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Health benefits of urban agriculture in countries of the Global North

PhD Thesis

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July 2022

Declaration of originality

I declare that the presented thesis is the result of my research and work. When the work of other authors is included it is referenced appropriately. The text shown here was derived from previously published work by the author in three conferences and four research papers. By being either the supervisors or advisers of this work, the other four authors agreed that the content of the articles could be used in this document.

For each of the published chapters of this thesis, I added the CRediT statement at the beginning of the chapter.

Catalina Cruz-Piedrahita (CID 01265901)

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Acknowledgements

I want to thank my supervisor Dr Audrey de Nazelle, for accepting the project and for all her help elaborating it. I also want to thank my co-supervisor, Dr Caroline Howe, for agreeing to help me with my PhD path and believe in it. She was most helpful and patient. A student could not wish for a better supervisor.

The Colombian government and the Administrative Department of Science, Technology and Innovation funded my PhD through its financial support with the program 'Doctorados en el exterior'. Thanks to this program, I focused on the research that I present in this document today.

To my PhD colleagues Karina Corada, Rosie Riley, Diego Hopkins, and Dylan Futzyder, who contributed to this project's culmination with their support, patience, and unconditional help.

Finally, I want to thank my family for being there every step of the way, and my friends, especially Juan Enciso, Ana Alvarez, Catalina Orejuela, and Santiago Herrera, for helping me with their knowledge and wisdom about these topics.

Abstract

BACKGROUND AND AIM: Urban agriculture may benefit the health of those who practice it by encouraging healthier habits such as increased consumption of fruit and vegetables, physical activity, exposure to green spaces, and social interaction. These habits may also act synergistically to improve health above and beyond that expected if the impacts of these habits were additive. The pathways by which urban agriculture may impact health and any potential synergies between healthy behaviours remains under-explored.

METHODS: A literature review informed the development of a conceptual model describing mechanisms by which urban agriculture has the potential to improve population health. A survey of 625 UK urban horticulturalists was undertaken to compare participants' healthy behaviours and health status with the general urban population represented by UK's large UK Biobank cohort (N $\sim$ 500,000). The cohort was additionally used to evaluate interactions between healthy behaviours and any synergistic effects of these on health markers.

RESULTS: Urban horticulturalists were found to display healthier behaviours (fruit and vegetable intake, physical activity, and time outdoors (or greenspace expossure)) than the general UK population sample. However, this was not necessarily reflected in health markers (Body mass index (BMI), medication use, loneliness, happiness, and self-health assessment). In contrast, evidence for synergies between healthy behaviours was found and these relationships are complex. Individually, the lifestyle behaviours: fruit and vegetable intake and physical activity positively correlate with health markers, but greenspace exposure does not. The interaction between fruit and vegetable intake and physical activity is also associated with good health markers. Still, when greenspace exposure is included, the associations are lost or, in some cases, are negatively associated. I showed that interactions between healthy behaviours are not simple with respect to synergistic effects: the relationships are not constant and vary depending on the level or state of the interacting lifestyle behaviours.

CONCLUSION: Urban agriculture has a clear potential to improve different health behaviours, and furthermore, these behaviours may act synergistically to either the further improvement of, or detriment to, health. With logical and systematic planning, urban agriculture can thus be seen as an effective and efficient approach to improve urban living and the health of urban populations in developed countries.

Preface: Thesis outline

This thesis explores the benefits of urban agriculture and its association to, and synergies with, public health. **Fig. 1** provides an illustrative framework for the thesis. This illustrates the topic for each chapter and the interactions between them and the overall structure and narrative of the thesis.

The dissertation consists of four main sections divided into eight chapters. The first section 'Introduction and relevant information for this thesis' introduces the topic and presents the main aim and objectives (**Chapters 1 and 2**) as they relate to the broader literature and research gaps.

Chapter 3 presents a scoping review of the health benefits of urban agriculture in countries of the Global North. It provides a theoretical framework illustrating the mechanisms and pathways between urban agriculture and public health. This chapter has been published; therefore, it has been formatted to include an introduction, methods, results, and discussion as a stand-alone chapter.

The second section containing the empirical methods is divided into four chapters (**Chapters 5 - 7**). **Chapter 4** presents the methodology followed for this research and provides information on the development and implementation of the horticulturalists' survey used in this research. It also introduces the UK Biobank cohort, which is the main external data source for this thesis. Finally, **Chapter 4** describes how these data bases were cleaned and prepared for the analysis in the empirical section. **Chapters 5 - 7** present the empirical evidence for this research. Each chapter tackles one objective of the thesis, and each chapter has been prepared for, and submitted as separate publications, so they contain an introduction, methods, results, and discussion.

The final section includes the general discussion and conclusion for the thesis. **Chapter 8** synthesises all the research findings, discusses their importance and relevance to urban agriculture concerning public health in the Global North, and compares the benefits and downsides of urban agriculture projects with other nature-based solutions. This section also covers the research limitations along with recommendations for future work, and the final conclusion of the entire thesis.

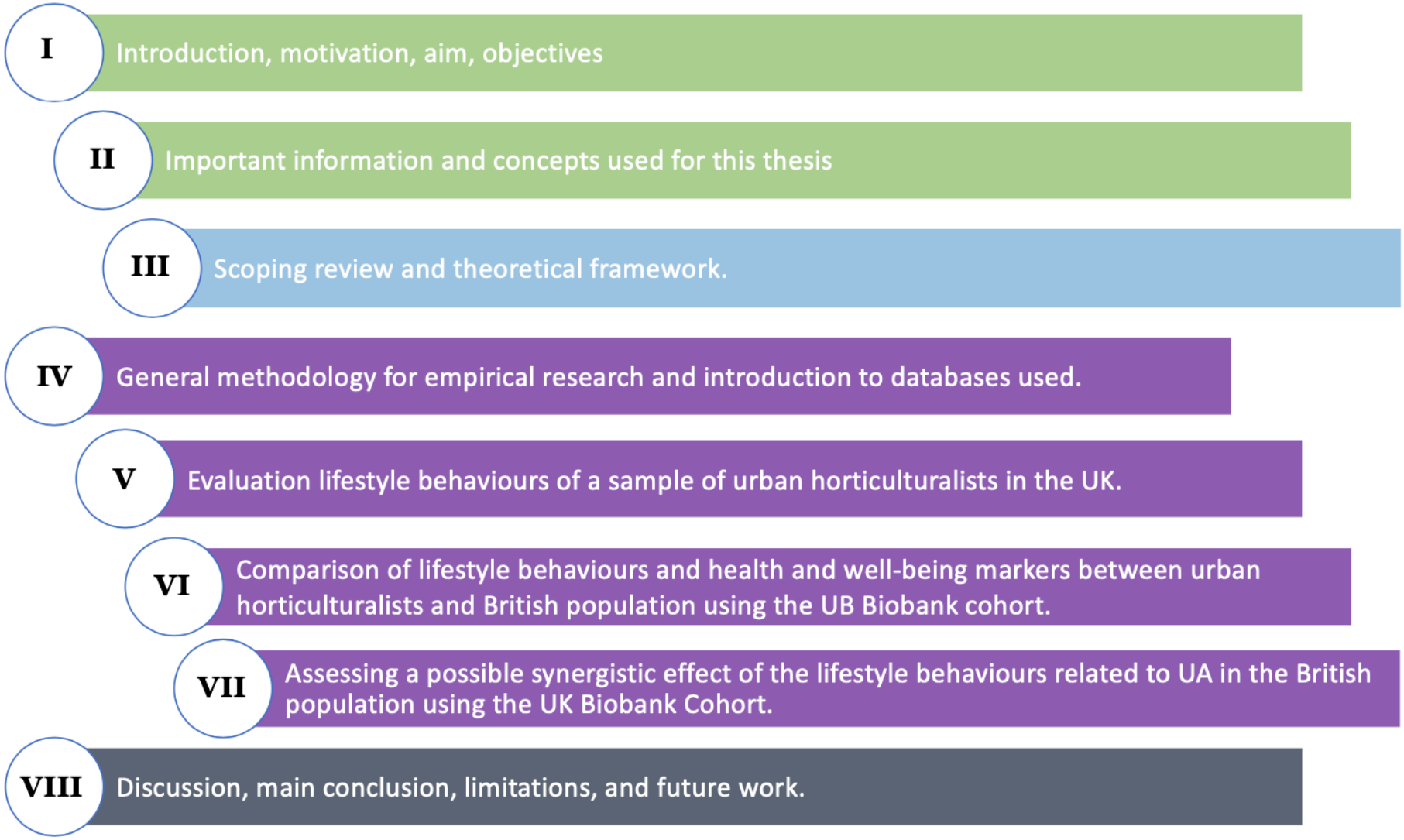

Figure 1: This image illustrates the framework for the thesis (eight chapters). The first chapters (Chapters 1 and 2; in green) introduce the topic of this research. The main body of the thesis consists of four chapters and explores the association between urban agriculture and public health. **3** (in blue) is the scoping review which provides the research background for the subsequent empirical chapters of the thesis (**Chapters 5 - 7; in purple**). **Chapter 4** (also in purple) provides the general methodology for the empirical part of the research, and the final chapter (**Chapter 8; in grey**) presents the discussion and conclusions for the whole thesis.

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Chapter 1

Introduction, motivation, aim, and objectives

1.1 Introduction

In today's world, for the first time in human history, more people live in cities (54% of the worldwide population) than in rural areas (46%), and this growth in urban populations is only set to continue. It is expected that by 2050, 66% of people will live in urban areas (United Nations, 2015). One of the main drivers of this growth in urban populations is that, on the whole, cities provide more options for livelihoods than rural areas and the migration to urban areas is often encouraged in the name of 'development' (*ibid*). For many residents, cities provide infrastructure that provides access to clean water, sanitation, hospitals, and education. However, with a growing global population increasingly agglomerated in urban centres (Zlotnik, 2017), new challenges in urban areas arise, such as lack of access to healthy food sources, recreational areas, and places to exercise or interact with nature (McMichael, 2000; Norton et al., 2015), as well as reduced access to services such as hospitals, schools and healthy living environments (safe buildings, sanitation and clean water). These issues have been linked to an increasing prevalence of obesity (Lachowycz and Jones, 2011; Swinburn et al., 2011), chronic diseases, mental health issues and feelings of isolation (Lachowycz and Jones, 2011; O'neil et al., 2014; Van Den Bosch and Nieuwenhuijsen, 2017). Today, inequality tends to be higher in cities than in rural areas (United Nations, 2015), and is a result differences in

income, ethnicity, migration status, gender, and assets. People in deprived areas of cities are particularly vulnerable to being negatively impacted by the urban environment and have greater exposure to health risks than other city dwellers, or even people with similar economic capacity living in rural areas (Orsini et al., 2013). With rates of migration rates to cities continuing to rise and a rapid increase in urban population density (United Nations, 2015; Orsini et al., 2014), it is vital to raise concerns, and seek solutions to, these social, environmental, and public health challenges. In 2012, after the Rio conference, the United Nations recognized the need to tackle urban poverty and prioritize sustainable development for cities worldwide (UN, 2012). Society has relied on technology to overcome these issues, such as clean energy (Østergaard et al., 2020) or sustainable industry (Dantas et al., 2021). Nevertheless, it has become clear that technology alone will not provide the solution to all of these issues (Huesemann, 2003) and other, bottom-top approaches, are required. For example, social changes, improved use of natural environments and resources (Jiménez-Aceituno et al., 2020; Maher and Buhmann, 2019), and application of nature-based solutions (Kabisch et al., 2017; Seddon et al., 2020).

One proposed solution to global challenges such as urbanisation, public health, food security, and climate change is urban and peri-urban agriculture. The United Nations' Food and Agriculture Organization (FAO) defines urban and peri-urban agriculture as the growing of plants or animals within or around cities and the processing and marketing of agricultural products (FAO, 1999). Produced in managed agro-ecosystems, environments suitable for urban food production include forests, (industrial) rooftop gardens and residential/community gardens (Thiesen et al., 2022). Other options include vacant land, edible landscaping, and vertical edible green infrastructure (*ibid*). Worldwide, cities grow 15–20% of the world's food (Armar-Klemesu, 2000) and can produce a wide range of plant and animal foods (*e.g.*, vegetables, fruits, eggs, milk). Moreover, urban and peri-urban agriculture has many advantages over rural agriculture, including proximity to markets, availability of fresh food, and lower transportation costs (De Bon et al., 2010; Orsini et al., 2013). Local food supply through urban and peri-urban agriculture can reduce negative environmental impacts due to the reduction of food miles, packaging waste, and energy used for storage (Specht et al., 2014; Lovell, 2010). Furthermore, urban and peri-urban agriculture can help tackle, at least at an urban level, three of the 17 United Nations' Sustainable Development Goals: sustainable cities and communities (Goal 11), zero hunger (Goal 2), and good health and well-being (Goal 3) (Nicholls et al., 2020). These three goals are, in part, caused by pervasive and long-lasting urban problems (*e.g*, elevated prices of goods

in urban areas) that can be tackle with urban and peri-urban agriculture, such as generating healthy foods whilst optimising undervalued urban spaces (Bank, 2013), minimising the environmental impact of the city (Mougeot, 2006), providing ecosystem services to the population (Thomas, 2014), disposing of organic waste, and treating wastewater and grey-water (Nicholls et al., 2020). Urban and peri-urban agriculture thus supports the improvement of key features of urban ecosystems as well as concurrently facilitating urban food supply through the creation and implementation of edible green infrastructure (Lin et al., 2017).

It is important to note, however, that the motivations and benefits of urban and peri-urban agriculture are not necessarily the same in the Global North as in the Global South; however, most of the research focuses only on the Global South (Tornaghi, 2014; Mok et al., 2014). Tornaghi (2014) highlighted the marked difference between research focusing on the Global South and research focusing on the Global North, calling it the "evident problem when approaching the literature on UA is its overwhelming focus on cities in the Global South" (**page 554**). It is likely that one of the reasons for this bias is the importance for food security and household income in developing countries (Zezza and Tasciotti, 2010; Bank, 2013; Thomas, 2014; Badami and Ramankutty, 2015). Another possibility might be that the percentage of people practising any type of urban agriculture is higher in the Global South than in Global North (Armar-Klemesu, 2000; Badami and Ramankutty, 2015). Many citizens in developing countries rely on urban and peri-urban agriculture for not only for food but also for income. According to Zezza and Tasciotti (2010), the percentage of urban dwellers in African countries involved in any type of these activities is close to 40%, and in Latin America it is up to 50% (Armar-Klemesu, 2000). The need to reduce poverty and food insecurity of city dwellers in countries of the Global South might be why, traditionally, research has focused mainly on developing countries. In the Global South, it is viewed as a strategy to combat food insecurity, minimise gender inequality, and generate economic support for the poorest sectors of the population (Thomas, 2014). In these countries, urban and peri-urban agriculture are usually considered primary tools for reducing hunger and improving nutritional status (Zezza and Tasciotti, 2010; Badami and Ramankutty, 2015; Bank, 2013; Thomas, 2014). By providing fresh produce, urban agriculture helps alleviate malnutrition and increase household income (Nugent, 2000; Pearson et al., 2010). Public initiatives by local and national governments with the collaboration of the World Bank, and the United Nations have led to increased regional awareness of urban agriculture growth and its potential to enable sustainable development (Bank, 2013; Thomas, 2014).

Recently, urban agriculture, more so than peri-urban agriculture, has also become a widespread land use in developed countries (Hardman and Larkham, 2014b; Thornbush, 2015; Tornaghi, 2014; Gray et al., 2020; Opitz et al., 2016; Tornaghi and Certomà, 2019). It has been linked to numerous environmental, social, and health movements in the Global North, such as the green movement, food justice movements, and guerrilla gardens (Tornaghi, 2014; Gray et al., 2020; Opitz et al., 2016; Hardman and Larkham, 2014a; Tornaghi and Certomà, 2019). It also appears to support inclusion and social interaction through access to green spaces and beautification of the city (Mougeot, 2006; Duchemin et al., 2008; Lovell, 2010; Cohen and Reynolds, 2015). Moreover, in these countries, urban agriculture has begun to be recognised as a tool to promote proper nutrition, including food security, to the most vulnerable populations within cities (Petts and Organization, 2001; Opitz et al., 2016; Clendenning et al., 2016; Gregory et al., 2016; Morgan, 2015; Vitiello and Wolf-Powers, 2014). It has been suggested that increasing inequalities in the Global North, added to increased food prices, have contributed to the rise of urban agriculture as a practice to address food insecurity (Algert et al., 2016; Diekmann et al., 2020; Kortright and Wakefield, 2011). Hence, addressing these inequalities is no longer a specific Global South issue. For instance, according to the FAO and the World Health Organisation (WHO), as of 2018, 2.2 million people were severely food-insecure in the UK (WHO, 2018), which was the worst in Europe. In a report commissioned by the British parliament, the UK has failed to address malnutrition in all its forms, with food insecurity and obesity both on the rise (House of Commons, 2019).

Regardless of differences between the Global South and Global North, urban agriculture provides both health and well-being benefits that have been widely recognised in the literature (Brown and Jameton, 2000). In particular, there is a benefit for people's health and well-being through direct effects such as stress reduction, fruit and vegetable consumption, and more robust social interactions (Soga et al., 2017b,a). Urban agriculture has also been shown to improve the health of urban dwellers indirectly through ecosystem services such as reductions in the heat island effect, storm-water filtration (Goldstein et al., 2016), and improvement in soil quality (Dubbeling et al., 2009). For example, in the past two decades, Detroit has implemented several urban agricultural programs to reduce obesity rates, increase fruits and vegetable intake, and even improve economic growth (Gray et al., 2020). In Baltimore the local government has included urban agriculture programs as part of its development plans (of Sustainability, 2013). However, there is still a lot of controversy around the impact of urban agriculture programs in the Global

North (Gray et al., 2020). Typically, policymakers in these countries do not consider urban agriculture as a potential population-based intervention to address multiple urban challenges (Lovell, 2010; Thornton, 2017; Kingsley et al., 2021). For policy-makers and urban planners to consider urban agriculture as a nature-based solution to some of the issues in cities and to implement it correctly, specific knowledge is required. As mentioned above, most of the research has been done in the Global South (Orsini et al., 2013), and Global North policymakers and urban planners lack the evidence required to push the urban agriculture agenda forward (Lovell, 2010; Taylor and Lovell, 2015; Cohen and Reynolds, 2015; Hardman et al., 2018). This gap needs to be filled an information regarding all aspects of urban agriculture and peri-urban agriculture, from its economic potential, governance, ecology, social implications, health, is urgently required *etc* (Pearson et al., 2010; Siegner et al., 2018). In this thesis I aim to fill part of the knowledge gap surround the implementation and potential impact of urban agriculture in the Global North by exploring the benefits of urban horticulture through an ecosystem services lens.

However, it is important to note, that urban and peri-urban agriculture encompass a wide variety of types of agriculture practised within cities and on their periphery. Evaluating them all is thus too broad a topic for a single thesis. For this reason, in this research, I focus on the most common type of urban agriculture in developed countries, urban horticulture (Mok et al., 2014). In the following section, I will explain in more depth the concepts of urban agriculture and urban horticulture and the definition of urban agriculture that will be used in this thesis.

1.2 Urban agriculture

1.2.1 Urban agriculture's definitions and important concepts

Definitions of urban agriculture

There are multiple definitions of urban agriculture, although no consensus on a universal definition. This is due in part to the diversity of activities, places, techniques, purposes, and products found in urban agriculture projects. Depending on the focus of the studies, urban agriculture might be defined by types of economic activities, food/non-food product categories and sub-

categories, the intra-urban and peri-urban character of the location, types of areas where it is practised, types of production systems, product destination, and production scale. However,most of the definitions tend to circle around food production and similar products inside urban and peri-urban areas. For example, Mougeot (2000) define urban agriculture as:

'Urban agriculture is an industry located within (intra-urban) or on the fringe (peri- urban) of a town, a city or a metropolis, which grows and raises, processes and distributes a diversity of food and non-food products, (re-)using largely human and material resources, products and services found in and around that urban area, and in turn supplying human and material resources, products and services largely to that urban area.' (**page 10**)

Zezza and Tasciotti (2010) defines it as:

'The production of crop and livestock goods within cities and towns.' (**page 265**)

Pearson et al. (2010) state that: 'Urban agriculture is the production, processing, and marketing of food and related products in urban and peri-urban areas, usually through intensive cultivation and for consumption in the same urban or peri-urban area.' (**page 7**)

Definition of urban agriculture use in this thesis

For this thesis I first define what I mean when I'm talking about urban agriculture, then I identify the forms of urban agriculture I'm focusing on. The definition of urban agriculture used in this project was based on the three previous definitions, but I made some changes for the purpose of this thesis. The focus of my thesis is on plant production, known as horticulture, because it is the most common type of urban agriculture in the Global North. As previous authors have done (Mok et al., 2014; Lin et al., 2017; Gulyas and Edmondson, 2021). I will still be using the broader term of urban agriculture throughout my thesis.

Finally, due to the focus on public health and well-being with respect to urban agriculture, I do not include urban agriculture projects that have an economic driver, such as private hydroponic farms. The final definition of urban agriculture as used in this thesis is as follows:

'Any practice of horticulture that takes place in open air, within the boundary of an urban area, like community gardens, private and public allotments, backyard gardens, and roof gardens,amongst others'.

