M. & Sagovsky, R. 1987. Detection of Postnatal Depression Developement of the 10-item Edinburgh Postnatal Depression Scale. *British Journal of Psychiatry,* 150**,** 782-786.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F. & Oja, P. 2003. International Physical Activity Questionnaire: 12-Country Reliability and Validity. *Medicine & Science in Sports & Exercise,* 35**,** 1381-1395.

Dadvand, P., De Nazelle, A., Figueras, F., Basagaña, X., Su, J., Amoly, E., Jerrett, M., Vrijheid, M., Sunyer, J. & Nieuwenhuijsen, M. J. 2012a. Green space, health inequality and pregnancy. *Environment International,* 40**,** 110-115.

Dadvand, P., Nazelle, A. D., Triguero-Mas, M., Schembari, A., Cirach, M., Amoly, E., Figueras, F., Basagaña, X., Ostro, B. & Nieuwenhuijsen, M. 2012b. Surrounding Greenness and Exposure to Air Pollution During Pregnancy: An Analysis of Personal Monitoring Data. *Environmental Health Perspectives,* 120**,** 1286-1290.

Dadvand, P., Ostro, B., Figueras, F., Foraster, M., Basagaña, X., Valentín, A., Martinez, D., Beelen, R., Cirach, M., Hoek, G., Jerrett, M., Brunekreef, B. & Nieuwenhuijsen, M. J. 2014a. Residential Proximity to Major Roads and Term Low Birth Weight: The Roles of Air Pollution, Heat, Noise, and Road-Adjacent Trees. *Epidemiology,* 25**,** 518-525.

Dadvand, P., Sunyer, J., Basagaña, X., Ballester, F., Lertxundi, A., Fernández-Somoano, A., Estarlich, M., García-Esteban, R., Mendez, M. A. & Nieuwenhuijsen, M. J. 2012c.

Surrounding Greenness and Pregnancy Outcomes in Four Spanish Birth Cohorts. *Environmental Health Perspectives*, 120**,** 1481–1487.

Dadvand, P., Wright, J., Martinez, D., Basagaña, X., Mceachan, R. R. C., Cirach, M., Gidlow, C. J., De Hoogh, K., Gražulevičienė, R. & Nieuwenhuijsen, M. J. 2014b. Inequality, green spaces, and pregnant women: Roles of ethnicity and individual and neighbourhood socioeconomic status. *Environment International,* 71**,** 101-108.

Dagklis, T., Papazisis, G., Tsakiridis, I., Chouliara, F., Mamopoulos, A. & Rousso, D. 2016. Prevalence of antenatal depression and associated factors among pregnant women hospitalized in a high-risk pregnancy unit in Greece. *Social Psychiatry and Psychiatric Epidemiology,* 51**,** 1025-1031.

Davis, P., Mcleod, K., Ransom, M. & Ongley, P. 1997. The New Zealand Socioeconomic Index of Occupational Status (NZSEI) New Zealand.

Day, K. L., Schmidt, L. A., Vaillancourt, T., Saigal, S., Boyle, M. H. & Van Lieshout, R. J. 2016. Long-term Psychiatric Impact of Peer Victimization in Adults Born at Extremely Low Birth Weight. *Paediatrics,* 137**,** 1-8.

De Vries, S., Verheij, R. A., Groenewegen, P. P. & Spreeuwenberg, P. 2003. Natural environments--healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning A,* 35**,** 1717-1731.

Dekrout, A. S., Clarkson, B. D. & Parsons, S. 2014. Temporal and spatial distribution and habitat associations of an urban population of New Zealand long-tailed bats (Chalinolobus tuberculatus). *New Zealand Journal of Zoology,* 41**,** 285-297.

Derraik, J. G. B., Lundgren, M., Cutfield, W. S. & Ahlsson, F. 2016. Maternal Height and Preterm Birth: A Study on 192,432 Swedish Women. *PLoS ONE,* 11**,** e0154304.

Diez Roux, A. V. 2002. A glossary for multilevel analysis. *Journal of Epidemiology and Community Health*, 56**,** 588-594.

Dumith, S. C., Domingues, M. R., Mendoza-Sassi, R. A. & Cesar, J. A. 2012. Physical activity during pregnancy and its association with maternal and child health indicators. *Rev Saúde Pública,* 46.

Duncombe, D., Wertheim, E. H., Skouteris, H., Paxton, S. J. & Kelly, L. 2009. Factors related to exercise over the course of pregnancy including women's beliefs about the safety of exercise during pregnancy. *Midwifery,* 25**,** 430-438.