Definition of people involved in urban agriculture projects use in this thesis

Defining people who practice urban agriculture presents similar challenges. Many terms apply to people who practice agriculture inside a city, but none of them embraces the total variation of these activities. For example, the term urban gardener is typical, but gardening is an activity that can be considered to be urban agriculture but not vice-versa, because the term urban agriculture includes other practices in addition to gardening, for example, hydroponics. 'Urban farmers' is another term used but it is related mainly to those working on urban farms. As this thesis only examines urban agriculture practices that use plants and not animals, the term 'urban horticulturalists' is used in this thesis to refer to the people practicing the types of urban agriculture assessed here. Types of urban agriculture used in this thesis.

As discussed above, the definition of urban agriculture presents several issues due to the heterogeneity of practices that are considered types of urban agriculture. Appendix ?? provides the types of agriculture identified in the literature, whilst below I list the types of urban agriculture considered in this thesis, which vary depending on the chapter. For the theoret- ical framework and scoping review (Chapter 3), I considered all kinds of urban horticulture practiced outdoors, including gardening, allotments, orchards, community gardens, open space vertical gardening, aquaponics programs performed outdoors, and roof gardens. These types of urban agriculture are also considered in the final discussion and conclusion chapters. Two quantitative chapters (Chapters 5 and 6) are based on a survey that specifically included participation from urban dwellers involved only in either allotments, community gardens, urban farms, or private gardens/backyards.

1.3 Motivation

The evidence supporting the links between positive lifestyle behaviours (such as healthy eating and exercise) and benefits for well-being and physical and mental health have been well established. Having an unhealthy diet, low levels of physical activity and lack of greenspace can contribute to mental health problems such as depression and stress (Van den Berg et al., 2015; Hu et al., 2003; Loprinzi, 2015) as well as physical health problems such as obesity, metabolic disorders (Freudenberg, 2011; Banks et al., 2011), diabetes, hypertension, cancer, strokes, and

cardiovascular diseases (Maas et al., 2008; Pitsavos et al., 2006). Given the prevalence of chronic diseases (Price, 2017) and mental health issues (Wittchen et al., 2011) in developed countries and their association with unhealthy lifestyle behaviours, urban agriculture can be seen as a potentially attractive tool to help address some of the problems related to urban living, for example sedentary behaviour (Banks et al., 2011), unhealthy diets (Mintz and McManus, 2014), and lack of exposure to greenspace (Van Den Bosch and Nieuwenhuijsen, 2017).

Research on the potential benefits of urban agriculture and the association to healthy lifestyle behaviours and potential resulting health impacts, in the Global North, has expanded in recent decades. However, the current empirical epidemiological evidence available on the health benefits of urban agriculture, exclusively in the Global North, is insufficiently robust. As shown in the results section of **Chapter 3**, most existing studies have relied on small sample sizes, lack longitudinal and intervention studies to establish causation, or have used solely qualitative interview-based techniques (Audate et al., 2019). In addition, existing epidemiological studies have assessed one health marker or one lifestyle behaviour at a time, thus failing to explore one of the critical attractions of urban agriculture, *i.e.*, which is its potential to to tackle multiple health determinants at once.

Strong social and epidemiological evidence is required in order for policymakers to consider urban agriculture as a nature-based solution to promote health and well-being in cities of the Global North (Pourias et al., 2016; Mok et al., 2014). Nature-based solutions seek to promote systemic approaches to economic, social, and environmental issues by supporting and maintaining the ecosystems. However, it is important to determine the added benefits or downsides urban agriculture has when compared to other nature-based solutions that are already being used, such as urban forests and green infrastructure.

For this project, I take advantage of the unique opportunity to evaluate lifestyle behaviours and health measures related to urban gardening, presented by the rise in popularity of urban agriculture in the UK population, alongside the availability of a large sample of urban residents provided by the UK Biobank. The motivation for conducting this research was to provide a holistic approach to evaluating the benefits from urban agriculture as well as deepening our understanding of the different pathways and mechanisms linking urban agriculture projects to health and well-being.

1.4 Aim

This PhD project aims to understand and provide guidance on how urban agriculture might be a useful resource to improve and promote population health and well-being in urban areas of the Global North, through its effects on multiple pathways to health such as exposure to greenspace, physical activity, social cohesion, and healthy eating behaviours.

1.5 Objectives

Objective I. To define the multiple mechanisms by which urban agriculture in the Global North may impact health through:

I.I. Conducting a scoping review of the literature on potential health, social and environmental impacts of urban agriculture particularly in the domains of:

- Ecosystem Services
- Physical activity
- Greenspace exposure
- Fruit and vegetable intake
- Social interaction

I.II. Developing a conceptual framework based on the literature to establish linkages and evaluate the strength of knowledge in these domains.

Objective II. To evaluate whether urban agriculture participation is associated with healthier lifestyles in a general population through:

II.I. A survey of urban horticulturalists in the main cities of the UK followed by an analysis of whether participants' beliefs on diet, physical activity, social interactions, greenspace exposure, and self-perceived health changed after being involved in urban agriculture projects.

II.II. Comparing the lifestyle and self-perceived health of urban horticulturalists sampled in the survey, with the general population as represented by the UK Biobank cohort.

Objective III. To assess whether a combined effect of the three main behaviours (fruit and vegetable intake, exercising, and being exposed to a green area) associated with urban agriculture improves population health more than the sum of their separate effects on health. In other words, are city dwellers that have a healthy diet, are physically active and interact with greenspace, healthier than expected? For this objective, I will undertake an analysis of the UK Biobank cohort comparing single versus joint effects of the behaviours mentioned.

1.6 Information to consider for the rest of the document

The chapters from the thesis body (**Chapter 3, Chapter 5, Chapter 6, and Chapter 7**) address specific research questions and objectives. At the beginning of each chapter, a section called: What this chapter is about? explains the purpose of the chapter and the objectives associated with it. The discussions within the individual chapters will only address the specific results to avoid repetition with the general discussion at the end of the thesis. In the last chapter of the thesis **Chapter 8**, I will discuss the general points of the thesis, limitations, the future work, and the main conclusions of the thesis as a whole.

Chapter 2

Important information and concepts used in this thesis

2.1 Relevant information for this work

This chapter provides the key concepts underpinning this thesis including the ecosystem services framework and definitions of urban agriculture used in this research. I provide an explanation of the potential health and well-being benefits and the health risks of urban agriculture as well as describing the importance of lifestyle behaviours or exposures related to urban agriculture projects for health and well-being. This section also includes a brief history of public health research as related to urban agriculture and lifestyle behaviours. Finally, in this chapter I introduce several definitions and concepts important for this thesis, **Appendix A** has a table with the definitions introduced here and the types of urban agriculture recognised in the literature.

2.2 Ecosystem services

History and classifications of ecosystem services

The concept of the environment as providing 'services' to people occurred at a similar period as the environmental movement arose in the late 1960s (Mooney and Ehrlich, 1997). There was, at that time, growing awareness of the impact people were having on the planet and biodiversity,

and the effect of this on the Earth's ability to be able to continue producing sufficient goods and services to support the world's growing human population and to provide a suitable climate for habitation (Mooney and Ehrlich, 1997; Costanza et al., 1997). The concept of 'ecosystem services' was thus coined, and a field of research emerged, focused on understanding the inter-relationship between, capital, the health and well-being of people, and the natural world (*ibid*).

As the concept of 'ecosystem services' has become more mainstream, the definitions of the idea itself have also evolved. Daily (1997) attempted to summarise some of the work in this area in her book *'Nature's Services: Societal Dependence on Natural Ecosystems'*. In this work, she defines ecosystem services as *'the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life'* (**page 3**). This definition emphasises the changing biophysical conditions within ecosystems and the interactions between these and their biotic components. At the same time, Costanza et al. (1997) emphasised, in their article, the role that ecosystems play in maintaining life support systems on the planet and the relationship these life support systems have with human well-being.

In 2000, an initiative that would last five years and bring together the efforts of nearly 2000 scientists and decision-makers from 85 countries, known as the Millennium Ecosystem Assessment (MEA) (Millennium ecosystem assessment, 2005), began. This was the first time the fundamental role of ecosystem services for human well-being was recognised at the global scale and resulted in the establishment of the first 'official' definition of ecosystem services as *'the benefits people obtain from ecosystems'* (**page 8**) (*ibid*). The outcomes of the MEA have since gone on to provide the foundation for most subsequent research on ecosystem services.

One of the main objectives of the MEA was to offer decision-makers and policymakers a baseline for the status of ecosystem services (as they were in 2005) as well as providing a framework for understanding and managing ecosystem services going forward. As such, a conceptual framework was developed as part of the MEA that not only included the definition of services and a typology of the latter, but also a conceptual schematic that illustrates the relationship between the environment and the services it delivers, with different components of human well-being (**Fig. 2.1**) (Millennium ecosystem assessment, 2005). The typology divides ecosystem services into four broad categories: provisioning (the resources provided by an ecosystem such as water and food, regulating (regulatory processes such as carbon cycling), supporting (the services required to produce all the other services such as primary production), and cultural (the

non-material benefits of an ecosystem such as recreational benefits). These categories remain one of the predominant means of defining services used by researchers and policy makers today (*ibid*). The MEA was also the basis for a series of regional and national Ecosystem Assessments such as the UK National Ecosystem Assessment (Watson et al., 2011b) and the European Ecosystem Assessment in 2013 (Maes et al., 2013).

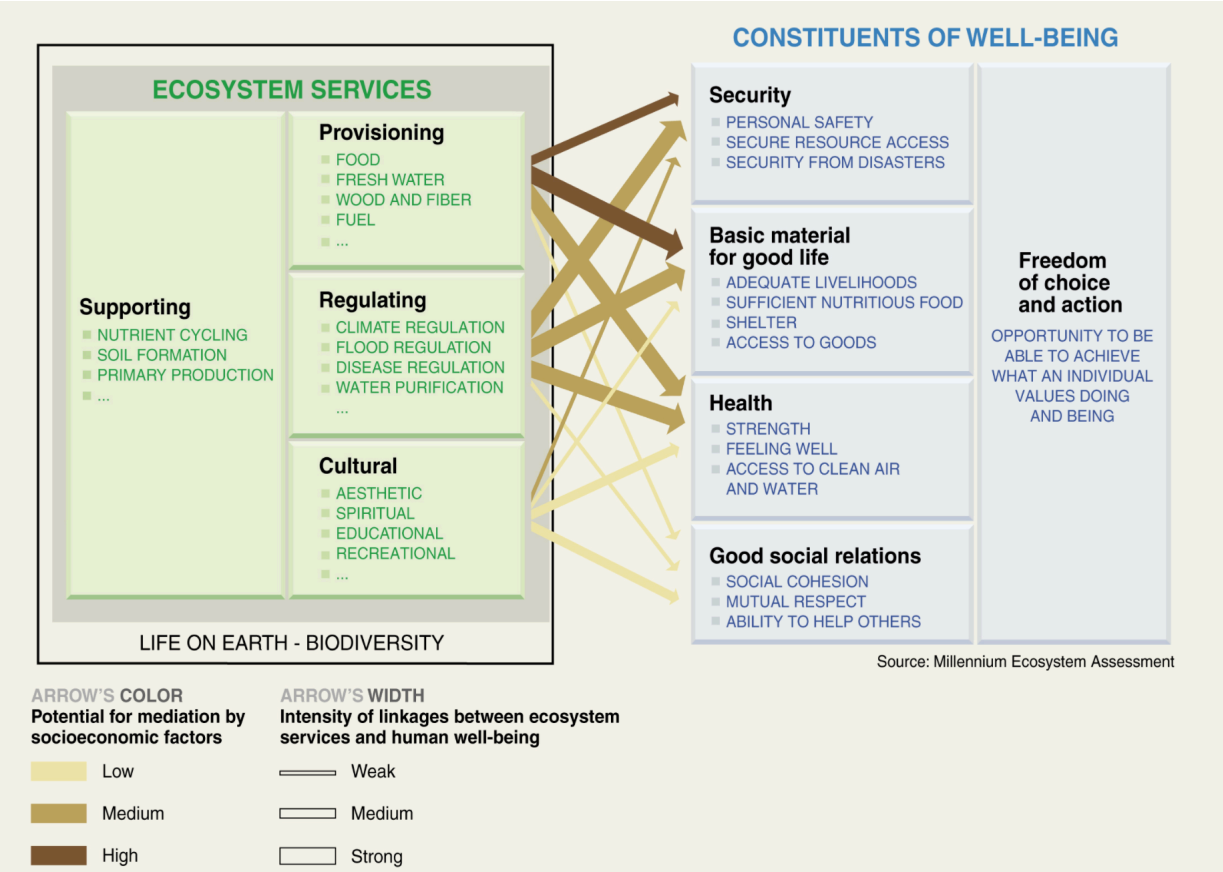

Figure 2.1: Framework of The Millennium Ecosystem Assessment (Millennium ecosystem assessment, 2005).

As stated above, Millennium ecosystem assessment (2005) defines services as *'the benefits people obtain from ecosystems'* (**page 8**). However, by this definition both the processes of ecosystems that create the service (*e.g.*, primary productivity) and the benefit (*e.g.*, more food) are considered to be one and the same. Later definitions, such as that used in the UKNEA (2011) (**Fig. 2.2**) separates benefits from ecosystem services whereby a benefit is something that has an explicit impact on changes in human welfare, such as more food (Fisher and Turner, 2008), this contrasts with the MEA definition of ecosystem services. In Watson et al. (2011b), therefore, ecosystem services are defined as *'the outputs of ecosystems from which people derive benefits'* (**page 16**). This definition builds on the work of Turner and Daily (2008), who pro-

posed a classification scheme dividing ecosystem services into 'intermediate services' and 'final services'. Within this, ecosystem processes and structure are considered services, but they can be either intermediate or final services, depending on their relationship with human well-being. For example, primary productivity maybe considered a primary or intermediate service that underpins food production as the final service.

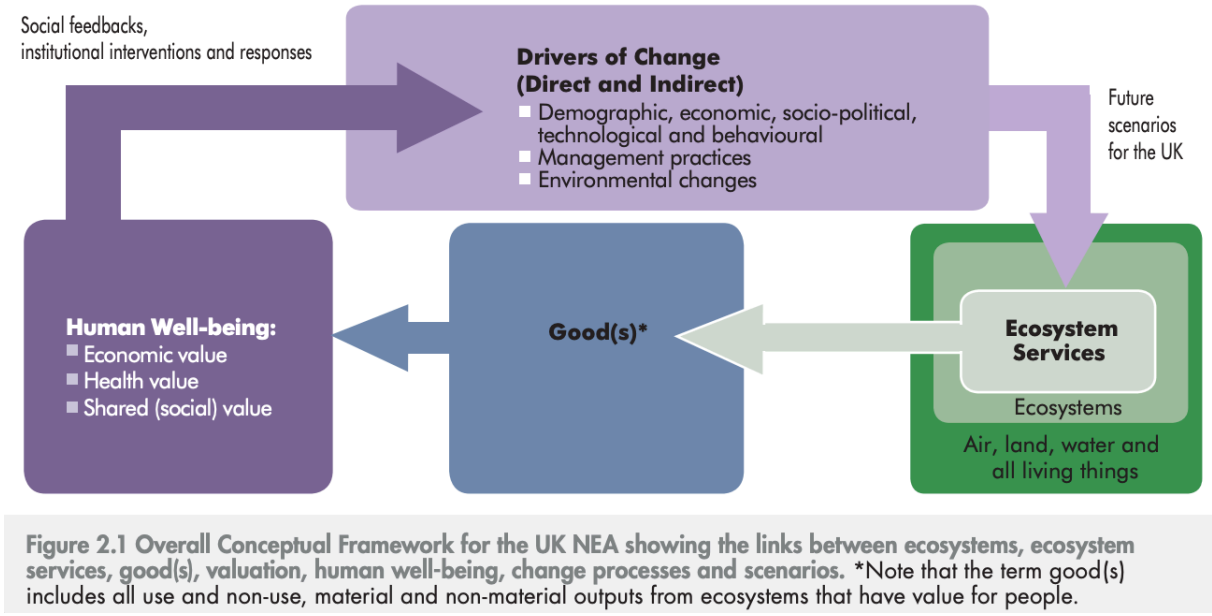

Figure 2.2: Framework of UK National Ecosystem Assessment (Watson et al., 2011b).

The Common International Classification of Ecosystem Services (CICES), developed by the European Environment Agency (EEA) and published in 2010 differs from the Millennium Ecosystem Assessment (MEA) in that it does not list 'supporting services' as services, considering them instead as ecological processes, which do not provide services or final products but that are the supporting structures for these (Haines-Young and Potschin, 2010). The authors update the framework in 2012 to include the concept of final services (**Fig. 2.3**), in the report authors argued that even if it includes 'final services' it is difficult to classify them, in part because ecosystems provide a wide variety of services that benefit human well-being in different ways, such that what is defined as a 'final service' will vary depending on the context (Haines-Young and Potschin, 2012).

A recent interpretation from the previous definitions comes from Bennett et al. (2015) in which they talked of *'A mainstream concept for the expression of values assigned by people to various functions of ecosystems'* (**page 1**). This interpretation captures the importance of values for nature (which may be both monetary or non-monetary) and which will vary from person

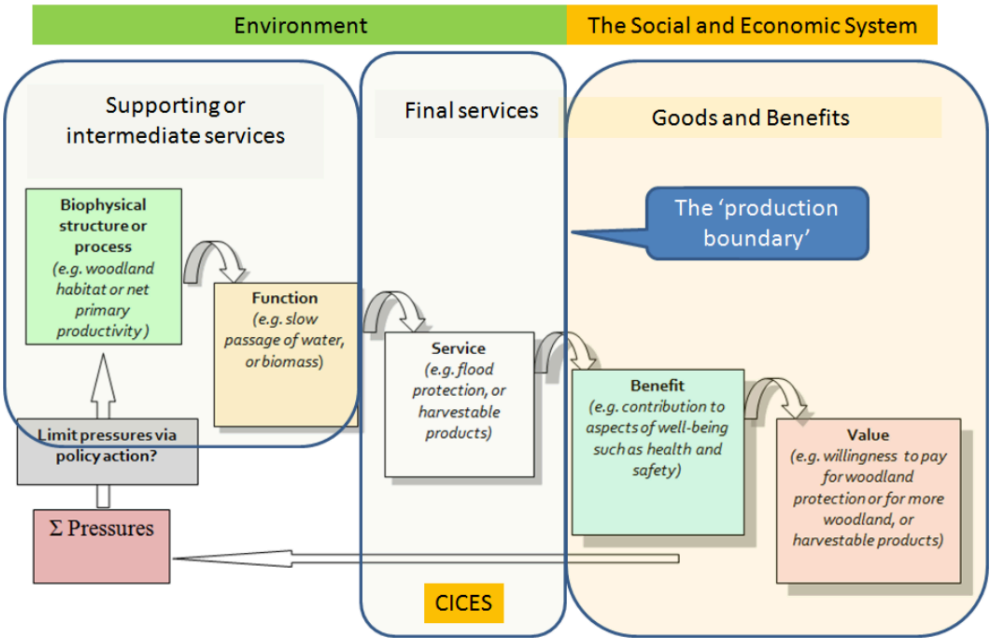

Figure 2.3: Framework of CICES report; version 4.1 (Haines-Young and Potschin, 2012).

to person and from culture to culture. Thus, the evolution of the definition of ecosystem services over time illustrates a change in the thinking of ecosystem services as being the benefits themselves or providers of benefits underpinned by a series of values. Assessing nature based on the services it provides to people introduced the concept of human well-being into the equation and raised the importance of recognising values that people hold for the environment.

2.2.1 Ecosystem services and urban agriculture

Ecosystem services provided by urban agriculture

Consideration of ecosystems, and how they fit within urban areas, is vital for the planning of the twenty first century sustainable and resilient cities (Etingoff, 2017). Managing coupled human-environmental systems is critical to creating sustainable and resilient communities that can adapt to, and mitigate for, climate change (*ibid*). Academics and planners alike are exploring new ways to link the built and natural environments, such that both environments benefit (*ibid*). The concept, and framing of, ecosystem services may help city planners better understand the benefits humans derive from greenspaces. The provision of ecosystem services, within urban areas, can have a significant impact on urban health (McPhearson et al., 2015; Luederitz et al.,

2015). Amongst the ecosystem service benefits identified within urban settings are stormwater management, food production (urban agriculture), water quality regulation, air purification, recreation, and heat island mitigation (Tan et al., 2020). However, whilst ecosystem services are widely discussed and researched, urban ecosystem services, particularly agroecosystems, have received little attention to date (McPhearson et al., 2015; Luederitz et al., 2015; Clinton et al., 2018). Similar to other green spaces in cities, agroecosystems can be multifunctional and provide environmental services beyond the harvesting fruits and vegetables (Artmann and Sartison, 2018; Clinton et al., 2018). However, most agricultural research has been conducted in rural areas, where agricultural production predominately occurs. Therefore, little is currently understood about how ecosystem services associated with urban farming vary by region, city, or even neighbourhood. Understanding the total value of urban agriculture and how that value is perceived will affect land use planning and is an essential, but often overlooked, aspect of community food systems (Newell et al., 2022; Wilhelm and Smith, 2018). This knowledge is fundamental to urban planning, where practitioners often directly influence land-use decisions based on community benefits and improved understanding in this area may help policymakers create policies that promote or conserve urban agriculture whilst concurrently improving the provision for ecosystem services and human health and well-being (Newell et al., 2022; Wilhelm and Smith, 2018).