Dzhambov, A. M. & Dimitrova, D. D. 2015. Green spaces and environmental noise perception. *Urban Forestry & Urban Greening,* 14**,** 1000-1008.

Ebisu, K., Holford, T. R. & Bell, M. L. 2016. Association between greenness, urbanicity, and birth weight. *Science of The Total Environment,* 542, Part A**,** 750-756.

Ekeroma, A. J., Ikenasio-Thorpe, B., Weeks, S., Kokaua, J., Puniani, K., Stone, P. & Foliaki, S. A. 2012. Validation of the Edinburgh Postnatal Depression Scale (EPDS) as a screening tool for postnatal depression in Samoan and Tongan women living in New Zealand. *The New Zealand Medical Journal,* 125.

EPA. 2017a. *Using Trees and Vegetation to Reduce Heat Islands* [Online]. USA. Available: https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands [Accessed 29 November 2017].

EPA. 2017b. *UV Radiation* [Online]. Available: https://www.epa.gov/sunsafety/uv-radiation-1 [Accessed 16 December 2017].

ESRI. 2006. *An overview of commonly used tools* [Online]. Available: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=An_overview_of_commonly_used_tools [Accessed 07 June 2016].

ESRI. 2008. *What is raster data?* [Online]. Available: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=What_is_raster_data%3F [Accessed 02 August 2016].

ESRI. 2017. *Vector definition* [Online]. Available: https://support.esri.com/en/other-resources/gis-dictionary/term/vector [Accessed 15 December 2017].

Freeman, C. & Buck, O. 2003. Development of an ecological mapping methodology for urban areas in New Zealand. *Landscape Urban Planning,* 63**,** 161-173.

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forns, J., Plasència, A. & Nieuwenhuijsen, M. J. 2015. Mental Health Benefits of Long-Term Exposure to Residential Green and Blue Spaces: A Systematic Review. *International Journal of Environmental Research and Public Health*, 12, 4354-4379.

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A. & Nieuwenhuijsen, M. J. 2016. Residential green spaces and mortality: A systematic review. *Environment International,* 86**,** 60-67.

Gaston, A. & Cramp, A. 2011. Exercise during pregnancy: A review of patterns and determinants. *Journal of Science and Medicine in Sport,* 14**,** 299–305.

Gehring, U., Tamburic, L., Sbihi, H., Davies, H. W. & Brauer, M. 2014. Impact of Noise and Air Pollution on Pregnancy Outcomes. *Epidemiology,* 25**,** 351-358.

Gisgeography. 2016. *Vector vs Raster: What's the Difference Between GIS Spatial Data Types?* [Online]. Available: http://gisgeography.com/spatial-data-types-vector-raster/ [Accessed 15 December 2017].

Givoni, B. 1991. Impact of planted areas on urban environmental quality: A review. *Atmospheric Environment. Part B. Urban Atmosphere*, 25**,** 289-299.

Goedhart, G., Snijders, A. C., Hesselink, A. E., Van Poppel, M. N., Bonsel, G. J. & Vrijkotte, T. G. M. 2010. Maternal Depressive Symptoms in Relation to Perinatal Mortality and Morbidity: Results From a Large Multiethnic Cohort Study. *Psychosomatic Medicine,* 72**,** 769-776.

Goldenberg, R. L. & Culhane, J. F. 2007. Low birth weight in the United States. *The American Journal of Clinical Nutrition,* 85**,** 584S-590S.

Grazuleviciene, R., Danileviciute, A., Dedele, A., Vencloviene, J., Andrusaityte, S., Uždanaviciute, I. & Nieuwenhuijsen, M. J. 2015. Surrounding greenness, proximity to city parks and pregnancy outcomes in Kaunas cohort study. *International Journal of Hygiene and Environmental Health,* 218**,** 358-365.

Greed, C. 2016. Taking women's bodily functions into account in urban planning and policy: public toilets and menstruation. *Town Planning Review,* 87**,** 505-524.

Groenewegen, P. P., Berg, A. E. V. D., Vries, S. D. & Verheij, R. A. 2006. Vitamin G: effects of green space on health, well-being, and social safety. *BMC Public Health,* 6.

Grote, N. K., Bridge, J. A., Gavin, A. R., Melville, J. L., Iyengar, S. & Katon, W. J. 2010. A meta-analysis of depression during pregnancy and the risk of preterm birth, low birth weight, and intrauterine growth restriction. *Archives of General Psychiatry,* 67**,** 1012-1024.

Han, Z., Mulla, S., Beyene, J., Liao, G. & Mcdonald, S. D. 2011. Maternal underweight and the risk of preterm birth and low birth weight: a systematic review and meta-analyses. *International Journal of Epidemiology,* 40**,** 65-101.

Hartig, T., Mitchell, R., Vries, S. D. & Frumkin, H. 2014. Nature and Health. *Annual Review of Public Health,* 35**,** 207-228.

Haskell, W. L., Lee, I.-M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., Macera, C. A., Heath, G. W., Thompson, P. D. & Bauman, A. 2007. Physical Activity and Public Health: Updated Recommendation for Adults from the American College of Sports Medicine and the American Heart Association. *Medicine & Science in Sports & Exercise,* 39**,** 1423-1434.

Hayes, L., Mcparlin, C., Kinnunen, T. I., Poston, L., Robson, S. C. & Bell, R. 2015. Change in level of physical activity during pregnancy in obese women: findings from the UPBEAT pilot trial. *BMC Pregnancy and Childbirth,* 15.

Hodgson, S., Lurz, P. W. W., Shirley, M. D. F., Bythell, M. & Rankin, J. 2015. Exposure misclassification due to residential mobility during pregnancy. *International Journal of Hygiene and Environmental Health,* 218**,** 414-421.

Hystad, P., Davies, H. W., Frank, L., Loon, J. V., Gehring, U., Tamburic, L. & Brauer, M. 2014. Residential greenness and birth outcomes: evaluating the influence of spatially correlated built-environment factors. *Environmental Health Perspectives,* 122**,** 1095–1102.

Iyoke, C., Lawani, L., Ezugwu, E., Kk Ilo, Ilechukwu, G. & Asinobi, I. 2015. Maternal risk factors for singleton preterm births and survival at the University of Nigeria Teaching Hospital, Enugu, Nigeria. *Nigerian Journal of Clinical Practice,* 18.

James, P., Banay, R. F., Hart, J. E. & Laden, F. 2015. A Review of the Health Benefits of Greenness. *Current Epidemiology Reports,* 2**,** 131-142.

Kader Maideen, S. F., Mohd. Sidik, S., Rampal, L. & Mukhtar, F. 2014. Prevalence, Associated Factors and Predictors of Depression among Adults in the Community of Selangor, Malaysia. *PLOS ONE,* 9**,** e95395.

Kaźmierczak, A. 2013. The contribution of local parks to neighbourhood social ties. *Landscape and Urban Planning,* 109**,** 31-44.

Kheirabadi, G. R., Maracy, M. R., Akbaripour, S. & Masaeli, N. 2012. Psychometric Properties and Diagnostic Accuracy of the Edinburgh Postnatal Depression Scale in a Sample of Iranian Women. *Iranian Journal of Medical Sciences,* 37**,** 32-38.

Koohsari, M. J., Mavoa, S., Villanueva, K., Sugiyama, T., Badland, H., Kaczynski, A. T., Owen, N. & Giles-Corti, B. 2015. Public open space, physical activity, urban design and public health: Concepts, methods and research agenda. *Health & Place,* 33**,** 75-82.

Kramer, M. S., Séguin, L., Lydon, J. & Goulet, L. 2000. Socio-economic disparities in pregnancy outcome: why do the poor fare so poorly? *Paediatric and Perinatal Epidemiology,* 14**,** 194-210.

Kuo, F. E., Bacaicoa, M. & Sullivan, W. C. 1998. Transforming Inner-City Landscapes: Trees, Sense of Safety, and Preference. *Environment and Behaviour,* 30**,** 28-59.

Kuo, F. E. & Sullivan, W. C. 2001. Environment and Crime in the Inner City: Does Vegetation Reduce Crime? *Environment and Behaviour,* 33**,** 343-367.

Laurent, O., Wu, J., Li, L. & Milesi, C. 2013. Green spaces and pregnancy outcomes in Southern California. *Health & Place,* 24**,** 190-195.

LCDB. 2013. The New Zealand Land Cover Database (LCDB). *In:* LCDB (ed.) 3.3 ed. New Zealand.

Leigh, B. & Milgrom, J. 2008. Risk factors for antenatal depression, postnatal depression and parenting stress. *BMC Psychiatry,* 8**,** 24.

Leyland, A. H. & Groenewegen, P. P. 2003. Multilevel modelling and public health policy. *Scand J Public Health,* 31**,** 267-274.