Whilst some studies have quantified certain ecosystem services provided by urban agriculture, such as food provision, a worldwide evaluation of ecosystem services related to urban agriculture has been rare in the literature (Lin et al., 2015). According to Clinton et al. (2018), globally, urban agriculture could provide ecosystem services worth $80-160 billion annually. However, this is a best-case scenario estimation that relies on conversion into areas of cultivation highly using context-dependent practice within cities. Other evidence shows that urban agriculture may provide added benefits to cities and metropolitan regions than food production alone (Egli et al., 2016; Hawkins et al., 2013). For example, green infrastructure is frequently used to improve the quality of life for residents in urban areas without access to nature (Kim and Miller, 2019; Svendsen et al., 2012). Functional green infrastructure includes parks, greenbelts, wetlands, and agroecosystems. In addition to preserving wildlife habitat and managing stormwater or air pollution, there is growing interest in how these places may also benefit human health and well-being (Kim and Miller, 2019; Svendsen et al., 2012). Many argue that urban agriculture can provide similar environmental benefits than other types of green infrastructure,

such as habitat creation and carbon sequestration alongside social benefits such as recreation (Lin et al., 2017; Newell et al., 2022). A study by Camps-Calvet et al. (2016) in Barcelona illustrated that ecosystem services related to urban agriculture were rated higher by respondents than ecosystem services from other greenspaces, indicating the potential of urban agriculture in urban resilience and public health. Compiled studies supporting the provision of ecosystem services by urban gardens, highlight the importance of undertaking local evaluation of such benefits in urban planning and policy-making as ecosystem services vary significantly between urban contexts and urban agriculture typologies (Soga et al., 2017b,a).

The urban agriculture framework in this thesis and the ecosystem services definitions used to create it

The UKNEA report includes a specific section on ecosystem services provided by green spaces in cities (Watson et al., 2011b). The report discusses how absence of natural environments can influence people's well-being, often with negative impacts. Ecosystem services' benefits within cities include, amongst others, regulation of noise and air pollution, physical and mental health, recreation, and aesthetics of neighbourhoods. Furthermore, the report suggests that there may be a synergistic effect on human well-being from ecosystem service provision (Watson et al., 2011b), such that there are multiple benefits from individual services that may act together to produce an effect that is greater than the sum of the benefits individually. This synergistic services effect is also suggested to occur in the CICES report which proposes a potential diversity of benefits from a single service (Watson et al., 2011b; Czúcz et al., 2018).

In this thesis, I have based the basic structure for the urban agriculture, ecosystem services and human well-being conceptual framework on that from the CICES report (**Fig. 2.3**), thus delineating between intermediate services, final services, and benefits, in other words I do not consider the human benefits as ecosystem services per say. Connections between services and benefits are based on the ecosystem services categorisations in urban areas as proposed in the UKNEA report (**Fig. 2.2**). Although the structure of the classification of ecosystem services according to the MEA was not used in the structure of the theoretical framework developed in this thesis (**Chapter 3, Fig. 3.2**), it was considered when evaluating and discussing the benefits of urban agriculture on human well-being. Also, the duality of the final services proposed by the CICES is preserved as well as the concept of synergies of ecosystem services

as explained in the UKNEA report.

2.2.2 Urban agriculture and health

There are multiple potential health benefits from urban agriculture, however, these are unlikely to be the same across the Global South and the Global North. In the former, the main advantages of urban agriculture are economic. Poverty is a primary determinant of health; reducing poverty reduces vulnerability to illness and increases options for coping. Moreover, in these countries, another major benefit of urban agriculture is increased access to food, not only for horticulturalists themselves but also from the use of crops as a source of income and exchange.

In contrast, in the Global North, it has been proposed that urban agriculture may indirectly improve the health of urban dwellers through the provision of ecosystem services such as reductions in the urban heat island effect, storm-water filtration (Goldstein et al., 2016), and improvement in soil quality (Dubbeling et al., 2009). Urban agriculture is increasingly recognised as a tool to promote proper nutrition, including improved food security for the most vulnerable populations within cities (Petts and Organization, 2001; Opitz et al., 2016; Clendenning et al., 2016; Gregory et al., 2016; Morgan, 2015; Vitiello and Wolf-Powers, 2014). Moreover, several authors have proposed urban agriculture as a tool to help address some of the most significant challenges of urban living, such as sedentary behaviours (Banks et al., 2011), improper diet (Mintz and McManus, 2014), and lack of exposure to greenspace (Van Den Bosch and Nieuwenhuijsen, 2017). Scientists and physicians have proposed that an unhealthy diet, low levels of physical activity and reduced interaction with green space contribute to mental health problems such as depression and stress (Van den Berg et al., 2015; Hu et al., 2003; Loprinzi, 2015) and physical health problems such as obesity, metabolic disorders (Freudenberg, 2011; Banks et al., 2011), diabetes, hypertension, cancer, strokes, and cardiovascular diseases among others (McMichael, 2000). Therefore, being involved in community gardening (Litt et al., 2015) or 'green exercise' (Gladwell et al., 2013) may improve health. Nonetheless, most epidemiological studies have looked at the advantages of having a healthy diet, being physically active and being exposed to greenspaces independently, and few studies have focused on combining them to assess interactions and any potential synergies between the different effects.

There are also potential disadvantages to urban agriculture, mainly when implemented without a prior risk assessment or correct practices that are observed in both the Global South and Global North. Lack of government support and investment, and uncertainty over land tenure are mentioned as obstacles and downsides of urban agriculture worldwide (Newell et al., 2022). In the Global North secondary transfer of heavy metals and other chemical residues from soil, air or water to the product being grown is the most reported hazard of urban agriculture (Litt and Burke, 2002; Diawara et al., 2006; Bank, 2013). Exposure to chemical hazards often results from horticulturalists having insufficient knowledge of the risks of growing crops in potentially contaminated urban land (Kim et al., 2014) as well as from a lack of resources to execute healthy and sustainable urban agriculture projects, such as insufficient space or access to clean water (Armstrong, 2000). However, land insecurity, evictions, and legal uncertainty have also been reported as another common issue for horticulturalists in cities of the Global North, similar to the Global South.

2.3 Lifestyle behaviours

2.3.1 Lifestyle behaviours and exposures related to urban agriculture of relevance to this thesis

In this section, I explain the four main lifestyle behaviours related to urban agriculture and health that I focus on within this thesis: fruits and vegetable intake, physical activity, green space exposure, and social cohesion or social capital. I provide a brief history of how these behaviours were shown to be essential for better human health, their association with health and well-being, the current recommendations by health authorities, and the challenges faced by today's health practitioners in encouraging people to develop these healthy lifestyles.

Chapter 3 (systematic map and conceptual framework) includes all four of these lifestyle behaviours as they were classified as critical components of the benefits related to urban agriculture projects. However, social cohesion/capital were not included in the quantitative analyses as it was difficult to quantify this in a way that was comparative to the other three lifestyle behaviours.

Physical activity

The importance of physical activity for health and well-being has been known for centuries (Blair and Morris, 2009). However, it was only in the 1950s that researchers began to highlight the importance of avoiding sedentary behaviours, giving birth to the modern epidemiology of physical activity (Dishman et al., 2021). The work of Professor J.N. Morris demonstrated that physical activity was linked to better health (Paffenbarger Jr et al., 2001). Morris surveyed people with different jobs and levels of activities. He found a correlation between bus drivers who spent most of their time sitting and an increase in coronary heart disease in comparison to people whose work made them more active (Paffenbarger Jr et al., 2001; Hardman and Stensel, 2009). He extended his work and evaluated different people and their exercise regimes with incidence of heart disease. Morris and his colleagues were the first to distinguish between moderate and vigorous exercise (*ibid*). However, since the work of Professor Morris, physical activity levels in the general population have decreased (Hardman and Stensel, 2009). People now walk less, tend not to use stairs, and have fewer physical jobs. The average loss of daily caloric expenditure in the UK between WW2 and 1995 was around 800 Kcal (*ibid*). Moreover, according to a UK government study, British people are 20% less active now than they were in the 1960s (England, 2016). The report highlights modern lifestyles as a key issue in the reduction of physical activity, and the current generation is the first one in history to have to make a conscious decision to exercise (*ibid*).

The World Health Organization (WHO) recommends that adults engage in moderate aerobic physical exercise for at least 150 to 300 minutes a week, or vigorous aerobic physical activity for at least 75 to 150 minutes a week. Being physically active reduces the chances of suffering from chronic diseases such as various types of cancer, high blood pressure problems, cholesterol, cardiorespiratory problems, mental illnesses, bone problems, muscular problems, obesity, and sleep problems, amongst others (Bouchard et al., 2012).

Despite the importance of being physically active, health authorities are still struggling to find public interventions that will encourage people to exercise and move more. As a publication in The Lancet explain 'Policies to increase population levels of physical activity need to be prioritised and called up urgently' (Guthold et al., 2018). This article assessed population trends from 2001 to 2016 and found that insufficient levels of physical inactivity are still on the rise worldwide. Therefore, even if the epidemiological evidence is clear, on average people on

do not engage sufficiently in physical activity and there is a need to find novel approaches that encourage people to reduce sedentary behaviours.

Fruits and vegetable intake

As with physical activity, the association between diet and health is well established. Nevertheless, unlike physical activity there is a lot of debate about the aspects that make a diet a healthy one. In previous decades, consuming proteins, fats, and carbs were believed to be bad for health (Pollan, 2009). Today, sugar is pointed to as a dangerous substance that we consume in excess (Lustig et al., 2012). Some propose processed food to be detrimental to health (Pollan, 2009; Monteiro et al., 2010, 2018; Shahidi, 2009), whilst others blame refined foods (Burkitt, 2012; Heaton et al., 1983; Kahan and Mehrzad, 2020), and the amount of food we consume. Most likely, a combination of several dietary factors determines if a diet is healthy (Bolhuis et al., 2013; Meyer and Pudel, 1972; Lennie et al., 2006). Nevertheless, it seems to be a consensus among health experts and nutritionists that fruits and vegetables are the pillars of a healthy diet. According to the WHO 1.7 million lives could be saved globally by increasing the consumption of fruits and vegetables (WHO, 2019). Consuming an average of 400 grams of these foods in the daily diet can help prevent chronic diseases such as diabetes and heart disease (*ibid*). Likewise, it is estimated that worldwide, insufficient intake of fruits and vegetables causes 31% of ischemic heart diseases, approximately 19% of gastrointestinal cancers, and 11% of stroke (Aune et al., 2017). It has also been shown that the intake of vegetables significantly reduces the risk of cardiovascular accidents (Aune et al., 2017; WHO, 2019). Moreover, fruits and vegetables are shown to contribute antioxidants to our diets and these substances may help to delay ageing and prevent some age-related diseases (P Galvan et al., 2017).

In countries of the Global North, several campaigns have been implemented to encourage people to eat more fruits and vegetables. For example, in the UK in 2003, the government launched the 5-a-day campaign to encourage people to eat five portions of fruits and vegetables. However, up to 2017, the average daily portion of fruits and vegetable intake in the UK is 3.3 (Information Centre and of Great Britain, 2019). Developing strategies to increase the population intake of fruits and vegetables has not been easy, probably because refined foods are more palatable and cheaper than healthy foods. Moreover, people tend to have more access to ultra-process food than healthy foods (Gordon-Larsen, 2014). In some countries of the Global

North, current strategies focus on policies that increase the affordability and availability of healthy foods (Keener et al., 2009), and according to Vereecken et al. (2015), the average consumption of fruits and vegetables increased in the first decade of the millennium, in part due to policy interventions promoting healthy eating. Still, the average consumption in countries of the Global North is lower than the recommended levels, only 29% of British adults eat at least 5 portions of fruits and vegetables, and the average consumption is 3.8 portions (Pinho-Gomes et al., 2021). Moreover, in western countries, only 30% to 40% of boys reached the recommended fruits and vegetable intake levels, and for girls, the percentage was 35% to 50% (Vereecken et al., 2015). The data show that public policy interventions are not good enough to increase fruit and vegetable consumption to the levels needed. Cobiac et al. (2010) show that interventions to encourage change in dietary behaviour, such as counselling or worksite promotion, are neither effective nor cost-effective. Therefore, new and more effective strategies are needed, as Pinho-Gomes et al. (2021) state: 'Although different strategies are available, such as provision of information by social marketing campaigns (SMC) and direct economic incentives, the ideal approach remains unclear' (**page 282**).

Greenspace

Evolutionary speaking, humans have spent more than 99% of their existence on Earth in natural environments (Song et al., 2016). There is evidence that humans have been attracted to the idea of nature within 'urban' environments since Babylonian times *e.g.*, the Babylonian gardens (Lefas, 2015). Romans valued benefits from nature and created natural spaces within their urban areas. The term 'Rus in Urbe' (meaning the illusion of countryside created by a building or garden within the city) was first coined around A.D. c40 – c104 and was used by the Romans to describe the importance of natural environments in cities (Thompson, 2011). During the Renaissance some of the first urban gardens in post-roman Europe began to appear, including the park La Alameda de Hercules in Sevilla in 1574 (Freire, 1998). In the UK, during the Victorian era, natural public parks in cities increased in number as it was believed that they would improve public health (Whitten, 2020). Between the beginning of the 1900s and the beginning of the twenty first century, exploring the association between natural spaces and public health became a research topic. The 'Biophilia hypothesis' proposed that humans have an innate attraction to nature due to our evolutionary history, with several works supporting

this theory (Kellert and Wilson, 1993). For example, Moore (1981) demonstrated that prisoners with windows that had views of nature were less likely to fall sick than other prisoners. Similarly, Ulrich (1984) found that patients in rooms with windows with views of natural scenes tended to recover better and asked for fewer painkillers. Likewise, some studies have shown that workers who can see nature whilst at work tend to be less stressed, have a higher work satisfaction and fewer illnesses than those who do not (Kaplan and Kaplan, 1989; Lewis, 1996; Leather et al., 1998). Kaplan and Kaplan (1989) proposed The Attention Restoration Theory (ART), which theorises that, cognitive traits, such as concentration, improve with exposure to natural spaces. In Japan, in 1982, Tomohide Akiyama introduced Shinrin-Yoku, or 'Forest Bathing', which was meant to encourage people to spend time in forest environments (Li, 2018; Timko Olson et al., 2020). This practice has now become a widely used method to improve health and well-being of Japanese people. There have been several studies, including that by Rohde and Kendle (1994) that have shown that a being closer to natural environments may reduce anger and anxiety, whilst resulting in increased attention spans. In a similar manner, Herzog et al. (1997) showed that being in natural environments was related to improved concentration and problem-solving skills alongside reduced irritability and mental fatigue. This association between mental health and natural spaces has given birth to a branch of psychology called 'Ecopsychology' (Roszak et al., 1995). Proponents of ecopsychology aim to understand, and improve mental health, through building on the relationship of human beings with nature (*ibid*).

More recently, the importance of green and blue spaces in cities has become a primary goal for architects, designers, and land space planners. The principle of 'biophilic design' tries to include nature as an essential part of developing urban spaces, from rooms and houses to entire cities. Singapore has used this principle as part of its development. Since 2009, the country has followed a green city model for its development (Wee and Hale, 2008). However, green spaces and natural environments are becoming rare commodities in cities (Fuller and Gaston, 2009), and the percentage of urban trees and green areas are decreasing (Mincey et al., 2013; Qureshi et al., 2010; WHO, 2016). Furthermore, as with access to healthy foods, access to green space in cities is unequal, and research from Canada, England, and Eastern Europe have shown a association between affluent groups and access to green space (Crouse et al., 2017; Sikorska et al., 2020; Mitchell and Popham, 2008). There is currently a need to increase the green areas in cities. However, the land is a rare commodity in urban areas, so other types of green infrastructure are starting to appear, such as green walls. Nevertheless, there are

still a lot of gaps regarding human-nature interactions and how different types of green spaces might influence health and well-being. Clayton et al. (2017) argues that 'contact with nature' is different from experience because the latter involves the perception of the environment by the individual. A similar approach to the one of Miller (2005) who argues that interaction with nature is needed, and current city parks are insufficient for this purpose. Finding novel ways to offer access to greenspace and engage city-dwellers with greenspaces is required.

Social cohesion, social capital, and loneliness

During the previous decades, researchers have begun to explore the association between social support and various physical and psychological health indicators (Lavis and Stoddart, 2016; Kawachi and Berkman, 2014). It has been shown that less isolated people, who have satisfying relationships and take advantage of the social support network, tend to have better health and well-being than those with fewer social interactions (Delhey and Dragolov, 2016; McGowan et al., 2021). It has also been established that having poor support networks, or bad relationships with friends and family, is associated with an increase in the risk of poor health, both in men and women (Steptoe et al., 2013). Studies show that improved social support networks, even under challenging circumstances, can eliminate or reduces the risk of depression (Brown and Andrews, 1986; Liu et al., 2016; Wang et al., 2014). Socialisation activities are therefore an important resource for improving well-being (Lavis and Stoddart, 2016) and is especially recommended for people who tend to be more isolated, such as older adults (Cramm et al., 2013; Cramm and Nieboer, 2015). Given the new trends relating to loneliness, socialisation and health and well-being, and how urban and natural areas affect these feelings and interactions, research has started to focus on understanding these associations and promoting socialisation. However, creating spaces where these interactions can happen is still not fully understood.

Health synergies between green space exposure, fruit and vegetable intake, and physical activity

Most of the studies described above have explored the advantages of having a healthy diet, being physically active or being exposed to greenspace as independent variables. Very few studies have investigated them concurrently to assess any interactions and potential synergies

between the different effects.

The limited available data suggests that there are likely to be significant interaction effects. For example, there is evidence which suggests that a diet high in fruit and vegetable and low in refined foods and animal products, whilst also being physically active, may create a synergy that alleviates some common lifestyle diseases (Loprinzi et al., 2014; Loprinzi, 2015; Pierce et al., 2007; Anderssen et al., 2007). When people improve their diet and concurrently increase their levels of physical activity, they lose on average more weight than expected than if the two behaviours are assessed independently (Sparling et al., 2013). Similar effects have been seen in reducing bloop pressure, cardiovascular diseases and certain cancers (*ibid*).

A few studies have focused on the benefits of exercising in green spaces on overall health and well-being. Exercising outdoors can reduce BP and improve mood and self-esteem to a greater extent than when compared to people exercising indoors, or in stressful environments, such as busy urban environments. (Barton and Pretty, 2010; Pretty et al., 2005). This possible synergistic effect to the health and well-being, of exercising outdoors, is known as 'green exercise' (Pretty et al., 2005). To-date there is has been no research evaluating synergies between food intake and green spaces nor research assessing the synergistic effect of the three main behaviours related to urban agriculture concurrently on overall health and well-being. But some multi-behaviour approaches have shown the benefits for the health of having several healthy lifestyles and established the potential of multiple-behaviour practices for epidemiology and public health (Loprinzi, 2015; Loprinzi et al., 2016; Cassidy et al., 2017).

Chapter 3

Scoping review and framework

This chapter relies heavily on the peer review journal article: 'Public health benefits of urban horticulture in the Global North: A scoping review and framework' (Cruz-Piedrahita et al., 2020). The other two authors of the article are the supervisors of this thesis and agreed to use its content here.

Reference here: *Cruz-Piedrahita, C., Howe, C. & de Nazelle, A. (2020) Public health benefits from urban horticulture in the global north: A scoping review and framework. Global Transitions. [Online] 2, 246–256. Available from: doi:10.1016/j.glt.2020.10.001

CRediT authorship contribution statement:

Catalina Cruz-Piedrahita: Conceptualization, methodology, search and selection of papers, formal analysis, investigation, writing - original draft, writing - review and editing, visualization.

Caroline Howe: Conceptualization, Methodology, review and editing, and, supervision.

Audrey de Nazelle: Conceptualization, review and editing, and, supervision.

3.1 What is this chapter about?

The following chapter consolidates and synthesises the scoping review findings to explain the different mechanisms that relate urban agriculture to people's health and well-being. The method used here was the scoping review technique because it seeks to collect all the necessary

information to create a theoretical framework that will serve as the cornerstone for the empirical part of this thesis. This method takes a systematic approach to review the literature on the impacts of urban agriculture on public health, the environment and health behaviours, using the ecosystem services concept as a lens.

In the context of the whole research, this chapter explores the following objectives:

3.1.1 Objective related to this chapter

Objective I. To describe the multiple mechanisms by which urban agriculture in the Global North may impact health through:

I.I. Conducting a scoping review of the literature on potential health, social and environmental impacts of urban agriculture particularly in the domains of:

- Ecosystem Services
- Physical activity
- Greenspace exposure
- Fruit and vegetable intake
- Social interaction

I.II

Developing a conceptual framework based on the literature which will establish linkages and evaluate the strength of knowledge in these domains.

3.2 Introduction

It is impossible to separate the history of agriculture from the history of humankind (Gupta, 2004). With the domestication of plants, people were able to stop hunter-gathering and began

to generate the first urban settlements (Zeder, 2008). In other words, it has been argued that without agriculture large civilisations would have never occurred (Bar-Yosef and Kislev, 1989). Although the co-evolution of farming and the history of human civilisation is well understood and studied, it is not very clear at what point in history urban agriculture and rural agriculture separated, and urban agriculture became a different concept. In the 1980s, The United Nations began to use the terms urban agriculture and peri-urban agriculture to describe the production of agricultural goods inside the boundaries of a city and its periphery, in relation to food insecurity in the Global South. Still, it was not until 1999 that the Food and Agriculture Organisation (FAO) officially defined the terms urban and peri-urban agriculture (FAO, 1999). In the official document, 'Urban and peri-urban agriculture', the FAO states the following:

'Urban and peri-urban [agriculture] occurs within and surrounding the boundaries of cities throughout the world and includes products from crop and livestock agriculture, fisheries and forestry in the urban and peri-urban area. It also includes non-wood forest products, as well as ecological services provided by agriculture, fisheries, and forestry. Often multiple farming and gardening systems exist in and near a single city' (**page 1**) (FAO, 1999).

In the following years, the concepts split further with urban agriculture becoming defined as:

'The growing of plants and the raising of animals for food and other uses within and around cities and towns, and related activities such as the production and delivery of inputs, processing and marketing of products' (**page 9**) (Drescher and Iaquinta, 2001).

The official definition might be only a decade old, but it has been argued that, if there was a time in history when urban agriculture acquired the meaning it has today and became a prominent concept, it was during the Industrial Revolution of 1760–1840 (Mok et al., 2014). During this period, there was a significant migration of people into urban areas (Rees and Wackernagel, 2008). Consequently, city boundaries, alongside demand for food and resources, increased whilst space for agriculture diminished (Lohrberg et al., 2016). Urban dwellers were faced with a lack of resources and food insecurity (*ibid*). In Britain, the birthplace of the Industrial Revolution, the growth of urban areas was also linked to another phenomenon: the creation of plots on land inside the city where people produced their food, areas known as orchards and public allotments (Lohrberg et al., 2016; Mok et al., 2014; Petts and Organization, 2001). These areas allowed people to provide their families with foods and other goods. Despite the lack of information available relating to the origins of urban agriculture and despite the hazards

associated with cultivating food in densely populated areas, urban agriculture has been part of urban development for centuries and has played a significant role in the life and history of many cities (Mougeot, 2000).

Since the Industrial Revolution urban areas have become a honeypot for economic development and social opportunities, but they rely on rural areas to provide them with supplies. When people in cities lack the financial resources to acquire goods, such as food, urban agriculture seems to be a social answer to alleviate food insecurity and poverty (Bank, 2013). Cities with higher poverty levels depend more on urban agriculture to increase food availability for the urban dwellers (Gray et al., 2020). Consequently, to-date most research on urban agriculture research has focused on developing countries mostly in the Global South. For example, during the embargo on the island of Cuba by the United States of America (USA) in the sixties, Cuba developed a system of urban agriculture based on traditional agricultural techniques (Koc, 1999) allowing food to be moved around the country to prevent starvation of their population. Today, the conventional urban agriculture system of the island of Cuba is considered one of the most successful models of sustainable agriculture in the world (Golden, 2013; Thomas, 2014).

Nevertheless, the history and presence of urban agriculture in countries of the Global North are as complex and important as that in the Global South. During the two World Wars, cities in several countries including Germany, USA, UK, Canada, and Australia, faced food scarcity and their governments encouraged urban families to cultivate private gardens, abandoned lots and public areas (Brown and Jameton, 2000; Al-Delaimy and Webb, 2017). This initiative was known as Victory Gardens in the UK and the USA (Draper and Freedman, 2010; Cleveland et al., 2017). During these periods, in some urban areas urban agriculture was responsible for supplying 40% of the food demand of the cities and the troops (Brown and Jameton, 2000; Al-Delaimy and Webb, 2017). Moreover, during the Great Depression of the 1930s, the USA implemented the Relief Gardens program to help the most impoverished families to obtain food, economic relief, and to avoid mental health problems caused by the financial situation (McClintock, 2010).

Today, the role of urban agriculture in urban development and design is once again rising in importance. Urban agriculture projects are increasing and are social responses to different economic and segregation pressures urban dwellers have in cities worldwide (Dieleman, 2017). In the Global South urban agriculture is used more as a strategy to combat food insecurity,

to minimise gender inequality (Thomas, 2014), and to generate some economic support for the poorest sectors of the population (Thomas, 2014). In contrast, in the Global North, urban agriculture seems to fulfil a role of increasing inclusion, social interactions, access to greenspace and beautification of the city (Deelstra and Girardet, 2000). In both cases, urban agriculture provides additional benefits to people's health through ecosystem services such as reduction of air pollution, environmental noise and 'heat islands' effect (Lin et al., 2015). It also has an immediate impact on human health such as reduction of stress (Hawkins et al., 2013), BMI (Wood et al., 2016), and an increase of well-being (Soga et al., 2017a,b). At a global scale, urban agriculture helps to minimise the negative environmental impacts of cities by providing ecosystem services such as improving soil quality, reducing soil erosion, and acting as a buffer against flooding (Dubbeling et al., 2009). Urban agriculture also increases the supply of locally produced food, hence avoiding potentially negative environmental impacts associated with food transport, storage, or food packaging (Milner et al., 2015).

As a social and ecological movement, urban agriculture has the potential to adapt to the needs of each city by providing food, income, public health, and environmental benefits for the public (Stewart et al., 2013; Taylor and Lovell, 2015; Goldstein et al., 2016). However, to maximise the potential benefits and reduce possible negative side effects, more research on urban agriculture is necessary. For example, in developing countries, most urban agriculture practitioners are women (Bank, 2013; Thomas, 2014), since in these countries urban agriculture is presented as an economical alternative for women allowing them to uphold family commitments without them having to leave home. In developed countries there is no information on the demographics of horticulturalists. Therefore, the reason or reasons why people in developed countries engage in urban agriculture must also be established. Finally, more information is needed on the mechanisms by which urban agriculture improves public health, reduces negative environmental impacts in urban areas, and the ecosystem services related to both. Research to fill these knowledge gaps could encourage local, and national authorities to pay more attention to their implementation and development. This paper aims to clarify some of these issues and elucidates the challenges that urban agriculture has in developed countries.

Overall, there is growing evidence that cities in the Global North could benefit from increased participation in urban agriculture (Opitz et al., 2016; Gray et al., 2020; Morgan, 2015). Previous reviews of the literature in this area have reported on the development of urban agriculture

in cities of the Global North (Mok et al., 2014; Pearson et al., 2010), fruit and vegetable intake (Robinson-O'Brien et al., 2009; Savoie-Roskos et al., 2017), and social, economic, and health impacts (Golden, 2013). Currently available meta-analyses relate specifically to the health benefits of gardening and not urban agriculture in the Global North *per se* (Soga et al., 2017b; Buck, 2017) and whilst they consider ecosystem services, they do not use the concept as a mechanism by which to study the urban agriculture system as a whole. The framework developed in this study explores the available evidence on the impacts of urban agriculture in the Global North through an ES lens, building on pre-existing structures such as the UK National Ecosystem Assessment Framework (Davies et al., 2011; Watson et al., 2011b) and the 'Millennium Ecosystem Assessment' (Reid et al., 2005; Finlayson, 2016). This novel system approach to exploring urban agriculture enables us to elucidate the associations and interactions between all elements of the pathways between urban agriculture and public health, synthesise existing knowledge, highlight gaps in current understanding, and provide an 'ecosystems framework' to support local authorities and urban stakeholders in improving public health through urban agriculture.

3.3 Methods

3.3.1 Scoping review

Scoping reviews aim to assess the volume and nature of research in a given area (Armstrong et al., 2011; Tricco et al., 2018). This contrasts with systematic reviews which are used to answer a specific research question with narrow inclusion criteria (Colquhoun et al., 2014; Armstrong et al., 2011). They are ideal for mapping broad and complex topics and developing new conceptual frameworks to synthesise an understanding of research in a general area (Arksey and O'Malley, 2005). Undertaking a scoping review involves establishing a research query as a first step, followed by identifying and selecting studies relevant to the query, extracting the data from those studies, and then summarising and reporting on the results identified (Armstrong et al., 2011).

3.3.2 Search methods

An online literature search was conducted between May 2017 and June 2018 using three electronic databases (PubMed, EBSCO, and ScienceDirect) combining the following terms ('urban horticulture' OR 'urban agriculture' OR 'allotment' OR 'community garden' OR 'roof garden' OR 'urban farm') AND ('health' OR 'well*' OR 'activity' OR 'social' OR 'diet' OR 'nutriti*' OR 'intake' OR 'green*' OR 'ecosystem services') NOT ('developing' OR 'The Global South' OR 'Economy' OR 'Policy' OR 'Governance'). Due to many articles found it was necessary to limit the search to English language peer-reviewed papers from 2005 onward. I acknowledge that some important papers may have been overlooked because of this decision. During the first stage of the screening process only titles were analysed, followed by abstracts and then full texts in subsequent screening rounds. Finally, references from selected articles were checked to search for additional relevant papers to ensure that no applicable articles had been missed, taking a snowball approach to searching for relevant literature (Goodman, 1961).

3.3.3 Exclusion criteria

Papers focusing on developing countries were excluded from the final study. Countries were defined according to the International Monetary Fund (IMF) definition (Long and Ascent, 2020). All economies were listed as advanced economies, 37 countries were classified as developed countries, and any other country was discarded. Studies that focused on animal agriculture, or economic analyses were also excluded (**Table 3.1, and Fig. 3.1**).

Table 3.1: **Selected countries**. List of the Global North countries used for the scoping review of this thesis. The countries were defined using the classification of the International Monetary Fund (Long and Ascent, 2020).

Country	Country	Country
Australia	Iceland	Portugal
Austria	Ireland	Puerto Rico
Belgium	Israel	San Marino

Continued on next page

(Continued)

Country	Country	Country
Canada	Italy	Singapore
Cyprus	Japan	Slovak Republic
Czech Republic	Korea	Slovenia
Denmark	Luxembourg	Spain
Estonia	Macao SAR	Sweden
Finland	Malta	Switzerland
France	Netherlands	Taiwan
Germany	New Zealand	United Kingdom
Greece	Norway	United States of America

3.3.4 Secondary search

This involved an additional search looking for reports, theses, and reviews of NGOs or Government organisations about urban agriculture in the Global North using the same Boolean loop with the advance search option of the Google search engine. I only considered theses from universities, reports, and literature reviews in English, and from 2005 onward, I stopped the search when the articles found were irrelevant (around middle of the fifth page).

3.3.5 Final classification

Information from each of the selected papers was classified and reported in a final table. Outcomes that were not that common (mentioned only in one or two articles) were used in the discussion but were not used to develop the framework itself. Using pre-existing frameworks for ecosystem services (Dieleman, 2017; Millennium ecosystem assessment, 2005; Watson et al., 2011a) a critical review of the literature was used to develop a conceptual 'ecosystems framework' which analyses and visualises the urban agriculture-public health system as a whole **Fig. 3.2**.

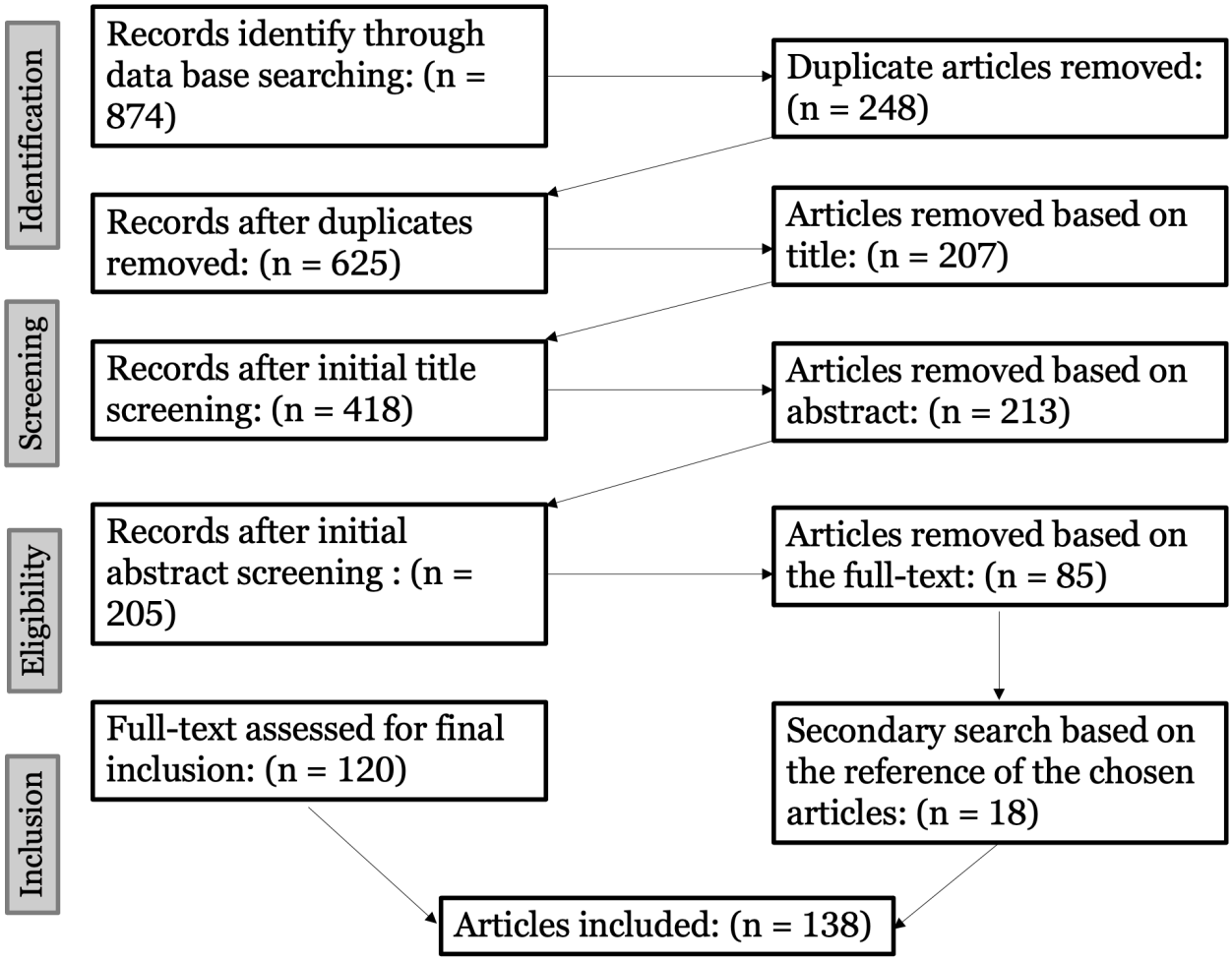

Figure 3.1: Flow chart illustrating methodology and exclusion criteria. After the initial search, there were 874 articles from the databases. After the exclusion process and the secondary search, 138 articles were selected.

3.4 Results

The database search identified 120 papers with an additional ten articles identified through cross-references from the initial search, and eight more papers from the Google search. Most studies used qualitative methods to collect data as opposed to quantitative approaches (62 to 44) and methods were classified according to the authors' assessment. When the authors did not state whether methods were quantitative or qualitative, I ranked as quantitative those studies that used statistical methods to analyse the data. Those that only described data were deemed qualitative. The mix of both methods was considered mixed methods. Surveys were the most common method authors used to gather data, followed by interviews, case studies and literature reviews. Research around urban agriculture in the Global North has increased over time, although not continuously, the low number of papers found for 2018 may be due to the search period ending in June 2018, consequently, other articles may have been published after the literature search. Most research in the field originates from the USA, Australia, UK, and Canada. Thirty-five studies focused on ecosystem services of urban agriculture; 37 on fruits and vegetable intake intake; 32 on social cohesion/social capital; 39 on health benefits; 12 on physical activity; 11 on the transfer of pollutants from the crops to the consumers; and 18 on other topics including involvement by authorities, land issues, BMI, and interaction with nature. Some papers touched on more than one single topic, and these were counted for each subject. Finally, most of the papers were from case studies in the USA, Australia, UK, and Germany.

3.4.1 General description of the framework

As discussed in detail in the next sections, the topics of the selected papers were classified into three broad categories of impact: direct benefits, indirect benefits, and unintended consequences. Direct benefits are those in which the participants benefit because they are directly involved in urban agriculture projects (Bellows et al., 2003; Carney et al., 2012; Schram-Bijkerk et al., 2015; Robert and Yengué, 2017; Soga et al., 2017a). Indirect benefits are those where the whole community in the vicinity of the urban agriculture project benefits due to broader ecosystem services that the gardens provide (Tsilini et al., 2015; Kulak et al., 2013; Zick et al., 2013). Unintended consequences refer to the downsides, such as transfer of pollutants which

often, arrows with straight lines represent direct pathways, arrows with dotted lines represent indirect pathways, and red squares represent unintended consequences. Five stages are identified in the urban agriculture-public health system depicted by different colours, the first two stages refer to intermediate and final ecosystem services as defined in Watson et al. (2011a); Brown et al. (2011), followed by a behaviour and exposure stage. The final impact and outcomes stages comprises direct impacts on the personal health of those engaged in urban agriculture, impacts on the immediate family and social relations, and impacts on the broader community (primarily neighbourhood, but possibly broader society).

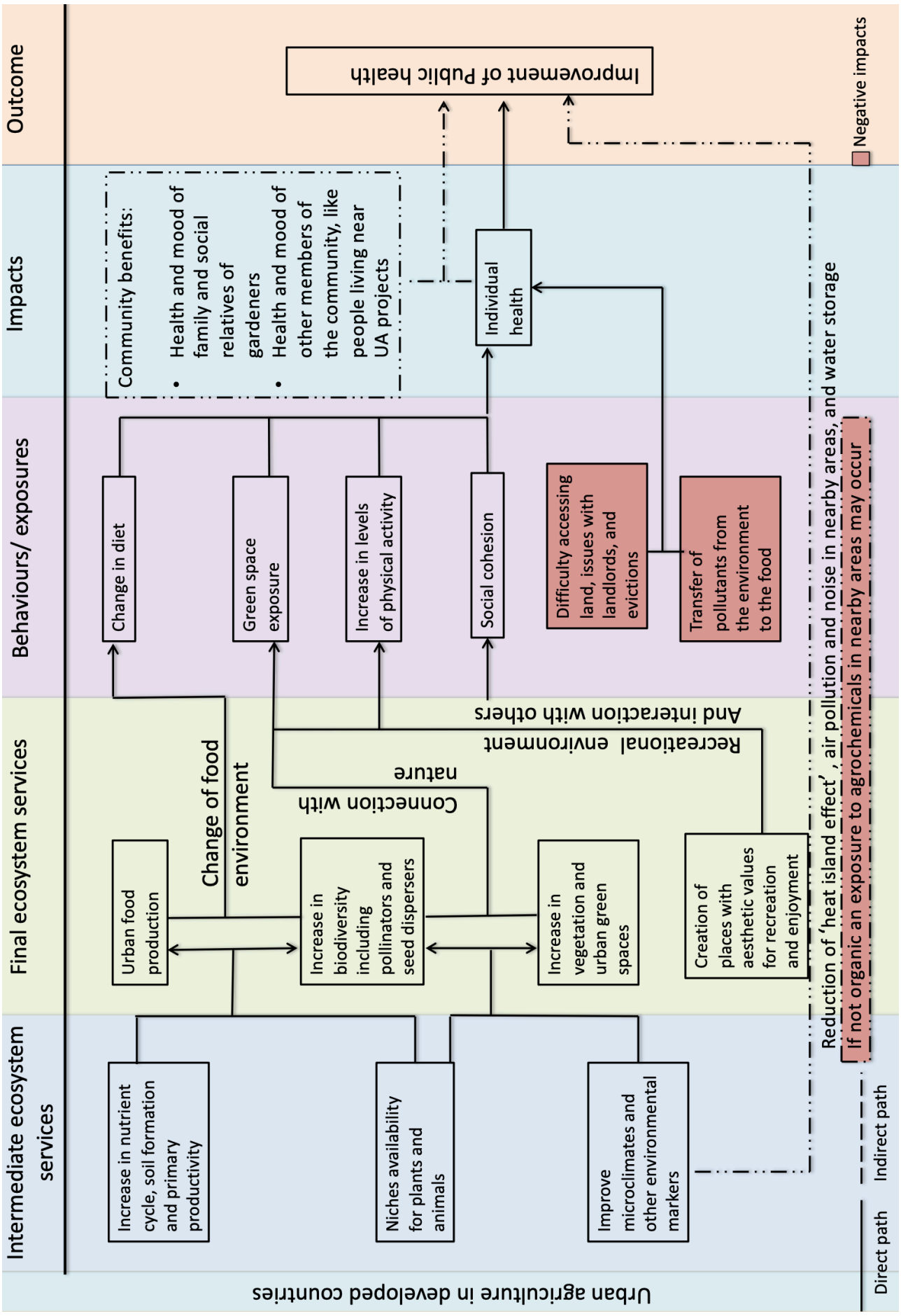

Figure 3.2: The conceptual framework that summarises and synthesises the different pathways through which urban agriculture can promote population health. The background was divided into five sections. Solid arrows represent the interactions linking urban agriculture and health directly. Red squares show unintended consequences (Cruz-Piedrahita et al., 2020).