Liu, J., Blair, S. N., Teng, Y., Ness, A. R., Lawlor, D. A. & Riddoch, C. 2011. Physical activity during pregnancy in a prospective cohort of British women: results from the Avon longitudinal study of parents and children. *European Journal of Epidemiology,* 26**,** 237-247.

Lu, L., Qu, Y., Tang, J., Chen, D. & Mu, D. 2015. Risk factors associated with late preterm births in the underdeveloped region of China: A cohort study and systematic review. *Taiwanese Journal of Obstetrics and Gynaecology,* 54**,** 647-653.

Lynch, K. E., Landsbaugh, J. R., Whitcomb, B. W., Pekow, P., Markenson, G. & Chasan-Taber, L. 2012. Physical Activity of Pregnant Hispanic Women. *American Journal of Preventive Medicine,* 43**,** 434-439.

Maas, J. 2008. *Vitamin G: Green environments - Healthy environments.* PhD, University in the Netherlands.

Maas, J., Van Dillen, S. M. E., Verheij, R. A. & Groenewegen, P. P. 2009a. Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place,* 15**,** 586-595.

Maas, J., Verheij, R., Spreeuwenberg, P. & Groenewegen, P. 2008. Physical activity as a possible mechanism behind the relationship between green space and health: A multilevel analysis. *BMC Public Health,* 8**,** 206.

Maas, J., Verheij, R. A., De Vries, S., Spreeuwenberg, P., Schellevis, F. G. & Groenewegen, P. P. 2009b. Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health,* 63**,** 967-973.

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S. & Spreeuwenberg, P. 2006. Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology and Community Health,* 60**,** 587-592.

Malambo, P., Kengne, A. P., Lambert, E. V., De Villiers, A. & Puoane, T. 2016. Prevalence and socio-demographic correlates of physical activity levels among South African adults in Cape Town and Mount Frere communities in 2008-2009. *Archives of Public Health,* 74**,** 54.

Markevych, I., Fuertes, E., Tiesler, C. M. T., Birk, M., Bauer, C.-P., Koletzko, S., Von Berg, A., Berdel, D. & Heinrich, J. 2014. Surrounding greenness and birth weight: Results from the GINIplus and LISAplus birth cohorts in Munich. *Health & Place,* 26**,** 39-46.

Marshall, E. S., Bland, H. & Melton, B. 2013. Perceived Barriers to Physical Activity Among Pregnant Women Living in a Rural Community. *Public Health Nursing,* 30**,** 361-369.

Matthey, S., Barnett, B. & White, T. 2003. The Edinburgh Postnatal Depression Scale. *British Journal of Psychiatry,* 182**,** 368.

Mccormack, G. R., Rock, M., Toohey, A. M. & Hignell, D. 2010. Characteristics of urban parks associated with park use and physical activity: A review of qualitative research. *Health & Place,* 16**,** 712-726.

Mccormack, G. R. & Shiell, A. 2011. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioural Nutrition and Physical Activity,* 8**,** 125.

McEachan, R. R. C., Prady, S. L., Smith, G., Fairley, L., Cabieses, B., Gidlow, C., Wright, J., Dadvand, P., Van Gent, D. & Nieuwenhuijsen, M. J. 2015. The association between green space and depressive symptoms in pregnant women: moderating roles of socioeconomic status and physical activity. *Journal of Epidemiology and Community Health,* 70**,** 253-259.

Mcmorris, O., Villeneuve, P. J., Su, J. & Jerrett, M. 2015. Urban greenness and physical activity in a national survey of Canadians. *Environmental Research,* 137**,** 94-100.

Melville, J. L., Gavin, A., Guo, Y., Fan, M.-Y. & Katon, W. J. 2010. Depressive Disorders During Pregnancy: Prevalence and Risk Factors in a Large Urban Sample. *Obstetrics and gynaecology,* 116**,** 1064-1070.

Merlo, J., Chaix, B., Yang, M., Lynch, J. & Ra˚stam, L. 2005. A brief conceptual tutorial of multilevel analysis in social epidemiology: linking the statistical concept of clustering to the idea of contextual phenomenon. *Journal of Epidemiology and Community Health,* 59**,** 443-449.

MFE. 2001. Valuing New Zealand's clean green image. New Zealand.

MFMER. 2017a. *Complications of postpartum depression* [Online]. Available: http://www.mayoclinic.org/diseases-conditions/postpartum-depression/basics/complications/con-20029130 [Accessed 19 February 2017].

MFMER. 2017b. *Depression (major depressive disorder)* [Online]. Available: http://www.mayoclinic.org/diseases-conditions/depression/basics/complications/con-20032977 [Accessed 18 February 2017].