3.4.2 Intermediate ecosystem services and final ecosystem services

Thirty-four studies showed the improvement in ecosystem service provision due to urban agriculture projects. Urban agriculture provides urban dwellers with ecosystem services of all The Millennium Ecosystem Assessment (MEA) categories: supporting services, provisional services, cultural services, and regulating services (Lohrberg et al., 2016). Moreover, the association between horticulturalists and the environment is bi-directional. The environmental benefits of urban agriculture projects not only increased the number of plants and greenspace available in a city (Russo et al., 2017), but concurrently re-generated the soil (Gulyas and Edmondson, 2021); improved the microbiota (Cabral et al., 2017; Gulyas and Edmondson, 2021; Lin et al., 2015; Schram-Bijkerk et al., 2018; Robert and Yengué, 2017); in some cases, reduced contaminants such as heavy metals (Cabral et al., 2017; Camps-Calvet et al., 2016); and improved nutrient recycling, which activates primary production (Schram-Bijkerk et al., 2015). By improving the porosity and microbiota of the soil, primary production increases (Schram-Bijkerk et al., 2015) resulting in an increase in biodiversity of the area at the same time (Lin et al., 2015; Camps-Calvet et al., 2016; Clarke and Jenerette, 2015). A more diverse soil environment translates into a significant increase in yield, such as food or flowers, which increases the availability of ecological niches for urban biodiversity (Lin et al., 2015; Camps-Calvet et al., 2016). Gardens also provide other ecosystem services including a reduction in air pollution and the 'heat island effect', and as a buffer against flooding (Buck, 2017). Furthermore, green areas and natural landscapes with aesthetic values become places of enjoyment with recreational benefits, thus improving people's well-being (Speak et al., 2015; Chan et al., 2015; Camps-Calvet et al., 2016).

3.4.3 Behaviours/exposures

Fruits and vegetable intake

Thirty-six studies demonstrated dietary benefits from participation in urban agriculture. Studies in the Global North, including the five longitudinal studies Parmer et al. (2009); Castro et al. (2013); Evans et al. (2012); Grier et al. (2015); Carney et al. (2012) showing that after having been involved in urban agriculture programs, some of them at school, children were more willing to try new food products (Savoie-Roskos et al., 2017), and increase their intake of fruits and vegetable (Alaimo et al., 2008; Ober Allen et al., 2008; Parmer et al., 2009; Evans et al.,

2012; Castro et al., 2013). One study by Wansink et al. (2015) found that children involved in a urban agriculture class were more likely to ask for a salad at the school cafeteria than those in the control group. Although they also threw away a third of the salad on their plate, this demonstrated that even if they did not like it, they were at least willing to try it. Parmer et al. (2009) found that children had increased knowledge about fruits and vegetable after being involved in nutrition programs, but if the program was backed up with a urban agriculture project, they were also more willing to try new healthy products at the school cafeteria.

Adults showed similar results as some studies found a association between an increase in fruits and vegetable intake and urban agriculture programs (Algert et al., 2016). For example, in communities in the Global North where 'food deserts' (areas of cities in which people cannot access or afford healthy and nutritious foods) are present, urban agriculture is a source of healthy food for its' residents (Clendenning et al., 2016; Martin et al., 2017). In Detroit, urban horticulturalists and the wider community used urban agriculture to guarantee food security whilst adopting healthier lifestyles (Taylor and Ard, 2015). Some studies have demonstrated that people involved in urban agriculture projects showed an increased interest in trying new products from urban gardens, followed by an increase in fruits and vegetable intake, thus providing them with fresh high-quality foods, increasing the variation of products consumed, in turn improving nutrient and mineral intake (Golden, 2013; Guitart et al., 2014). Evidence showed that combining urban agriculture with nutrition programs had a higher impact on fruits and vegetable intake (Algert et al., 2016; Robinson-O'Brien et al., 2009; Mintz and McManus, 2014; Parmer et al., 2009).

Social cohesion and social capital

Thirty-two studies demonstrated the social cohesion/social capital benefits of participation in urban agriculture. Although not all types of urban agriculture increased social interaction, social cohesion and social capital appeared as some of the most common outcomes amongst studies focusing on community gardens (Schmutz et al., 2014; Schram-Bijkerk et al., 2015; Veen et al., 2016). Some of these studies also found benefits from inclusion for groups that were traditionally excluded, such as people with disabilities, people with mental health illnesses, and immigrants and refugees (Whatley et al., 2015; Hartwig and Mason, 2016; Agustina and Beilin, 2012). For the latter groups, urban agriculture allowed communities to keep part of their identity by being able to plant endemic products from their countries (Algert et al., 2016) thus

reducing stress and increasing interactions with their new environment (Hartwig and Mason, 2016). These projects enhanced cooperative work and social interactions (Agustina and Beilin, 2012) and became an integral part of the communities where other activities such as social meetings, parties, or communal dinners could take place (Firth et al., 2011). For example, Firth et al. (2011) showed that when correctly done, the presence of a communal garden improved the communication between members of the community, not only between the horticulturalists themselves, but also other members of the neighbourhood, since the garden became a meeting place for several activities such as dinners and social parties. Sharing products with others appeared to increase social interactions and the sense of community present amongst horticulturalists and other actors in urban agriculture projects (Poulsen et al., 2014; Veen et al., 2016; Teig et al., 2009). People from different backgrounds, age, and nationalities shared a similar goal, enhancing the perception of community, and creating a sense of empowerment and belonging (Hartwig and Mason, 2016). Many of these gardens also provided refuge for young people in poor neighbourhoods, allowing them to engage in social projects and use their time to produce food and improve the community (Ober Allen et al., 2008).

Urban agriculture as a greenspace: exposure and interaction

Studies that dealt with ecosystem services (19 out of 34) mentioned greenspace exposure or interaction with nature as an added benefit. urban agriculture programs involving community gardens, public and private allotments, green roofs, and in some cases vertical agriculture, have the potential to expand urban greenspace (Robert and Yengué, 2017; Lin et al., 2015; Cabral et al., 2017), and consequently increase the exposure of local communities to greenspace (Middle et al., 2014). Being in greenspace whilst gardening has also been shown to have significant benefits on health and well-being (Soga et al., 2017a,b; Hale et al., 2011). For example, Kingsley et al. (2009) reported that horticulturalists in Melbourne felt that the gardens were places for spirituality and meditation. Participants, in general, tended to associate gardens with peaceful spaces where people can enjoy themselves whilst interacting with the environment and other members of the community (Agustina and Beilin, 2012; Firth et al., 2011; Lindemann-Matthies and Brieger, 2016). In some low-income areas of cities greenspace are often sparse, in poor condition or abandoned. In many cities like Detroit or New York, people are using urban agriculture as a tool to enhance the beautification of neighbourhoods and increase greenspace (Morckel, 2015). They are replacing vacant lots with trees, bushes, and other plants improving

and organising the urban landscape and their surroundings (Morckel, 2015; Orsini et al., 2014).

Physical activity

Twelve studies demonstrated physical activity benefits from participation in urban agriculture. Gardening can be characterised as a form of light to moderate physical activity similar to brisk walking, Tai Chi or golf (Hartwig and Mason, 2016; Schmutz et al., 2014). Although everyone can enjoy the benefits of urban agriculture and gardening, in particular people with disabilities, families with young children, and older people, may find urban agriculture projects a well-suited tool for avoiding sedentary behaviour because it does not require a substantial physical effort (Middle et al., 2014; Nicklett et al., 2016; Hermann et al., 2006). Travelling to the garden by walking or cycling has also been reported as an additional physical activity benefit of urban agriculture (Kingsley et al., 2009).

Transfer of pollutants

On the negative side, it was found that people involved in urban agriculture programs may be prone to higher intakes of heavy metals and other pollutants (Audate et al., 2018). Sometimes, urban gardens or allotments were placed in vacant lots in industrial areas, *i.e.*, sites of abandoned factories or dumpsters (Castillo et al., 2013; Al-Delaimy and Webb, 2017; Boente et al., 2017). In these cases, transfer of pollutants from the soil, water and air to the products harvested was an unintended detrimental consequence of urban agriculture (Kim et al., 2014; Oshunsanya and Adeniran, 2014; Al-Delaimy and Webb, 2017; Amato-Lourenco et al., 2017). Proximity to roads with heavy traffic may also result in transfer of contaminants to water streams and air currents polluting the produce harvested from urban gardens (Antisari et al., 2015; Mitchell et al., 2014; Spliethoff et al., 2016). The most common transmission was of heavy metals to the food being grown (Antisari et al., 2015), but there was also evidence for organic chemical contamination (Russo et al., 2017; Kim et al., 2014; Mitchell et al., 2014; Poulsen et al., 2014). However, the transfer could be avoided or minimised by following certain practices, including examining soil composition and determining if it was contaminated in advance of starting a urban agriculture project, and if contaminated, trying to change to a new location or using raised beds with new soils (Mitchell et al., 2014). Two peer-reviewed literature reviews concluded, after studying several papers on the topic, that health benefits outweighed risks due to contaminants in the food. Nevertheless, the authors highlighted the importance of more research related to cross-contamination and transfer of pollutants in urban agriculture (Leake

et al., 2009; Al-Delaimy and Webb, 2017).

Land issues

One primary constraint to urban agriculture was land availability and lack of land ownership amongst horticulturalists (Angotti, 2015; Wekerle and Classens, 2015). In many densely populated cities, land is an expensive commodity, many horticulturalists do not own the property that they use, and there is competition for land. Moreover, in some deprived areas, people tended to use vacant lots for urban agriculture projects, which increased the risk of eviction at any time (Wekerle and Classens, 2015). In some cases urban agriculture projects increased property values as it beautified the area, which in turn led landowners to sell the property (Vitiello and Wolf-Powers, 2014; Wekerle and Classens, 2015). In many cases, the project then needed to be moved into another area, where some of the previous participants could not continue due to issues of accessibility. According to Middle et al. (2014) the issue of land ownership and land availability was a common problem in urban agriculture. As a result, projects closed, or participants lost interest. Furthermore, lack of land ownership and transfer of pollutants were linked because in cities where land was an expensive commodity horticulturalists tended to use the only available land, and these were more likely to be abandoned lots from industry sectors that could be contaminated (Fox-Kämper et al., 2018; Wekerle and Classens, 2015).

Individual and public health

Thirty-nine papers focused on health (Some papers examined more than one health behaviours, so I counted them in each category), including positive outcomes on stress reduction (23 papers), anxiety (3 papers), BMI (7 papers), and food insecurity (28 papers). There was also evidence that urban agriculture increased general well-being (14 papers) and self-perceived health (4 papers). Out of the 39 papers, 29 used qualitative methods, 13 quantitative approaches, six were reviews, one was a review with a meta-analysis, and one used mixed methods. Most qualitative studies were observational and interview-based assessments or surveys. The quantitative studies included randomly controlled group trials, surveys comparing the horticulturalists' population with a peer population, and in five cases pre- and post-intervention assessments.

horticulturalists' health has been shown to improve as a direct consequence of the gardening activity through a variety of pathways due to the ecosystem services provided by urban agriculture and the healthy behaviours it promoted. Contact with nature and exposure to

greenspace that may occur when participating in urban agriculture reduced stress, BP (Soga et al., 2017a), depression and anxiety (Hartwig and Mason, 2016). The physical activity and fruits and vegetables consumption obtained during urban agriculture can contribute to daily consumption levels of fruits and vegetables recommended by the World Health Organization (Shrivastava et al., 2016). Urban horticulturalists and their families have been shown to have a lower BMI than their peers (Zick et al., 2013; Utter et al., 2016; Wood et al., 2016; Castro et al., 2013). Urban agriculture initiatives were revealed to help reduce the BMI of obese children in a pre-post intervention study assessing if gardening, plus cooking and nutrition workshops affected the consumption of fruits and vegetables of children at school (Castro et al., 2013). Finally, horticulturalists were shown to use their gardens for recreation and socialisation purposes within their community (Teig et al., 2009; Veen et al., 2016; Soga et al., 2017b), which may improve participants' mental well-being (Wood et al., 2016; Soga et al., 2017a).

Furthermore, other ecosystem service benefits are obtained from greenspace that improve the health of people living near the urban agriculture projects who are not involved in the projects directly. Green areas and natural landscapes with enhanced aesthetic values become places of enjoyment and gain recreational value thus improving peoples well-being, benefiting the broader community through social interactions, changes in behaviour, and changes in the urban landscape (Kingsley et al., 2009; Hale et al., 2011; Webber et al., 2015). Zick et al. (2013) demonstrated that relatives of people involved in urban agriculture tended to have a similar BMI, in contrast to their neighbours who had a higher one. It is believed that participants not only cooked with the products of the garden but also shared them with family members and friends (Algert et al., 2016; Martin et al., 2017).

3.5 Discussion

The scoping review and development of the 'ecosystems conceptual framework' provides evidence of the potential for urban agriculture to improve the health of citizens both directly and indirectly. I found data demonstrating that urban agriculture can improve soil porosity and micro-diversity and regenerate urban soils thus enhancing greenspace and increasing biodiversity availability in cities. The systems framework illustrates how people who are involved in urban agriculture projects tend to eat more fruit and vegetables, are more active, participate in

their social environment and interact more with nature. Participants of urban agriculture projects tend to have a BMI within healthy ranges and benefit from reductions in stress, anxiety, and food insecurity. Even those who do not participate directly in urban agriculture benefit indirectly due to the ecosystem services that gardens, community gardens, allotments and other forms of urban agriculture provide to them. I found evidence showing that horticulturalists eat and share their produce, use gardening as a moderate type of physical activity, a space for relaxation, and interaction with others and natural environments. Unfortunately, in some cases, when the soil, water or air are contaminated, pollutants such as heavy metals or organic chemicals may be transferred. Moreover, for people in cities where access to land is complicated, communities often struggle to find and maintain an appropriate place to develop a urban agriculture project. However, I also found that after considering the possible risks related to soil contamination, the advantages for it are higher than the potential negative impacts of urban agriculture on health.

While I found multiple sources of evidence demonstrating benefits of urban agriculture from ecosystem and health perspectives, the level of consistency and robustness of these findings is not reliable across the different pathways. Half of the articles identified use qualitative approaches, (51% of papers), a third used quantitative approach (35%), and the rest (14%) were reviews and reports, including one meta-analysis. The most robust evidence and reliable evidence was found for diet and social interactions. These associations, however, are still uncertain as evidence in these studies was based mostly on correlation findings from cross-sectional studies. Nevertheless, the few longitudinal studies (five papers with a pre-post intervention approach) I found, did point towards a change of behaviour, at least for fruits and vegetable intake after being involved in urban agriculture projects (Grier et al., 2015; Carney et al., 2012; Parmer et al., 2009; Castro et al., 2013; Evans et al., 2012).

Complementing, and lending support to the hypothesis that urban agriculture can have direct health benefits, there is ample and robust evidence from the literature beyond urban agriculture which establishes health benefits associated with behaviours and exposures that I have identified as being promoted by urban agriculture. These include benefits of moderate levels of physical activity (Ruggeri et al., 2016; Speak et al., 2015), fruit and vegetable intake (Kanoski and Davidson, 2011; Curioni and Lourenco, 2005), greenspace exposures (Hartig et al., 2014; Lee and Maheswaran, 2011; Van den Berg et al., 2015), and social cohesion and social capital

(Kingsley et al., 2009; Veen et al., 2016; Al-Delaimy and Webb, 2017). However, on the down side, I also found articles talking about social exclusion in community gardens due to ethnicity and social status (Angotti, 2015). Similarly, complementing the urban agriculture literature, there is ample evidence on the benefits of improved ecosystem services resulting from urban greenspace, including: improvement of soils; beautification of the urban landscape (Alaimo et al., 2010; Schram-Bijkerk et al., 2015); reductions in air pollution (Bank, 2013; Buck, 2017); and mitigation of 'heat island' effects (Lin et al., 2015; Brown-Fraser et al., 2015; Wood et al., 2016). It is essential to highlight that the ecosystem services mentioned above have an indirect connection with health. People do not need to participate directly in urban agriculture programs to gain some of the benefits. However, other benefits only occur during the direct interaction with nature. Hence it is vital that urban agriculture projects guarantee access to everybody and try to integrate as many people as possible.

While there is evidence that hints at associations between urban agriculture participation and health and behavioural benefits, the direction of impacts cannot be established based on current data, and reverse causality cannot be discarded. For instance, while some urban dwellers may start to eat more fruits and vegetables after being involved in a urban agriculture project (Algert et al., 2016; Hermann et al., 2006), others who already had such healthy habits may decide to participate in urban agriculture to support their healthy lifestyles. Healthy lifestyles can be an outcome of horticulture or a reason to become involved in it. Rigorous studies are needed, with natural experiment approaches, including longitudinal data collection and control populations to compare trends in order to establish causality (Levin, 2006; Craig et al., 2017). Due to the lack of longitudinal and controlled 'experimental' studies, I was only able to conclude that there is a relation between public health and urban agriculture, but I cannot be certain of the direction of the effect. However, as mentioned above, evidence points towards urban agriculture projects being able to change people's behaviours towards a healthier lifestyle.

The urban agriculture literature combined with the well-established health behaviour and ecosystem service literature, however, provide a strong argument in favour of the implementation of nature-based tools such as urban agriculture to tackle current urban environment and health emergencies. Urban agriculture presents a promising strategy with the potential to beautify the urban landscape, improve the urban biodiversity, and reduce the environmental impact of cities whilst improving public health (Lindemann-Matthies and Brieger, 2016; Cleveland et al.,

2017; Teig et al., 2009; Benis and Ferrão, 2017). Additionally, the broader literature has also identified crime reduction as an additional benefit, due to the fact that people spend more time outdoors, and repair and beautify derelict lots among other social benefits (Brown and Jameton, 2000; Saldivar-Tanaka and Krasny, 2004; Egli et al., 2016). Once again, there are also potential negative consequences. For example some studies have reported increased pain in different parts of the body in older adults due to positions adopted while gardening (Park and Shoemaker, 2009). As emphasised in the review, care must be taken to minimise such unintended outcomes.

The promotion of urban agriculture is particularly crucial at a time where urban area greenspace are being diminished (Fuller and Gaston, 2009). Multiple authors have noted how, in the Global North in particular, people do not have sufficient spaces to connect with nature (Litt et al., 2011; Cleveland et al., 2017) and lack easy access (Shrivastava et al., 2016; Rigolon et al., 2018; Ostoić et al., 2017; Fox-Kämper et al., 2018; Wolch et al., 2014; Badiu et al., 2016; Astell-Burt et al., 2014). Re-establishing the link between people and nature is therefore an essential step for the conservation of the environment and improvement in people's well-being (Takeuchi, 2010; Maller et al., 2009). Many urban dwellers do not know where their food comes from, nor the effort needed to get it. programs such as school gardens or community gardens allow people, especially children, to enjoy some of the advantages of natural environments such as green areas (Ernwein, 2014), to take care of nature and diversity and learn how the food they consume is produced (Parmer et al., 2009). In theory, this should increase their willingness to protect the environment, as well as to consume the food they produce (Teig et al., 2009; Buck, 2017). Overall, urban agriculture has the potential to teach urban dwellers how interact between with natural environments (Pitt, 2014).

The results go hand in hand with findings from other authors who, like us, have reviewed the literature to conclude that urban agriculture is an effective mechanism that can be used to promote urban sustainability. To use urban agriculture as a public health approach, municipal authorities should encourage different stakeholders to participate. For example, I found strong evidence illustrating how school gardens and nutrition classes improved children's eating habits and thus I recommend implementing school gardens as part of the school curriculum. Moreover, local authorities should promote urban agriculture practice by creating designated areas and producing guidance for such initiatives to take place. For example programs aimed at changing

vacant lots into garden areas may help local communities develop urban agriculture projects in a regulated way so that authorities can increase the benefits and reduce the downside of urban agriculture projects (Pearson et al., 2010; Lovell, 2010; Deelstra and Girardet, 2000; Mougeot, 2006; Mintz and McManus, 2014).

The study goes beyond the existing literature by establishing the pathways linking urban agriculture and public health taking a novel 'eco' systems approach. Unlike the frameworks presented by Buck (2017) on urban agriculture and public health, and the one presented by Schram-Bijkerk et al. (2018) on ecosystem services, ecosystem health and human health, I focused on the system as a whole, tracing the pathways between urban agriculture and public health, via the provision of specifically identified intermediate and final ecosystem services (and disservices) through to recognised changes in behaviour and exposure to the resulting impacts and final outcomes for public health. The approach took the ecosystems concept as a lens, drawing on frameworks from the Millennial Ecosystem services (MEA) and the UK National Ecosystem Assessment (UK NEA) enabling me to identify, not only positive outcomes, but also trade-offs and unintended consequences that must be addressed so that the full potential of improvements in public health and well-being, reduction of social injustice, and conservation of ecosystems can be achieved (Pearson et al., 2010; Lovell, 2010). Finally, I acknowledge that different countries have different challenges, however, many of the issues related to urban agriculture projects are similar across all projects (Mok et al., 2014). Hence, it is possible that solutions developed in one country might be implemented in another. More importantly, urban agriculture programs can be adapted to the needs of each city and each community (Mok et al., 2014), especially with the active involvement of local authorities and stakeholders.