Miles, L. 2007. Physical activity and health. *British Nutrition Foundation Nutrition Bulletin* 32**,** 314-363.

Mitchell, R. 2013. Is physical activity in natural environments better for mental health than physical activity in other environments? *Social Science & Medicine,* 91**,** 130-134.

MOH. 2010. Hospital-based Maternity Events 2006. Wellington, New Zealand: Ministry of Health.

MOH. 2012a. Healthy Beginnings: Developing perinatal and infant mental health services in New Zealand. New Zealand.

MOH. 2012b. Report on Maternity, 2010. Wellington, New Zealand Ministry of Health.

MOH. 2014. *Location boundaries (map)* [Online]. New Zealand: MOH. Available: http://www.health.govt.nz/new-zealand-health-system/key-health-sector-organisations-and-people/district-health-boards/location-boundaries-map [Accessed 23 September 2016].

MOH. 2017. *District health boards* [Online]. New Zealand. Available: https://www.health.govt.nz/new-zealand-health-system/key-health-sector-organisations-and-people/district-health-boards [Accessed 27 November 2017].

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G. & The, P. G. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLOS Medicine,* 6**,** e1000097.

Mokhtarian, P. L. & Cao, X. 2008. Examining the impacts of residential self-selection on travel behaviour: A focus on methodologies. *Transportation Research Part B: Methodological,* 42**,** 204-228.

Molyneaux, E., Poston, L., Khondoker, M. & Howard, L. M. 2016. Obesity, antenatal depression, diet and gestational weight gain in a population cohort study. *Archives of Women's Mental Health,* 19**,** 899-907.

Moniruzzaman, M., Ahmed, M. S. A. M. & Zaman, M. M. 2017. Physical activity levels and associated socio-demographic factors in Bangladeshi adults: a cross-sectional study. *BMC Public Health,* 17**,** 59.

Moore, M., Gould, P. & Keary, B. S. 2003. Global urbanisation and impact on health. *International Journal of Hygiene and Environmental Health,* 206**,** 269-278.

Morse, S. B., Zheng, H., Tang, Y. & Roth, J. 2009. Early School-Age Outcomes of Late Preterm Infants. *Paediatrics,* 123**,** e622-e629.

Morseth, B., Jacobsen, B. K., Emaus, N., Wilsgaard, T. & Jørgensen, L. 2016. Secular trends and correlates of physical activity: The Tromsø Study 1979-2008. *BMC Public Health,* 16**,** 1215.

Morton, S., Atatoa Carr, P. E., Bandara, D., Grant, C., Ivory, V. C., Kingi, T. K. R., Liang, R., Perese, L. M., Pryor, J. E., Reese, E., Robinson, E., Schmidt, J. M. & Waldie, K. E. 2010. Growing Up in New Zealand: A longitudinal study of New Zealand children and their families. Report 1: Before we are born. Auckland: Growing Up In New Zealand.

Morton, S. M. B., Atatoa Carr, P. E., Grant, C. C., Lee, A. C., Bandara, D. K., Mohal, J., Kinloch, J. M., Schmidt, J. M., Hedges, M. R., Ivory, V. C., Kingi, T. R., Liang, R., Perese, L. M., Peterson, E., Pryor, J. E., Reese, E., Robinson, E. M., Waldie, K. E. & Wall, C. R. 2012. Growing Up in New Zealand: A longitudinal study of New Zealand children and their families. Report 2: Now we are born. New Zealand.

Morton, S. M. B., Atatoa Carr, P. E., Grant, C. C., Robinson, E. M., Bandara, D. K., Bird, A., Ivory, V. C., Kingi, T. K. R., Liang, R., Marks, E. J., Perese, L. M., Peterson, E. R., Pryor, J. E., Reese, E., Schmidt, J. M., Waldie, K. E. & Wall, C. 2013. Cohort Profile: Growing Up in New Zealand. *International Journal of Epidemiology,* 42**,** 65-75.

Morton, S. M. B., Ramke, J., Kinloch, J., Grant, C. C., Carr, P. A., Leeson, H., Lee, A. C. L. & Robinson, E. 2015. Growing Up in New Zealand cohort alignment with all New Zealand births. *Australian and New Zealand Journal of Public Health,* 39**,** 82-87.

Mytton, O. T., Townsend, N., Rutter, H. & Foster, C. 2012. Green space and physical activity: an observational study using health survey for England data. *Health Place,* 18.