3.5.1 Urban agriculture and its regulations

Based on the scoping review, I propose that many of the issues related to urban agriculture projects such as land eviction, pesticides used, and transfer of pollutants can be avoided if different stakeholders are provided with support to enable them to promote and regulate their practice. Most of the disservices related to urban agriculture are caused by horticulturalists' lack of knowledge regarding issues such as land rights and access, a deficiency of regulation regarding greenspace and urban land improvement as well as limited support from local authorities (Armstrong, 2000; Kim et al., 2014; Castillo et al., 2013; Lovell, 2010). Other actors

play a role in these situations including private landowners, policymakers, and urban developers (Kim et al., 2014; WHO, 2001; Lovell, 2010) and due to a lack of clear legislation and information in many cities, confusion and disputes between them and the horticulturalists arise. For example, a survey-based study in the city of Chicago found that urban planners and urban farmers believed that the main problems faced by urban agriculture in the city were: the lack of transparent and inclusive ordinances (54% and 28% respectively), regulated use of land (31% and 28%), access to available areas (28% and 23%), lack of funding (28% by the farmers), lack of preparation by farmers (23% and 8%), lack of water (23% and 20%) and finding insurance (8% and 16%) (Castillo et al., 2013). To avoid these issues and support urban agriculture projects, local authorities and urban planners need to improve legalisation and regulation of urban agriculture. If regulated, city authorities may help by checking, prior to approval, resources the project will need (WHO, 2001). Moreover, local authorities may be able to pair with NGOs to promote urban agriculture.

3.6 Study limitations

I acknowledge that the study has some limitations in the selection and analysis of the papers included. Firstly, I only took into consideration papers written in English, and other sources of information may have been lost due to this language bias. Secondly, I only included articles from 2005 onward, to make the number of possible papers identified in the initial search manageable. As a result, some classic papers and studies may be missing in this literature review. Nevertheless, I also took a snowball approach to sampling the literature and was able to include additional older relevant articles that were not included in the literature review to make sure I was not missing any vital information. I also want to highlight the weight of the evidence. Despite finding reported evidence for health benefits, I only found five longitudinal studies, moreover much of the research was based on self-reported behaviours or assessments, consequently, more experimental, and longitudinal studies are needed in this field to strengthen the robustness of the available evidence.

3.7 Conslusion

Urban agriculture has a lot to offer, in terms of improved environmental quality and health in cities. It not only increases ecosystem services in urban areas but can also increase fruits and vegetables consumption, physical activity, social cohesion, and social capital among urban communities. These initiatives are particularly relevant in more deprived areas of cities in the Global North, especially in those where food deserts occur. In these areas, obesity and its related diseases are the most common form of malnutrition, due to the lack of supermarkets and other healthy grocery stores forcing their inhabitants to depend on fast foods full of refined carbohydrates, saturated fat, and sugar. Such foods are often cheaper to obtain as well, providing an economic incentive for people to choose less healthy foods. In these areas, urban agriculture projects have the potential to improve food security by providing people with high nutritional value foods such as fruits, vegetables, legumes, and whole grains for free or at a much lower price. However, to develop successful urban agriculture initiatives, urban planners need to take the characteristics of the environment and the needs and requirements of local communities into account. Considering these factors while planning urban agriculture projects can reduce risks and increase benefits. Finally, urban agriculture is a relatively economic measure to increase urban greenspace to increase social interactions and improve the environment of local urban areas.

The study provides a novel 'ecosystems framework', that not only classifies the complex associations between urban agriculture and public health but enables me to identify current gaps in research in this field. I suggest that there is a need for further longitudinal and experimental studies to be undertaken under controlled conditions to establish causality as well as exploring other pathways and correlations between variables of urban agriculture on public health and environmental impacts. Including urban agriculture projects as part of city planning would support policy making for urban sustainable development, public health, and conservation, and ultimately support cities in their climate and public health goals. There may be unintended consequences and hurdles such as contaminated soils or evictions due to land price increases, which call for a role from local authorities to support urban agriculture schemes. To promote a healthy environment and society, I recommend that local governments, NGOs, and private entities encourage, stimulate, and help the practice of community gardens, allotments, and green roofs. The 'ecosystems framework' provides a supportive structure to enable local authorities

and urban stakeholders to maximise the benefits from, and reduce the risks related to, the of urban agriculture at a systems level.

Chapter 4

General methodology for empirical research

4.1 What is this chapter about?

This chapter presents the general research approach and describes the two data bases used in the quantitative analyses, *i.e.*, data collected from the urban horticulturalists' survey, and the UK-wide cohort from the UK Biobank. Further methodological details are provided in specific subsequent chapters: **Chapter 5** on analysing lifestyle behaviours and health and well-being markers of respondents of the horticulturalists' survey, **Chapter 6** on comparing lifestyle behaviours and health and well-being markers of horticulturalists vs participants of the UK Biobank, and **Chapter 7** on analysis synergistic effects of lifestyle behaviours of UK Biobank participants. Although the horticulturalists' survey is used first in the thesis, the UK Biobank was presented first in this chapter as this was the basis of the horticulturalists' survey. **Table B.1**, **Table B.2**, **Table B.3** in **Appendix B** provide the details for all the variables present in the databases developed.

4.2 General methodology

The following three chapters (**Chapters 5, 6, and 7**) focus on the empirical assessment of the associations identified within the theoretical framework (**Chapter 3**). I created two

data bases for the empirical analyses as part of this thesis: the UK Biobank cohort, and the survey of urban horticulturalists. Thus, both data bases are samples of the UK population with potentially overlapping constituents. The variables I have chosen to examine focus on markers linked to people's health and well-being (*e.g.*, BMI or happiness levels), demographic information of the participants (*e.g.*, age or gender), and lifestyle behaviours (*e.g.*, smoking status, or physical activity). This chapter details the general methodology followed across the three quantitative chapters. To assess causality, epidemiologists use either longitudinal studies (observational approach) or randomised control trials (experimental approach) (Wassertheil-Smoller and Smoller, 2004). However, these study designs are costly and not always practical or ethically possible (Pearce et al., 2019). Unfortunately, due to a lack of resources, these methodologies were out of the limits of this research and, as such, I chose a cross-sectional approach instead. The cross-sectional approximation cannot establish causality because the population is only sampled once, however, this approach is a standard observational study that can be used to analyse surveys and to measure associations between the outcome and exposure variables (Wassertheil-Smoller and Smoller, 2004) (**Fig. 4.1**). Cross-sectional studies include participants based on inclusion and exclusion criteria (Levin, 2006), which in this case referred to those who were horticulturalists (included) or not (excluded).

In this thesis, I used the UK Biobank and the horticulturalists' survey in multiple ways to address the different research objectives outlined in **Chapter 1**. I developed the horticulturalists' survey to carry out a comparison between lifestyle factors and health and well-being outcomes between urban horticulturalists (as represented by the urban horticulturalists' sample) and a sample of the UK population (represented by the UK Biobank cohort). The Urban horticulturalist's survey is also analysed on its own to assess self-perceived impacts of participating in urban agriculture on lifestyle behaviours and overall health and well-being markers (**Chapter 5**). Likewise, the UK Biobank cohort is analysed separately to explore potential synergistic impacts of the three lifestyles behaviours (fruit and vegetable intake, physical activity, and green-space exposure) associated with urban gardening on health and well-being markers (**Chapter 7**).

Each empirical chapter (**Chapters 5 − 7**) in the thesis also includes a section on the detailed methods related to the specific chapter which complements the general information on methods presented below. The UK Biobank data base, which has been extensively described and utilised

in previous studies, will first be briefly summarized here. This will be followed by a summary of the survey on horticulturalists, which utilised a small selection of questions from the UK Biobank questionnaire.

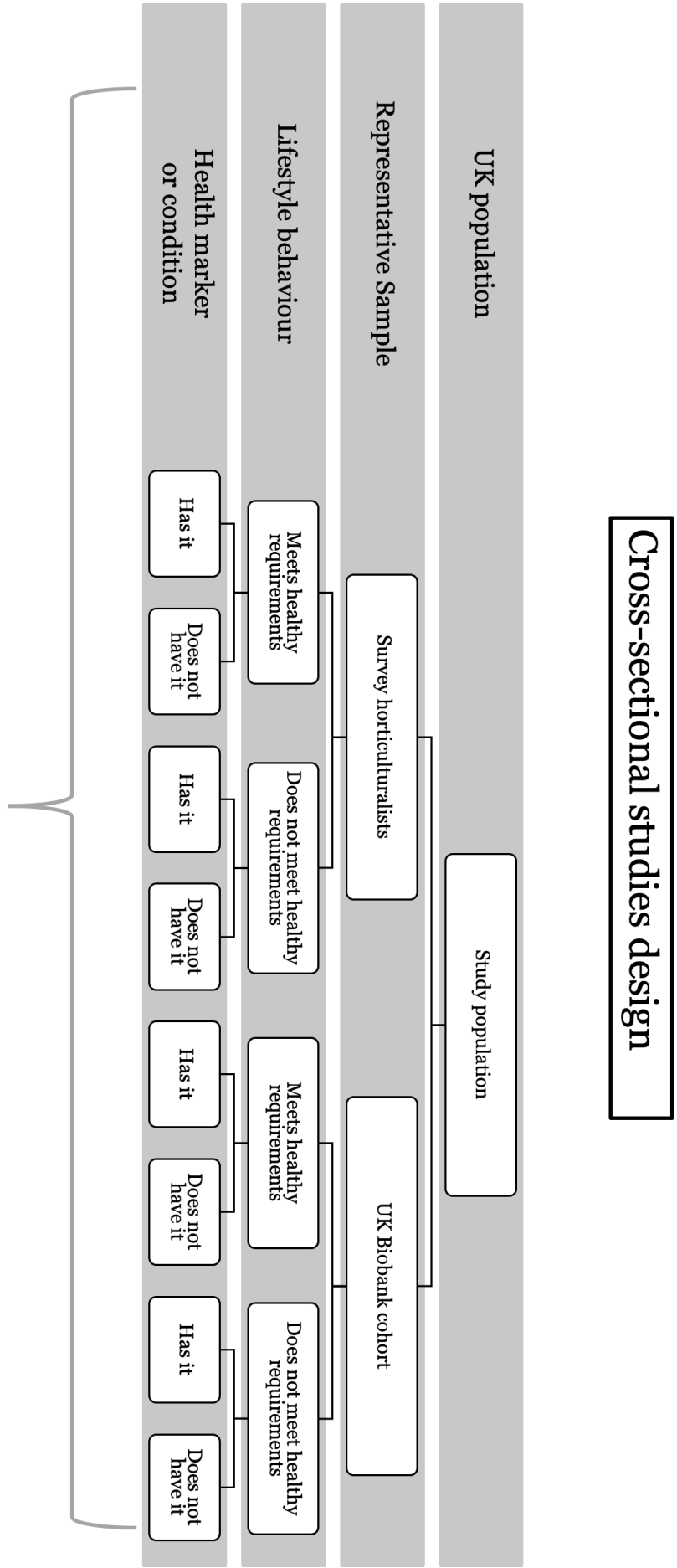

Figure 4.1: Figure illustrating the cross-sectional design of this research, detailing how the prevalence of health and well-being markers within the study samples was compiled. Depending of the objective, each empirical chapter (**Chapters 5, 6, and 7**) compares different lifestyle behaviours and health and well-being markers.

4.3 Description of the UK Biobank cohort and horticulturalists' survey

4.3.1 UK Biobank cohort

The UK Biobank cohort is a sample of the British population containing health and lifestyle information for around ∼500,000 people between 40 and 69 years old at recruitment between 2006 and 2010. Possible participants were identified using the NHS patient registers living near an assessment centre (∼25 miles or ∼40 Km) across England, Wales, and Scotland. The invitations to participate were sent via post. In total, 9.2 million invitations were sent, and 503,000 people agreed to participate (Littlejohns et al., 2019). At the assessment centres, participants completed a touchscreen questionnaire answering questions related to socio-demographics, lifestyle, environmental, and health-related factors (Biobank, 2014; Littlejohns et al., 2019). Participants were also verbally interviewed and gave urine, blood, and saliva samples. UK Biobank's protocol, and procedures are reported in detail elsewhere (Sudlow et al., 2015; Bycroft et al., 2018). I used 23 variables from the questionnaire and from the measures taken at the assessment centre. In the analyses, some variables were used directly, or used to create new variables (**Table B.1**, **Table B.2**, **Table B.3** in **Appendix B**).

The variables were chosen based on these principles:

1. *Literature:* I carried out a review of papers on urban agriculture, lifestyle behaviours, and health and well-being markers, and chose the most applied variables listed in these studies (**Chapter 3**).

2. *Practicality:* for the analyses that entailed a comparison with the urban horticulturalists' survey, only data that was possible to gather for the survey were retained. For example, variables measured using an accelerometer or blood sample were discarded. For the analysis of synergies of health and well-being pathways that relied on the UK Biobank sample alone (**Chapter 6**), some variables that were key health and well-being markers or demographics that I could not collect in the survey were retained (*e.g.*, blood pressure).

3. *Aim and objective:* The variables were chosen keeping in mind the research aim of the thesis and/or specific objective(s) being studied. Variables assessing information beyond the scope of

this research were discarded.

4.3.2 Horticulturalists' survey

The main goal of the horticulturalist's survey was to assess the impact of urban agriculture on people's health and well-being. To do so, I collected information from urban horticulturalists that could be compared with the data available from the UK Biobank. Specifically, I was interested in lifestyle behaviours (such as fruits and vegetables consumed and physical activity), exposures to greenspace, and self-perceived health and well-being. The secondary objective was to establish horticulturalists' perceptions of the benefits of practicing urban agriculture, to gather information on urban horticulturalists, and on the types of urban agriculture practised in the UK.

Selection of cities

There is a lack of consensus around the definition of what constitutes an urban environment and/or the definition of a city (United Nations, 2015) (**See Appendix A**). Definitions can be linked to the population itself, population density, area of the city, access to essential services, and the presence of education and health services (United Nations, 2015). Due to the heterogeneity of definitions, and based in the definition of the United Nations, I chose cities (urban areas) with more than 250,000 inhabitants for inclusion in this study. However, cities with fewer than 150,000 citizens, where according to the literature, urban agriculture is widely practised, were also included despite their smaller size (Oxford and Cambridge). The cities selected are provided in **Table 4.1** with their geographic location provided in **Fig. 4.2**.

Table 4.1: **The list of 20 cities selected for the horticulturalists' survey, the cities were ordered alphabetically with information about the population and the urban area in Km^2. The cities were selected following the definition of city by the United Nations (United Nations, 2015).** (ONS, 2016)

City	Population millions	Area Km^2
Birmingham	2.6	267.8
Bradford	0.35	64.48
Bristol	0.54	110
Cardiff	0.34	140.3
Edinburgh	0.49	264
Glasgow	0.63	175
Leeds	0.44	551.7
Liverpool	0.47	199.6
London	9.30	1572
Manchester	2.72	630
Newcastle upon Tyne	0.26	114
Leicester	0.32	73.3
Belfast	0.28	115
Cambridge	0.12	40.7
Coventry	0.32	98.56
Nottingham	0.28	74.61
Oxford	0.15	45.59
Plymouth	0.23	79.83
Salford	0.25	21
Sheffield	0.73	367.9

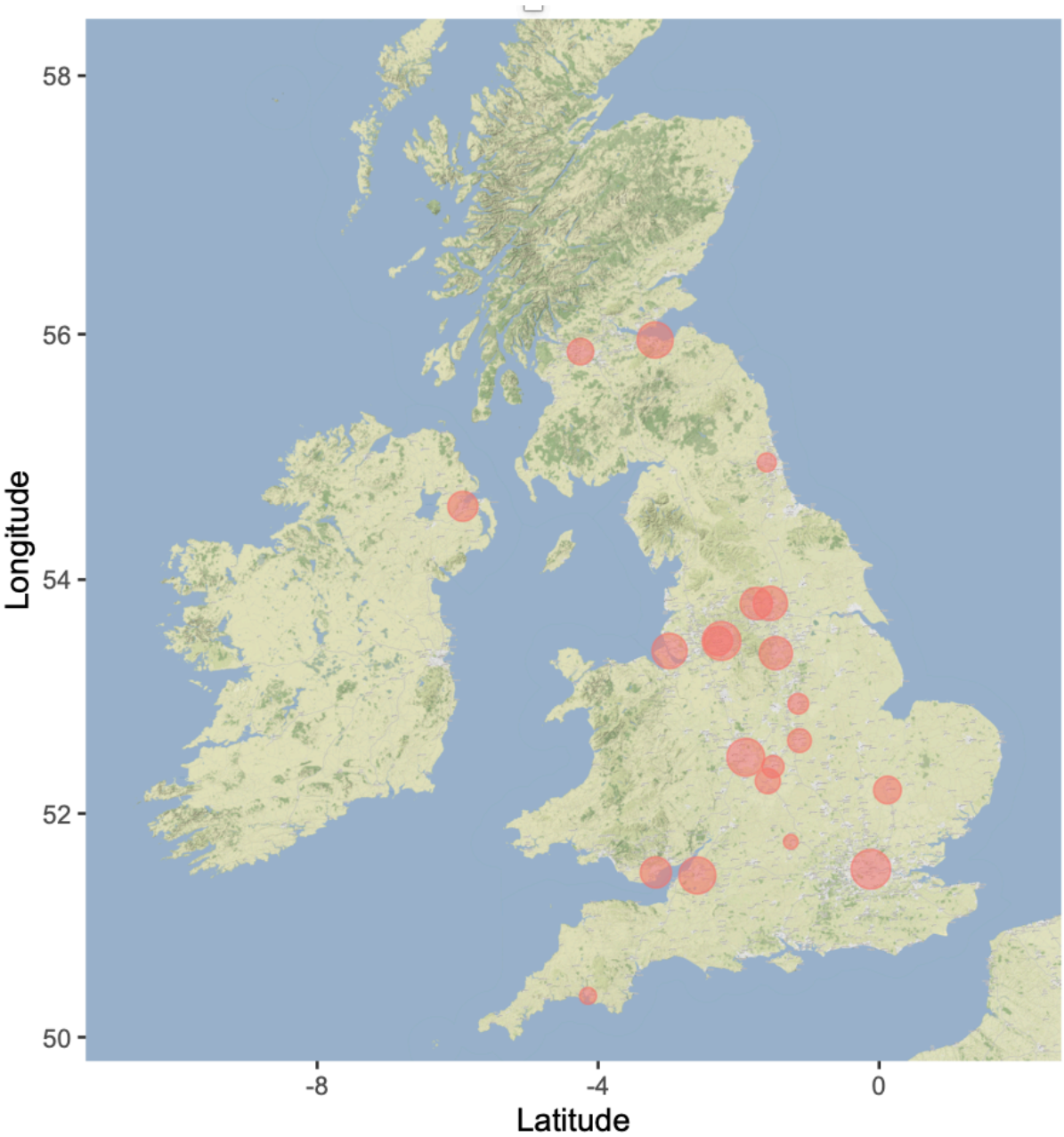

Figure 4.2: Map of the United Kingdom (Selected Country for this research). The red dots indicate a city were I sampled urban horticulturalists. The size of the point indicates the population size of the urban area (ONS, 2016).

Questionnaire development and recruitment strategy

To enable comparisons to be made between participants in the survey and the UK Biobank, I used the UK Biobank touchscreen questionnaire as the basis for the horticulturalists' Survey. Twenty questions from the original questionnaire were selected. These covered measures of lifestyle behaviours, physical health, well-being, and potential confounders (**Appendix B; Table**

B.1). Additionally, 15 questions were developed to capture the different types of urban agriculture practice (*e.g.*, allotments or community gardens); the length of time urban agriculture had been practised; and perceptions about urban agriculture and its association with health and well-being (**Appendix B; Table B.1**).Body Mass Index (BMI) was measure directly in the UK Biobank assessment centres. Hence, in my survey, participants weight (Kg) and height (cm) were requested so that I could calculate BMI for comparison. Nevertheless, it is important to mention that both variables were self-reported, so, BMI of horticulturalists might be subject of selection bias (**See limitations section; Chapter 8**) while the BMI of the UK Biobank is not.

Ethics approval was granted in September 2018 by the Imperial College Research ethics, and with the reference number 18IC4734. The software Qualtrics (Qualtrics, 2019) was used to create the survey. Some questions were open questions, others were multiple-choice with either one answer or multiple possible answers. During October 2018, a small sample of horticulturalists in Newcastle (28 horticulturalists that were excluded from the final analysis) piloted the questionnaire. Feedback from the pilot was incorporated into the final survey, which was uploaded to Qualtrics in February 2019. In total, the urban horticulturalists' survey collected data on 37 variables. For the empirical analysis, 23 variables from the final survey were used (**Appendix B; Table B.1, Table B.2, Table B.3**).

The survey was disseminated via email, Facebook, web-pages of urban agriculture-related organisations and local councils. Community gardens, allotments, and similar organisations were identified for each city, using the search engines Google and Duckduckgo. One initial message (email or direct message) invited them to participate and asked them if they were also happy to circulate the survey amongst other horticulturalists they knew (snowballing sample). Two additional messages were sent as reminders. A total of 350 electronic mails and messages on social networks were sent. Participants could access the survey from the first week of February 2019 to the last week of November 2019.

Selected variables

The explanatory variables and health and well-being markers were selected *a priori* due to their previously assessed association with urban agriculture projects, and their relevance to public

health (Camps-Calvet et al., 2016; Van den Berg et al., 2015; Haider et al., 2021; Wheeler et al., 2015). I used 'fruit and vegetable intake', 'physical activity', 'time spent outdoors in summer', 'percentage of greenness at home (100 m circular buffer)', 'loneliness', 'self-health assessment', 'happiness', 'medication for blood pressure, diabetes, or cholesterol', 'blood pressure', and 'BMI'.