NASA. 2017. *Measuring Vegetation* [Online]. USA. Available: https://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php [Accessed 15 December 2017].

Nih. 2016. *Recommendations For Physical Activity* [Online]. Available: Http://Www.Nhlbi.Nih.Gov/Health/Health-Topics/Topics/Phys/Recommend [Accessed 30 August 2016].

Nowak, D. J., Crane, D. E. & Stevens, J. C. 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening,* 4**,** 115-123.

Nutsford, D., Pearson, A. L. & Kingham, S. 2013. An ecological study investigating the association between access to urban green space and mental health. *Public Health,* 127**,** 1005-1011.

Nutsford, D., Pearson, A. L., Kingham, S. & Reitsma, F. 2016. Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. *Health & Place,* 39**,** 70-78.

Odell, D. C., Kotelchuck, M., Chetty, V. K., Fowler, J., Stubblefield, G. P., Orejuela, M. & Jack, W. B. 2006. Maternal Hypertension as a Risk Factor for Low Birth Weight

Infants: Comparison of Haitian and African-American Women. *Maternal and Child Health Journal,* 10**,** 39-46.

ODPHP. 2016a. *Physical activity guidelines for adults* [Online]. Available: https://health.gov/paguidelines/guidelines/chapter4.aspx [Accessed 30 August 2016].

ODPHP. 2016b. *Physical activity guidelines: Additional Considerations for Some Adults* [Online]. Available: https://health.gov/paguidelines/guidelines/chapter7.aspx [Accessed 30 August 2016].

Oliver-Quetglas, A., Torres, E., March, S., Socias, I. M. & Esteva, M. 2013. Risk factors of depressive syndrome in young adults. *Actas espanolas de psiquiatria,* 41**,** 84-96.

Ord, K., Mitchell, R. & Pearce, J. 2013. Is level of neighbourhood green space associated with physical activity in green space? *International Journal of Behavioural Nutrition and Physical Activity,* 10**,** 127.

OWH. 2016. *Types of physical activity* [Online]. Available: http://www.womenshealth.gov/fitness-nutrition/how-to-be-active-for-health/type-of-physical-activity.html [Accessed 30 August 2016].

Pearce, J., Witten, K., Hiscock, R. & Blakely, T. 2007. Are socially disadvantaged neighbourhoods deprived of health-related community resources? *International Journal of Epidemiology,* 36**,** 348-355.

Pei, L., Kang, Y., Zhao, Y., Cheng, Y. & Yan, H. 2016. Changes in Socioeconomic Inequality of Low Birth Weight and Macrosomia in Shaanxi Province of Northwest China, 2010–2013: A Cross-sectional Study. *Medicine,* 95**,** e2471.

PHAC. 2012. *The Healthy Pregnancy Guide. Physical Activity and Pregnancy* [Online]. Public Health Agency of Canada. Available: http://www.phac-aspc.gc.ca/hp-gs/guide/04_pa-ap-eng.php [Accessed 01 December 2014].

Prince, S., Adamo, K., Hamel, M., Hardt, J., Gorber, S. & Tremblay, M. 2008. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioural Nutrition and Physical Activity,* 5**,** 56.

Richardson, E., Pearce, J., Mitchell, R., Day, P. & Kingham, S. 2010. The association between green space and cause-specific mortality in urban New Zealand: an ecological analysis of green space utility. *BMC Public Health,* 10**,** 240.

Richardson, E. A., Pearce, J., Mitchell, R. & Kingham, S. 2013. Role of physical activity in the relationship between urban green space and health. *Public Health,* 127**,** 318-324.

Rugel, E. J., Henderson, S. B., Carpiano, R. M. & Brauer, M. 2017. Beyond the Normalised Difference Vegetation Index (NDVI): Developing a Natural Space Index for population-level health research. *Environmental Research,* 159**,** 474-483.

Rwakarema, M., Premji, S. S., Nyanza, E. C., Riziki, P. & Palacios-Derflingher, L. 2015. Antenatal depression is associated with pregnancy-related anxiety, partner relations, and wealth in women in Northern Tanzania: a cross-sectional study. *BMC Women's Health,* 15**,** 68.

Sallis, J. F. & Saelens, B. E. 2000. Assessment of Physical Activity by Self-Report: Status, Limitations, and Future Directions. *Research Quarterly for Exercise and Sport,* 71**,** 1-14.

Salmond, C., Crampton, P. & Atkinson, J. 2007. NZDep2006 Index of Deprivation University of Otago.

Satyanarayana, V. A., Lukose, A. & Srinivasan, K. 2011. Maternal mental health in pregnancy and child behaviour. *Indian Journal of Psychiatry,* 53**,** 351-361.

Shanahan, D. F., Fuller, R. A., Bush, R., Lin, B. B. & Gaston, K. J. 2015. The Health Benefits of Urban Nature: How Much Do We Need? *BioScience,* 65.

Slama, R., Darrow, L., Parker, J., Woodruff, T. J., Strickland, M., Nieuwenhuijsen, M., Glinianaia, S., Hoggatt, K. J., Kannan, S., Hurley, F., Kalinka, J., Rám, R. S., Brauer, M., Wilhelm, M., Heinrich, J. & Ritz, B. 2008. Meeting Report: Atmospheric Pollution and Human Reproduction. *Environmental Health Perspectives,* 116.

Soames Job, R. 1999. Noise sensitivity as a factor influencing human reaction to noise. *Noise and Health,* 1**,** 57-68.

Solomon, E., Rees, T., Ukoumunne, O. C., Metcalf, B. & Hillsdon, M. 2013. Personal, social, and environmental correlates of physical activity in adults living in rural south-west England: a cross-sectional analysis. *International Journal of Behavioural Nutrition and Physical Activity,* 10**,** 129.

STAT. 2006. *Geographic definitions.* [Online]. New Zealand Statistics New Zealand. Available: http://www.stats.govt.nz/Census/about-2006-census/2006-census-definitions-questionnaires/definitions/geographic.aspx [Accessed 01 December 2014].

STAT. 2013. Geographic boundary files. *In:* NZ.STAT (ed.). New Zealand: NZ.Stat.

STAT. 2017. *Ethnicity* [Online]. New Zealand. Available: http://www.stats.govt.nz/methods/classifications-and-standards/classification-related-stats-standards/ethnicity/definition.aspx# [Accessed 21 November 2017].

Stigsdotter, U. A. & Grahn, P. 2004. A Garden at Your Doorstep May Reduce Stress–Private Gardens as Restorative Environments in the City. In Proceedings of Open Space, People Space: International Conference on Inclusive Environments, Open Space Research.

Strath, S. J., Kaminsky, L. A., Ainsworth, B. E., Ekelund, U., Freedson, P. S., Gary, R. A., Richardson, C. R., Smith, D. T. & Swartz, A. M. 2013. Guide to the Assessment of Physical Activity: Clinical and Research Applications. A Scientific Statement From the American Heart Association. *Circulation*, 128.

Sugiyama, T., Leslie, E., Giles-Corti, B. & Owen, N. 2008. Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? *Journal of Epidemiology and Community Health,* 62**,** e9-e9.

Sullivan, W. C., Kuo, F. E. & Depooter, S. F. 2004. The Fruit of Urban Nature: Vital Neighbourhood Spaces. *Environment and Behaviour,* 36**,** 678-700.

Suttorp, M. M., Siegerink, B., Jager, K. J., Zoccali, C. & Dekker, F. 2015. Graphical presentation of confounding in directed acyclic graphs. *Nephrology Dialysis Transplantation,* 30**,** 1418-1423.

Thompson, O. & Ajayi, I. 2016. Prevalence of Antenatal Depression and Associated Risk Factors among Pregnant Women Attending Antenatal Clinics in Abeokuta North Local Government Area, Nigeria. *Depression Research and Treatment,* Article ID 4518979.

Toftager, M., Ekholm, O., Schipperijn, J., Stigsdotter, U., Bentsen, P., Grønbæk, M., Randrup, T. B. & Kamper-Jørgensen, F. 2011. Distance to Green Space and Physical Activity: A Danish National Representative Survey. *Journal of Physical Activity and Health,* 8**,** 741-749.

Tsai, A. C., Scott, J. A., Hung, K. J., Zhu, J. Q., Matthews, L. T., Psaros, C. & Tomlinson, M. 2013. Reliability and Validity of Instruments for Assessing Perinatal Depression in African Settings: Systematic Review and Meta-Analysis. *PLoS ONE,* 8**,** e82521.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A. & Zelson, M. 1991. Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology,* 11**,** 201-230.

USEPA. 2014. *What is Open Space/Green Space?* [Online]. Washington DC: United States Environmental Protection Agency Available: http://www.epa.gov/region1/eco/uep/openspace.html [Accessed 01 December 2014].