Co-variables were selected based on assumptions that they would confound the association between the exposure and outcome, and/or were important risk factors identified by other UK Biobank researchers for the health or well-being markers under investigation (Cassidy et al., 2017; Dregan et al., 2017; Flint et al., 2016; Edwards and Loprinzi, 2018; Richardson et al., 2013; Hillsdon et al., 2006; Mytton et al., 2012; Kwon et al., 2015). I included from the UK Biobank: 'Sex (Female, Male)', 'age at baseline assessment', 'ethnicity', 'highest educational qualification', 'Index of Multiple Deprivation for England (IMD)', 'smoking status', and 'previous smoking status'. In the horticulturalists' survey, the variable 'sex' was called 'gender', and the variable 'age' was a categorical variable (**Appendix B; Table B.1**). The index of multiple deprivation comprises assessments of seven different categories experienced by people: Income Deprivation, Employment Deprivation, Health Deprivation and Disability, Education Skills and Training Deprivation, Barriers to Housing and Services, Living Environment Deprivation, and Crime DCLG (2011).

Data cleaning of the UK Biobank and horticulturalists' survey

The variables were cleaned based on previous work found in the literature and also the chapter's objective in mind. The principles to determine the cleaning of the data were the following:

1. *Literature:* I read several papers that assessed similar topics to those assessed here, using the UK Biobank cohort or a sample of urban horticulturalists for their research and using their cleaning methods. When the cleaning method is based on a paper, it is cited.

2. *Expert's opinion:* This project was developed with the assistance of experts from the School of Public Health. They were experts in treating the UK Biobank data; hence, their recommendations were taken into account to clean the data and choose the statistical methods used in this thesis. The references justifying this methods are also cited in each chapter.

3. *Research objective of the chapter:* Each chapter has a research objective, so the data were treated differently depending on the goal.

All the statistical analyses were carried out with R (R Core Team, 2018).

- All data were examined before cleaning using visualisation methods (Chai, 2020). Graphical exploration of data is a mandatory step before statistical analysis to familiarise oneself with the data, establish outliers and percentage of missing values, and explore associations between variables, amongst others (Chai, 2020).

  In the UK Biobank questionnaire and the horticulturalists' survey, participants had the option to answer 'Do not know' or 'Prefer not to answer'. For the lifestyle behaviours, well-being markers and socio-demographics variables I discarded those answers by changing them for missing values, this decision is made because these answers have no valuable information for the analyses, so they were discarded (NAs), similar previous peer-review works have followed this method (Hagenaars et al., 2017; Bradbury et al., 2017).

- For the horticulturalists' survey, participants were asked to give their measures (of weight and height), if possible, in the international metric system, but were free to choose the Imperial system if they wanted. Many participants provided their measurements in Imperial units which were then converted to the metric system for consistency.

- The number of people participating in the horticulturalists' survey was 904. I excluded those missing more than 10% of the answers. Participants with less than 10% of missing answers were not excluded.

- Missing values in the UK Biobank were discarted.

- For the variables ethnicity (UK Biobank) and Type of agriculture (horticulturalists' survey I used the NAs as a category for the analysis).

- The UK Biobank and the horticulturalists' survey measured vegetable intake in tablespoons, a different unit of measure than the one used by the World Health Organisation (WHO). (WHO-FAO, 2003). Hence, I used the National Health Service (NHS) guidelines for fruits and vegetable intake to transform tablespoons into daily portions (Choices, 2011). According to the NHS, approximately three tablespoons of cooked vegetables

and four tablespoons of raw vegetables equal one portion. I divided the variable cooked vegetables by three and the variable raw vegetables by four.

- The variable fruit and vegetable intake was created by adding the portions of fresh fruits, raw vegetables, and cooked vegetables obtained from three questions from the UK Biobank touchscreen questionnaire and the horticulturalists' survey: 1) 'On average, how many heaped tablespoons of COOKED vegetables would you eat per DAY? (Do not include potatoes; put '0' if you do not eat any)', 2) 'On average, how many heaped tablespoons of SALAD or RAW vegetables would you eat per DAY? (Include lettuce and tomato in sandwiches; put '0' if you do not eat any)', and 3) 'About how many pieces of FRESH fruit would you eat per DAY? (Count one apple, one banana, 10 grapes etc as one piece; put '0' if you do not eat any)'. The three questions have the same instruction for the participants (Please provide an average considering your intake over the last year. If you are unsure, please provide an estimate or select Do not know), and the same answer options ('Enter a number / Less than one / Do not know / Prefer not to answer'). If participants answered, 'Less than one', I replaced it for a value of 0.5 (Bradbury et al., 2018), and, as explained above, I excluded participants who answered 'Do not know', or 'Prefer not to answer'.

- I collapsed the variable highest qualification (four categories) as follow: 'College or University Degree'; 'Other professional qualification or education to age 18' (original Biobank categories: "A levels/AS levels or equivalent", "NVQ or HND or HNC or equivalent", and "Higher National Certificate (HNC) or equivalent, other professional qualifications"); 'High School Qualifications' (original Biobank categories: "CSEs or equivalent" and "O levels/GCSEs or equivalent"); 'None of the above' (Mutz et al., 2021).

- I used the tidy data obtained after the exploratory and cleaning processes for the quantitative methods of the empirical chapters of this thesis(**Chapters 5 − 7**).

Chapter 5

Analysis of a sample of urban horticulturalists. Results from the urban agriculture survey

The introduction of this chapter relies heavily on the submitted journal article: 'Self-reported health benefits in a sample of urban gardeners in the UK'. The other author of the article is one of the supervisors of this thesis and agreed to use its content here.

References:

*Cruz-Piedrahita, C. de Nazelle A. Howe, C. (2022). Self-reported health benefits in a sample of urban gardeners in the UK. [in press]

CRediT authorship contribution statement:

Catalina Cruz-Piedrahita: Ethics approval, creation and dissemination of the survey, performed data analysis, interpretation, and statistical analysis from the two databases, wrote the first draft, and Wrote the final paper.

Caroline Howe: Review and editing, conceptualization and supervision.

Audrey de Nazelle: Conceptualization and supervision.

5.1 What is this chapter about?

The purpose of this chapter is to investigate whether the behaviours related to urban agriculture in the Global North that were unearthed in the conceptual framework were reflected in the sample of urban horticulturalists from the UK. In the context of the whole research, this chapter addresses the need to increase empirical evidence of the health benefits of urban agriculture in the Global North by evaluating the first part of the second objective of this research work:

5.1.1 Objective related to this chapter

Objective II. To assess whether urban agriculture participation is associated with healthier lifestyles than a general population:

II.I. A survey of urban horticulturalists in the main cities of the UK followed by an analysis of whether participants' beliefs on fruit and vegetable intake, physical activity, social interactions, greenspace exposure, and self−perceived health changed after being involved in urban agriculture projects.

To address these objectives, I developed the following methods:

- I developed a survey and sampling framework to assess health behaviours, exposures, and outcomes in a sample of UK urban horticulturists. These were chosen based on known impacts of participation in urban agriculture or of behaviours associated with urban agriculture participation (**See Chapter 4**). They include fruit and vegetable intake and physical activity for health behaviours; hours spent outdoors as a proxy for greenspace exposure; BMI, and medication for chronic diseases intake as physical health outcomes; happiness, self-perceived health, and loneliness as mental health outcomes.

- To assess levels of the lifestyle behaviours fruit and vegetable, physical activity, and hours spent outdoors in summer in my sample of urban horticulturalists I performed a one sample t−test with a bootstrap comparing the average of each health behaviours with the recommended levels by health authorities, *i.e.*, 5 daily portions of fruits and vegetable.

- I explored self−reported behaviour change, *i.e.*, whether the horticulturalists believed their health behaviours had changed after starting urban agriculture programs using an analysis of proportion with a simulated sample. I use a permutation test with a chi−square to assess if the change was positive or negative depending on the type of agriculture.
- I examined whether the health markers BMI, and medication for chronic diseases and the well−being markers self−health assessment, levels of happiness, and loneliness varied significantly depending on the type of agriculture practised using Generalised Linear Models (GLMs).

The results show that horticulturalists have healthy levels of lifestyle behaviours and even exceed the levels recommended by health authorities. I also found that horticulturalists believe their actions changed after they started to participate in urban agriculture programs. The results show that the type of agriculture practised does not affect horticulturalists' perception of change, but it influences daily intake of fruits and vegetables, the time spent outdoors in summer, BMI, and self-health assessment.

5.2 Introduction

Historically, urban agriculture in the UK emerged at times when the country found itself in times of crises, such as during the First and Second World Wars, in which access to food became limited (Mok et al., 2014; Barthel et al., 2015). As such, urban agriculture has been associated with urban resilience in the UK.

During the Industrial Revolution in the late 19th and early 20th centuries, the main functions of urban agriculture were subsistence, health, and social stability (Barthel et al., 2015). At this time, the allotments that we know today were established, sponsored by charitable associations or by the church, as a tool to provide resources to those most in need whilst allowing these organisations to obtain moral and behavioural control over the population (King, 2007). The Enclosure Acts, a policy from the 18th century, privatised communal lands and fenced off 5 million acres of land from use by the general population (*ibid*). This policy caused an increase in poverty and forced the state to provide more impoverished families with subsidies and space

for allotments to continue to grow their food. However, a condition of receiving these subsidies and land was to follow certain 'desired' social practices such as attendance at church (*ibid*).

The Industrial Revolution caused mass urban migration as people headed to cities to fill jobs and make money. During this time, incomes were often insufficient to cover the cost of food. Consequently, employers provided urban land to their workers on the condition that they did not join the workers' unions and did not profit from the products grown (Crouch and Ward, 1988). In 1819, the Select Vestries Act gave pastors and other authorities the ability to rent land to the unemployed (Spudić, 2007). Based on this law, smaller allotments began to be developed in cities. Throughout the nineteenth century, the number of rural allotments decreased as the rural population moved to urban areas. Nevertheless, it was only at the end of the 19th century that the Allotments Act 1887 and then in 1908 made it mandatory for local authorities to provide land for the working classes to grow food (Wilson, 2010). Between 1850 and 1890, the number of allotments in the United Kingdom rose from approximately 100,000 allotments to 448,586 (Spudić, 2007). These allotments have historically been known as the 'Gardens of the Poor'.

During the two World Wars, urban agriculture served a crucial role in providing food to the urban population (Barthel et al., 2015). Before World War I, urban agriculture was practised mainly by men, however as men went to war, more women became involved, a trend which is reflected today, not only in the UK but in most developed countries where urban agriculture is widely practised (Hardman et al., 2018; Lindemann-Matthies and Brieger, 2016; Hannen, 2020). During the war years, urban agriculture became a pastime of the middle classes and it was not only something poorer socio−economic groups engaged in (Barthel et al., 2015). Between the period 1913 to 1918, the number of allotments in the UK rose from 600,000 to 1,500,000 (Spudić, 2007).

During the Second World War, the United Kingdom launched the 'Dig for Victory' campaign, which encouraged all civilians to grow food for both the country and the troops (Mok et al., 2014; Deelstra and Girardet, 2000; Barthel et al., 2015). To encourage citizens to participate in this movement, the government created 'Potato Peter' and 'Dr Carrot' **Fig. 5.1**. In London, large amounts of space were converted to grow food, and 1,750,000 allotments produced more than 1 million tons of produce (Crouch and Ward, 1988).

Figure 5.1: Propaganda showing 'Dr Carrot' and 'Potato Pete' used during second world war to incentivise people to cultivate vegetables (**Image courtesy of Flickr user jocki84**).

After the Second World War, the allotments lost prominence, and the land was repurposed. Between 1950 and 1997, the number of allotments fell from 100,000 to 29,600 (Spudić, 2007). In recent years, however, demand for allotments has risen, outpacing available spaces and resulting in waiting lists that can be up to 10 years (Fletcher and Collins, 2020; Miller, 2015; Campbell et al., 2011). Between 1997 and 2008, excess demand for allotments rose from 4% to 49% and by 2009 reached 59% (Campbell et al., 2011). Unlike allotments, urban farms and community gardens are more recent variations of urban agriculture that have started to gain popularity, diversifying their functions to include the sale of vegetables, meat, eggs, milk, cheese or honey (Mincyte and Dobernig, 2016; Pitt, 2014). Today, various initiatives and organisations exist, they campaign to increase space for urban agriculture. In some cases, local authorities provide financial support to urban agriculture movements such as Capital Growth in London or the National Trust 'Grow Your Own Campaign' and make land available to the public whilst offering technical advice and expertise.

Today, new types of urban agricultural projects are emerging within schools, nursing homes and hospitals (Parmer et al., 2009; George et al., 2015). Participation in urban agriculture is seen as a leisure activity or past time rather than a mean for subsistence and food provision (Mok et al., 2014; Schmutz et al., 2014). The popularity of urban agriculture projects has led several authorities to improve public health and well−being (Schmutz et al., 2014). Further examples include the University of Nottingham's research centre dedicated to urban agriculture studies and the Life Science Department at Liverpool University, which developed the 'Farm Urban Project' to focus on vertical farming in cities. Nevertheless, it is not possible to establish the exact amount of people in the UK involved in urban agriculture today (Mok et al., 2014), because most people practising urban agriculture in the UK are using their private gardens. According to the UK Natural Capital Report, 29% of the green areas in cities across the UK are private greenspaces (Brownbill and Dutton, 2019). So far, it has not been possible to establish what portion of these green areas are being used for horticultural activities. According to the UK Government, around 10,000 hectares across the country are dedicated to allotments or community growing spaces (Anderson, 2018), moreover, the government reported that food from allotments was up to 80,000,000 kg per year with a monetary value of £114 million (Anderson, 2018). Urban areas contained 55% of those allotments (Watson et al., 2011b) which gives an estimated number of around 163,350 plots, but as stated above the number of people using these allotments cannot be established. Even if the number of people involved in urban agriculture projects is unknown the historical and cultural importance of urban agriculture in the UK is undisputed.

5.3 Methods

* ***Chapter 4*** *contains the description of the data used here. For this chapter, I only worked with the horticulturalists' data frame, and in this section, I am explaining the specific methods.*

Urban horticulturalists from several large UK cities were surveyed to assess self−reported lifestyle behaviours, alongside health and well−being markers potentially associated with urban agriculture projects. To evaluate whether being involved in urban agriculture projects is related to good lifestyle behaviours, I compared the average daily intake of fruit and vegetable (portions/day), levels of physical activity (min/day), and time spent outdoors (hours/day) with recommended values by health authorities for those lifestyle behaviours (5 portions of fruit and vegetable a day, 20

minutes of physical activity a day, and three hours outdoors a day). Then I assessed if horticulturalists believed their lifestyle behaviours improved due to their participation in urban agriculture projects.

5.3.1 Behavioural and health traits

I assessed four behavioural traits: 1) intake of fruit and vegetables (portions/day), 2) physical activity levels (min/day), 3) socialisation and 4) greenspace exposure (hours/day). The variables were chosen because the literature suggests that they may be affected by engagement in urban agriculture. Within the urban horticulturalists' questionnaire that this chapter draws on (Appendix B), several questions focused on self−reported change in physical activity and daily intake of fruit and vegetables due to participation in urban agriculture projects (binomial response requested of either 'Yes' or 'No'). In the case of an affirmative answer, the survey then asked horticulturalists to report on the nature of that change ('Mostly negative', 'Somehow negative', 'Somehow positive', and 'Very positive'). The survey also asked respondents to report on any increase in socialisation with others or interactions with nature since beginning to practice urban agriculture ('Yes' or 'No').

In terms of self−reported mental health benefits, the survey asked respondents for levels of happiness ('Extremely unhappy', 'Very unhappy', 'Moderately unhappy', 'Extremely happy', 'Very happy', and 'Moderately happy', 'Prefer not to answer', 'Do not know'), self−perceived health ('Excellent', 'Good', 'Fair', 'Poor', ', 'Prefer not to answer', 'Do not know'), and feelings of loneliness ('No', 'Yes', 'Prefer not to answer', 'Do not know'). Likewise, the questionnaire also contained questions about physical health, including medication intake for non−communicable diseases (NCDs) ('Cholesterol medication', 'Blood pressure medication', 'Insulin', 'None of the above', 'Prefer not to answer', 'Do not know'), and hours spent outdoors during summer. Respondents were asked to report their daily consumption of fruit and vegetables and daily levels of moderate and vigorous exercise.

5.3.2 Descriptive analysis

The first step in understanding the data for the horticulturalists' population sample, and before tackling the more complex statistical analyses, was to do a descriptive analysis. I present this information so that it can be viewed in a more systematic and summarized way.

5.3.3 Statistical analysis

Comparing horticulturalists' health behaviours with health authorities' recommendations: one sample t-test

I used a one-sample t-test with a 10,000 bootstrap to see if horticulturalists met the healthy requirements suggested by the health authorities (5 daily portions of fruit and vegetables, 20 minutes of exercise, a BMI of less than 25). To my knowledge, there is no official recommendation for the time adults should spend outdoors, so I used the recommendation for children, which is three hours. The distribution of the data did not follow a normal distribution. I used the bootstrap to avoid violation of assumptions(Havlicek and Peterson, 1974; Dwivedi et al., 2017).

Assessing horticulturalists self−reported change in health behaviours: simulation and analysis of proportions

To measure whether horticulturalists reported a change in their behaviour after starting urban agriculture programs, I proposed the null hypothesis that '20%' of horticulturalists changed their behaviour due to other factors different than gardening'. I calculated this percentage by combining different information about the percentage of people who decided every year (new year's resolutions and self−control) to live a healthy lifestyle and the likelihood that they succeeded (Marlatt and Kaplan, 1972; Duckworth et al., 2018; Neal et al., 2013). I simulated a null population with 10,000 iterations, that is, a population distribution given that the null hypothesis was real and evaluated the proportion of horticulturalists who perceived they changed their lifestyle behaviours due to urban agriculture versus the population distribution (null distribution).

Assessing if the type of urban agriculture affects perceived change in lifestyle behaviours: chi−square and contingency table with a permutation test

To measure whether the type of urban agriculture practised influenced perceived behavioural change ('Yes' or 'No'), I undertook a permutation test with 10,000 iterations. I evaluated whether variable responses (*e.g.*, Diet changed due to urban agriculture) were independent of the type of urban agriculture (explanatory variable). Then I compared the observed value of the chi−square test with the expected one under the null hypothesis.

Assessing if the type of urban agriculture affects lifestyle behaviours and health traits: general linear models

To explore if the type of agriculture (reference = 'allotments') practised influenced different behaviours (fruit and vegetable intake, physical activity, and hours spent outdoors in summer) and health markers (BMI, happiness, loneliness, self-health assessment, and medication intake), I created four general linear models for BMI, fruit and vegetable intake, physical activity, and hours spent outdoors in summer. I conducted a logistic regression for loneliness (reference = No) and one for medication intake (reference = None of the above). I did ordinal logistic regression models for happiness (Extremely unhappy, Very unhhapy, Moderately unhappy, Moderately happy, Very happy, Extremely happy) and self−health assessment (Poor, Fair, Good, Excellent). I used a 10,000 generation bootstrap for all the models to avoid issues with violation of assumptions. Because I was not looking for the best model and wanted to avoid the step-wise method's bias (Budtz-Jørgensen et al., 2007) I used a forced entry method for the confounders (Field et al., 2012). This method does not allow the inclusion or exclusion of confounders, the confounders are chosen before doing the models based on information from the literature, and then the same confounders are used for every model. All logistic regression models were adjusted for: age (reference '18 to 29'), gender (reference = 'Female'), highest qualifications (reference = 'University or College degree'), and smoking status (reference = No).

5.4 Results

5.4.1 Descriptive analysis

All the tables containing the information of the descriptive analysis are in **Appendix C**. Out of the 625 horticulturalists, 414 were female, and 211 were male. Only 28 participants had between 18 and 29 years of age, 95 horticulturalists were between 30 to 44 years of age. Most of the horticulturalists (391) were between 45−69 years of age, and 111 were said to be older than 70 years old. London was over−represented, with 260 horticulturalists being from this city, followed by Sheffield (52) and Manchester (44). The cities with the lowest number of horticulturalists participating in the survey were Cardiff (5), followed by Birmingham (7), and Leicester. The rest of the cities had between 13 and 33 participants. For qualifications, most of the horticulturalists reported having a college degree (257), only 12 answered 'none of the above'.

Of the 493 horticulturalists who reported the type of agriculture they practice, 378 reported being

involved in allotment gardening. Of those, 282 were involved only in allotments gardens, and the rest in allotment gardening and other types of agriculture. One hundred seventy-four horticulturalists practised backyard gardening; of the latter, 62 horticulturalists reported to be involved in backyard gardening exclusively, and the rest were engaged in more than one type of agriculture. Only six people said being involved in city farms, and only three reported being exclusively in this type of urban agriculture. Twenty people reported being in public gardens projects different from community gardens or allotments, but only one of the 20 was exclusively involved in this type of urban agriculture. Finally, 66 horticulturalists reported participating in community gardens, and 28 solely practised this type of urban agriculture.

Regarding lifestyle behaviours, horticulturalists reported consuming 5.11 portions of fruits and vegetables daily, exercising 78.71 minutes a day, and spending 4 hours outside. Four hundred eighty-six horticulturalists did not take any medication for chronic diseases. Most of the horticulturalists assessed their general health as good (358), followed by fair (123) and excellent (116). Only 27 horticulturalists reported their self−perceived health as poor. Out of the 625 horticulturalists in the survey, 509 reported not feeling alone, 328 reported feeling moderately happy, and 210 were very happy. Only two said to be extremely unhappy, and ten were very unhappy.