Van Den Berg, M., Van Poppel, M., Van Kamp, I., Andrusaityte, S., Balseviciene, B., Cirach, M., Danileviciute, A., Ellis, N., Hurst, G., Masterson, D., Smith, G., Triguero-Mas, M., Uzdanaviciute, I., Wit, P. D., Mechelen, W. V., Gidlow, C., Grazuleviciene, R., Nieuwenhuijsen, M. J., Kruize, H. & Maas, J. 2016. Visiting green space is associated with mental health and vitality: A cross-sectional study in four european cities. *Health & Place,* 38**,** 8-15.

Verheij, R. A. 1996. Explaining urban-rural variations in health: A review of interactions between individual and environment. *Social Science & Medicine,* 42**,** 923-935.

Villeneuve, P. J., Jerrett, M., G. Su, J., Burnett, R. T., Chen, H., Wheeler, A. J. & Goldberg, M. S. 2012. A cohort study relating urban green space with mortality in Ontario, Canada. *Environmental Research,* 115**,** 51-58.

Vintzileos, A. M., Ananth, C. V., Smulian, J. C., Scorza, W. E. & Knuppel, R. A. 2002. The impact of prenatal care in the United States on preterm births in the presence and absence of antenatal high-risk conditions. *American Journal of Obstetrics & Gynaecology,* 187**,** 1254-1257.

Waldie, K. E., Peterson, E. R., D'souza, S., Underwood, L., Pryor, J. E., Carr, P. A., Grant, C. & Morton, S. M. B. 2015. Depression symptoms during pregnancy: Evidence from Growing Up in New Zealand. *Journal of Affective Disorders,* 186**,** 66-73.

Ward Thompson, C., Aspinall, P., Roe, J., Robertson, L. & Miller, D. 2016. Mitigating Stress and Supporting Health in Deprived Urban Communities: The Importance of Green Space and the Social Environment. *International Journal of Environmental Research and Public Health,* 13**,** 440.

WHO. 2001. Mental Health A Call for Action by World Health Ministers.

WHO. 2004. Occupational noise : assessing the burden of disease from work-related hearing impairment at national and local levels. *WHO Environmental Burden of Disease Series.* Geneva.

WHO. 2016a. *Depression* [Online]. Available: http://www.who.int/topics/depression/en/ [Accessed 23 November 2016].

WHO. 2016b. *Physical Activity* [Online]. Available: http://www.who.int/dietphysicalactivity/pa/en/ [Accessed 29 August 2016].

WHO. 2016c. Urban green spaces and health. Copenhagen, Denmark.

WHO. 2016d. *Urbanisation and health* [Online]. Available: http://www.who.int/bulletin/volumes/88/4/10-010410/en/ [Accessed 14 December 2016].

WHO. 2017a. *Global recommendations on physical activity for health* [Online]. Available: http://www.who.int/dietphysicalactivity/publications/9789241599979/en/ [Accessed 06 December 2017].

WHO. 2017b. *Health topics: Pregnancy* [Online]. Available: http://www.who.int/topics/pregnancy/en/ [Accessed 28 November 2017].

WHO. 2017c. *Physical Activity and Adults* [Online]. Available: http://www.who.int/dietphysicalactivity/factsheet_adults/en/ [Accessed 02 February 2017].

WHO & UNICEF. 2004. Low birthweight: Country, regional and global estimates. New York: UNICEF.

Witten, K., Hiscock, R., Pearce, J. & Blakely, T. 2008. Neighbourhood access to open spaces and the physical activity of residents: A national study. *Preventive Medicine,* 47**,** 299-303.

Witten, K., Mccreanor, T. & Kearns, R. 2003. The place of neighbourhood in social cohesion: insights from massey, West Auckland. *Urban Policy and Research,* 21**,** 321-338.

Xu, H., Dai, Q., Xu, Y., Gong, Z., Dai, G., Ding, M., Duggan, C., Hu, Z. & Hu, F. B. 2015. Time trends and risk factor associated with premature birth and infants deaths due to prematurity in Hubei Province, China from 2001 to 2012. *BMC Pregnancy and Childbirth,* 15**,** 1-9.

Zhang, Y., Van Dijk, T., Tang, J. & Berg, A. 2015. Green Space Attachment and Health: A Comparative Study in Two Urban Neighbourhoods. *International Journal of Environmental Research and Public Health,* 12**,** 14342.

Zhou, M., Feng, X., Yong, J., Li, Y., Zhang, M., Page, A., Astell-Burt, T. & Zhao, W. 2017. Lifting the lid on geographic complexity in the relationship between body mass index and education in China. *Health & Place,* 46**,** 1-5.