Finally, 317 horticulturalists reported that their fruits and vegetable intake changed after being involved in urban agriculture projects; of those, 282 said the change was primarily positive, 33 somehow positive, and only one reported that the change was somehow negative. Four−hundred and twenty−three horticulturalists reported that physical activity levels changed due to urban agriculture. Of those, 368 said the change was mostly positive, 46 somehow positive, five somehow negative, and three said the change was mostly negative **Table 5.1**.

Table 5.1: **Descriptive analysis**. Table showing the results of the descriptive analysis of the sample of urban horticulturalists. For each health trait (Body Mass Index, Fruit and vegetable intake, Physical activity, and Time spent outdoors) the table shows the average value and the standard deviation in the sample. For the categorical variables the table shows the name of the variable, the different categories, the number of participants in each category and the percentage.

Characteristic	N = 625
Body Mass Index (BMI)	24.5 (6.1)
Fruit and vegetable intake (portions/day)	5.11 (3.34)

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(Continued)

Characteristic	N = 625
Physical activity (minutes/day)	78.71 (23.73)
Time spent outdoors (hours/day)	4.03 (2.13)
Type of urban agriculture	
Allotments	283 (45%)
Allotments and backyards	77 (12%)
Backyards	62 (9.9%)
Community garden or other	40 (6.4%)
Three types of urban agriculture	35 (5.6%)
Unknown	128 (20%)
Highest educational qualification	
None of the above	12 (3.3%)
Education until 16	31 (8.6%)
18 above no degree	59 (16%)
College or university degree	257 (72%)
Age	
18–29	28 (4.5%)
30–44	95 (15%)
45–69	391 (63%)
More than 70	111 (18%)
Gender	
Female	414 (66%)
Male	211 (34%)
Smoker	
No	521 (88%)
Only occasionally	30 (5.1%)

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(Continued)

Characteristic	N = 625
Yes, on most or all days	42 (7.1%)
Loneliness	
No	513 (85%)
Yes	92 (15%)
Medication intake	
None of the above	486 (78%)
At least one	138 (22%)
Happiness	
Extremely unhappy	2 (0.3%)
Very unhappy	8 (1.3%)
Moderately unhappy	42 (6.8%)
Moderately happy	328 (53%)
Very unhappy	210 (34%)
Extremely unhappy	25 (4.1%)
Self−health assessment	
Poor	27 (4.3%)
Fair	123 (20%)
Good	358 (57%)
Excellent	116 (19%)
Fruit and vegetable intake changed after participation in urban agriculture	
Yes	317 (53%)
No	285 (47%)
Describe the change; Fruit and vegetable intake	
Mostly positive	282 (89%)
Somehow positive	33 (10%)

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(Continued)

Characteristic	N = 625
Somehow negative	1 (0.3%)
Physical activity changed after participation in urban agriculture	
Yes	423 (70%)
No	179 (30%)
Describe the change; Physical activity	
Mostly positive	368 (87%)
Somehow positive	46 (11%)
Somehow negative	5 (1.2%)
Mostly negative	3 (0.7%)
Socialising more after participation in urban agriculture	
Yes	401 (67%)
No	198 (33%)
Interacting more with greenspaces after participation in urban agriculture	
Yes	476 (80%)
No	122 (20%)

* Categorical variables show the number of participants in each category and the percentage in parenthesis. Numeric variables show the mean value for the group and the standard deviation in parenthesis.

5.4.2 Comparing horticulturalists' health behaviours with health authorities' recommendations: one sample t-test

The respondents' BMI was within the WHO recommended levels ($\leq$ 25) (mean= 24.5, 95% CI = [243.81, 25.48], p value = 0.19). Horticulturalist meet fruits and vegetable recommended value (5 portions a day) (mean = 5.1, 95% CI = [4.8, 5.5], p value = 0.46), spent more time outdoors than the recommended three hours a day (mean = 4, 95% CI = [3.8, 4.6], p value $\leq$ 0.001), and exercised more than the recommended 20 minutes a day (mean = 78.71, 95% CI = [73.7, 84.1], p value $\leq$ 0.001) **Table C.1**.

5.4.3 Assessing horticulturalists self-reported change in health behaviours: simulation and analysis of proportions

I found significant results in all the four health traits measure when compared to an estimate of a 20% change in lifestyle behaviours (null hypothesis). The horticulturalists surveyed believed they ate more fruit and vegetables (53%, p value ≤ 0.001), around 68% reported they socialised more (p value ≤ 0.001), 73% reported exercising more, and 80% thought they were more exposed to greenspace than before due to urban agriculture projects (p value ≤ 0.001) **Table C.2**.

5.4.4 Assessing if the type of urban agriculture is associated with the self-reported change in health behaviours: chi-square and contingency table with a permutation test

The comparison between type of urban agriculture and the perceived changed of healthy behaviours shows no association between the perceived changed any type of agriculture; p value ≥ 0.05 **Table C.3**.

5.4.5 Assessing if the type of urban agriculture affects health behaviours and traits health traits: general linear models

Logistic regression models showed no relation between the type of agriculture with loneliness and medication intake. Ordinal logistic models showed differences between self−health assessment and the type of urban agriculture practised. Horticulturalists involved in 'community gardens or other' and 'three types of agriculture' had higher odds of reporting good health than horticulturalists who only used allotments (OR = 1.889, 95% CI = 1.301, 2.625, p value = 0.03), and (OR = 2.297, 95% CI = 1.500, 4.557, p value ≤ 0.001), respectively. People with an 'unknown type' of urban agriculture had lower odds of being happy than those involved on allotment gardening (OR = 0.858, 95% CI = 0.477, 0.942, p value = 0.048). I found significant difference between the type of agriculture and daily fruit and vegetable intake, time spent outdoors, and BMI. Horticulturalists who were involved in 'community gardens or other' or other and 'Three types of urban agriculture', ate more fruit and vegetables than those involved only in allotments (β = 1.89, 95% CI = 1.413, 3.376, p value = 0.012), and (β = 2.074, 95% CI = 1.574 , 2.426, p value = 0.032), respectively. Horticulturalists involved in 'Three types of urban agriculture' spent more time outdoors than those who were only involved

in allotments (β = 0.274, 95% CI = 0.148, 1.032, p value = 0.0481). Finally, horticulturalists who practiced 'allotments and backyards' had a higher BMI than those only involved in allotments (β = 2.316, 95% CI = 0.129, 4.503, p value = 0.0387) **Table 5.2**.

Table 5.2: **GLMs' results: The table shows the results of the models for lifestyle behaviours and health and well-being markers (BMI, fruits and vegetable intake, time spent outdoors, self-health assessment, happiness, medication intake, and loneliness) by type of agriculture (Allotments, Allotments and backyards, Backyards, Community garden or other, Three types of urban agriculture, Unknown)**. Each model has the R^2, the β coefficient, or the estimated odds ratio (OR) for the logistic and ordinal logistic models, the 95% confidence interval, and the p value. The complete table is in **Appendix C; Table C.4**

Type of urban agriculture (reference = Allotments)	**Estimate (β)**	**95% CI**	**p value**
BMI (R^2 = 0.44)			
Allotments and backyards	2.316	0.129, 4.503	0.0387
Self-health assessment (R^2 = NA)			
Community gardens or other	(OR) 1.889	1.301, 2.625	0.0315
Three types of urban agriculture	(OR) 2.297	1.500, 4.557	$\leq$ 0.001
Fruit and vegetable intake (R^2 = 0.52)			
Community gardens or other	1.894	1.413, 3.376	0.012
Three types of urban agriculture	2.074	1.092, 3.413	0.032
Time outdoors in summer (R^2 = 0.51)			
Three types of urban agriculture	0.237	0.148, 1.032	0.048

5.5 Discussion

In this chapter, I evaluated the findings highlighted in the conceptual framework using horticulturalists from the main cities of the UK as a study sample. The results showed that participating in urban agriculture was related to meeting the daily fruit and vegetable intake recommendation of 5 portions, the physical activity recommended levels of 20 minutes, and meeting the recommended time spent outdoors; 3 hours (note: children's recommended values were adopted for adults). The literature points to these behaviours as health−related behaviours (WHO-FAO, 2003; Anderssen et al., 2007; Gladwell et al., 2013; Bijnens et al., 2020). Moreover, from the sample, it seems that participants of urban agriculture have, on average, a healthy BMI, and the horticulturalists think their lifestyle behaviours changed after starting urban agriculture projects.

The data suggest a correlation between urban agriculture and healthy behaviours. These results corroborate others that have been reported in previous studies (Guitart et al., 2014; Mok et al., 2014). For example, Van den Berg et al. (2010) found that urban horticulturalists were more active in the summer than people who did not garden. Several authors have claimed the importance of greenspace and outdoor activities for mental health, well−being, and even physical health (Hofmann and Javed, 2018; WHO, 2016; Van den Berg et al., 2015). For the particular case of urban agriculture, Poulsen et al. (2014) reported that horticulturalists think of this activity as a type of exercise and describe how horticulturalists explained that the connection to nature they experienced while practising urban agriculture was related to their mental health and well−being. According to these results, gardening could be an excellent activity to increase the number of hours outdoors with the potential outcome of improving physical and mental health (Poulsen et al., 2014; Bellows et al., 2003).

Horticulturalists reported higher consumption of fruit and vegetables and physical activity than the recommended levels. These results coincide with Wakefield et al. (2007) who similarly reported that people involved in community gardens in Canada had better access to food and were physically more active. Moreover, the results suggest that horticulturalists believed that fruit and vegetable consumption and physical activity increased due to urban agriculture. Even if I cannot establish causality given the cross−sectional study design (Pearce, 2012) and self−reported nature of the data (Baker et al., 2004), the reported effect is interesting because it shows that people at least think they have changed. This effect is known as the placebo effect (Colagiuri et al., 2015), and it has been tested in several medical studies (Colagiuri et al., 2015). The placebo effect says that a person merely believing that they are taking a drug (even if it is not true) improves health (Price et al., 2008). The same effect happens at a psychological level (Price et al., 2008). If a person believes that is improving

his diet or physical activity (whether it is true or not), he can improve its well−being and eventually its own health, since a person's behaviour may eventually change in the direction, they think they are going.

I did not find a significant difference between the BMI recommended by the health authorities and the BMI of horticulturalists. This means that horticulturalists in our sample have, on average, a healthy BMI. Our results go in the same line as those of Alaimo et al. (2008) and Zick et al. (2013) who found that after controlling for confounders, horticulturalists had a lower BMI than the group of non−horticulturalists. In the context of the broader literature, it is possible to suggest that engagement in urban agriculture may encourage healthy behaviours and a healthy BMI (Schmutz et al., 2014; Grier et al., 2015; Soga et al., 2017b).

The simulations show no differences between people who reported a change in their behaviour due to urban agriculture and the type of urban agriculture they practised. This result implies that regardless of the type of urban agriculture practised, people think that their lifestyle behaviours improve. Many investigations show the association between the feeling of well−being and greenspaces (Lafortezza et al., 2009; Gascon et al., 2016; Thomas, 2014). Some authors even speak of 'therapeutic landscapes' (Camps-Calvet et al., 2016; Litt et al., 2011). Urban agriculture may act as a green space, improving the participants' feeling of well−being regardless of the type practised (Clarke and Jenerette, 2015; Schmutz et al., 2014), which is reflected in the percentage of people who reported having changed their lifestyle behaviours after getting involved in urban agriculture projects. On the other hand, the models show a difference between the type of urban agriculture and the consumption of fruit and vegetables, the hours outdoors in summer and the daily physical activity levels. However, the models also show, that other confounders have even more impact than agriculture itself. Hence, The differences between the lifestyle behaviours, health and well-being markers and the type of agriculture, even if they exist, don't impact as much as other confounders, showing that practising urban agriculture is more critical than the type of urban agriculture practised.

In this chapter, I could not assess if being involved in urban agriculture is associated with better health and well−being markers (except for BMI) because I don't have another group to compare. In the next chapter, I use the UK Biobank as a British population sample and compare it with the horticulturalists.

Chapter 6

Health and well-being benefits from urban agriculture; a cross-sectional study using a sample of urban horticulturalists and the UK Biobank cohort

The introduction of this chapter relies heavily on the peer review journal article: 'Public health benefits of urban horticulture in the Global North: A scoping review and framework' (Cruz-Piedrahita et al., 2020). The other two authors of the article are the supervisors of this thesis and agreed to use its content here.

This chapter relies heavily on the accepted manuscript: 'Health and well-being benefits from urban agriculture; a cross-sectional study using a sample of urban horticulturalists and the UK Biobank cohort' (Cruz-Piedrahita et al., ndd). The other authors of the article are the supervisors of this thesis or advisers of the UK Biobank and agreed to use its content here.

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*Cruz-Piedrahita, C. Howe, C. & de Nazelle, A. (2020) Public health benefits from urban horticulture in the global north: A scoping review and framework. Global Transitions. [Online] 2, 246–256. Available from: doi:10.1016/j.glt.2020.10.001.

*Cruz-Piedrahita, C. Howe, C. Roscoe, C. Fetch, D. & de Nazelle, A. (2022) Health and well-being benefits from urban agriculture; a cross-sectional study using a sample of urban horticulturalists and the UK Biobank cohort. [in press].

CRediT authorship contribution statement:

Catalina Cruz-Piedrahita: Ethics approval, creation and dissemination of the survey. Performed data analysis, interpretation, and statistical analysis from the two databases. Wrote the first draft. Wrote the final paper.

Caroline Howe: Review and editing, conceptualization, and, Supervision.

Audrey de Nazelle: Review and editing, conceptualization, and, Supervision.

Charlotte Roscoe: Review and editing, adviser in statistical analysis, cleaning of the data, data analysis.

Daniela Fecht: Review and editing, adviser in statistical analysis.

6.1 What is this chapter about?

In this chapter, I contrasted the health behaviours of horticulturalists and the general UK population by comparing the sample of 45 to 69-year-old urban horticulturalists from the survey with the UK Biobank cohort participants from the same cities as the horticulturalists.

In the context of the whole research, and similar to the previous chapter, this chapter explores the following objectives:

6.1.1 Objective related to this chapter

Objective II. To assess whether urban agriculture participation is associated with healthier lifestyles than a general population:

II.II Comparing the lifestyle and self-perceived health of urban horticulturalists sampled in the survey, with the general population represented in the UK Biobank cohort.

To address the objective and see if the two samples have differences in the same behaviours, I undertook a randomisation analysis for all the variables included in the survey, comparing the means of the two

samples (the horticulturalists' survey and the UK Biobank). Then, I fitted GLMs to assess if being an urban horticulturalist is related to the health and well-being markers BMI, medication intake, loneliness, happiness, and self-health assessment. All models were corrected for confounders (gender, highest qualifications, smoking status) and the lifestyle behaviours (fruit and vegetable intake, physical activity, and time spent outdoors). The results show that horticulturalists' have healthier behaviours than their peers, and this trend is reflected in the health the markers BMI and medication intake for chronic diseases, but this is not reflected in the well-being traits loneliness, happiness, and self-health assessment.

6.2 Introduction

Poor diet and inadequate physical activity have been linked to obesity, Type 2 Diabetes, hypertension, cancer, and coronary disorders (Swinburn et al., 2011; Flint et al., 2016; Müller and Soares, 2019). The number of people recognised as obese and with obesity-related diseases has increased in the past two decades, and it is estimated that non-communicable diseases (NCDs) are responsible for almost three-quarters of all deaths worldwide (WHO-FAO, 2003; Allen et al., 2020; Lancet, 2018). Although it has been suggested that the BMI of individuals might be determined by genetics, many researchers have suggested that the urban environment of the present day encourages sedentary lifestyles, and the ultra-process food consumption with high calorific content contributes significantly to the current obesity pandemic (Lopez and Hynes, 2006; Mayne et al., 2015). Food insecurity has increased in cities worldwide, including those of the Global North, resulting from the continuing growth in urban populations and concurrent escalation in social inequality. Mental health issues related to urban life represents another concern (Lederbogen et al., 2011; Krefis et al., 2018) including anxiety, depression, stress and social isolation (McKenzie, 2008; Holt-Lunstad et al., 2015). Therefore, different options must be explored concerning providing urban communities with more nutritious foods such as fruit and vegetable. Moreover, cities need places where their populations can increase their physical activity levels, social interactions, and exposure to 'natural' environments. Urban agriculture might be an attractive solution that can potentially address many of these top priorities (Keech and Redepenning, 2020; Fetouh, 2018; Van Veenhuizen and Danso, 2007; Brown and Jameton, 2000; Deelstra and Girardet, 2000).

While current motivations for urban agriculture in the Global North tend to be different, in the past, developed countries had used urban agriculture during extraordinary times, such as the Victory Gardens during WWI and WW2 (Brown and Jameton, 2000; Al-Delaimy and Webb, 2017) and the

Relief Gardens during the Great Depression (McClintock, 2010). More recently, social and ecological factors have explained a considerable part of the increasing popularity of urban agriculture in the Global North (Van Tuijl et al., 2018; Margenat et al., 2019). Nevertheless, at the same time, urban agriculture is also becoming a valuable tool to improve food security (Blair et al., 1991; Hermann et al., 2006; WHO, 2001; Diekmann et al., 2020; Siegner et al., 2018). Despite the growing scientific evidence-base for the contribution of urban agriculture to public health through the provision of ecosystem services (the benefits from nature to human beings) (Carpenter et al., 2009; Clinton et al., 2018) and uptake in healthy behaviours (Brown and Jameton, 2000; Bank, 2013), local authorities and health professionals tend to ignore its potential as a tool for increasing health and well-being in societies (Bellows et al., 2003; Ferreira et al., 2018).

Private and public agriculture projects, such as community gardens or allotments, have direct and indirect links to public health (Bellows et al., 2003; Petts and Organization, 2001; Audate et al., 2018) many of which are recognised as different forms of ecosystem services. Urban agriculture provides all four categories of services identified by the Millennium Ecosystem Assessment: supporting services (*e.g.*, soil formation and regeneration), provisional services (*e.g.*, food production), cultural services (*e.g.*, recreational spaces) and regulating services (*e.g.*, flood control) (Lovell, 2010; Pulighe and Lupia, 2016; Cabral et al., 2017). For example,urban agriculture projects have the potential to increase green-area coverage in cities, decreasing negative environmental phenomena such as the 'heat island effect', noise and air pollution, and improving health through reducing social isolation, sedentarism, and mental health problems (Elmqvist et al., 2015; Andersson et al., 2014; Cox et al., 2017). Furthermore, several authors have also acknowledged the possible direct benefits of urban agriculture in terms of positive changes in diet, food security, physical activity, social cohesion and social capital (Blair et al., 1991; Bellows et al., 2003; Firth et al., 2011; Poulsen et al., 2015; Audate et al., 2019). Finally, urban agriculture can also increase the supply of locally produced food, thus reducing transport, storage and packaging of food, with knock-on consequences of reducing greenhouse gas, pollutant emissions and waste production (Deelstra and Girardet, 2000; Milner et al., 2015). However, there are potential pitfalls, and care should be taken to prevent urban gardening from harming human health through unintended consequences such as a secondary transfer of pollutants present in the soil, water, or air (López et al., 2019; Sevik et al., 2020).

As seen in **Chapter 3**, the current evidence shows how urban agriculture can improve public health directly or indirectly. In this chapter, I try to assess whether being involved in urban agriculture projects is associated with increased healthy behaviours compared to the general population, as the theory suggests. For this aim, I hypothesise that people involved in urban agriculture projects eat

more fruit and vegetable than the general population, do more minutes of exercise a day, socialise with others more often, and have greater exposure to nature and greenspace due to the time spent in gardens or plots. Therefore, I expect that the horticulturalists, in general, should be healthier than the average population. I used the same health and well-being markers from the previous chapter to compared the sample of urban horticulturalists and a sample of the UK population represented by the UK Biobank cohort.

6.3 Methods

* ***Chapter 4*** *contains the description of the data used here. For this chapter, I worked with the horticulturalists' data frame and the UK Biobank. In this section, I am explaining the specific methods.*

Urban horticulturalists from several large UK cities were surveyed to assess self-reported lifestyle behaviours, alongside health and well-being markers potentially associated with urban agriculture projects. The sample was compared to the general population, as represented by the UK Biobank cohort, to assess whether differences in outcomes between the two samples could be attributed to participation in urban agriculture.

6.3.1 Importance of cohorts

An essential tool used in public health to understand NCDs and health traits is cohort studies. Cohort studies are a type of observational study in which a group of people is followed for a specific period (which can vary from a couple of months to several years) to study the impact exposures or behaviours have in the population (Wassertheil-Smoller and Smoller, 2004). A cohort is defined as a group of people with common characteristics, including age, gender, occupation. Most cohort studies in the field of public health are used to determine if the frequency of an illness or event varies depending on the exposure to a particular potential risk factor, such as the frequency of Type 2 Diabetes in those who exercise versus those with more sedentary lifestyles. The importance of using the UK Biobank for this study lies in the fact that I created a survey to extract the same variables from a sample of urban horticulturalists.

6.3.2 Description of data and variables

Various adjustments to the UK Biobank and horticulturalist data frames were made to compare the two samples – horticulturalists and UK Biobank. Firstly, I filtered the UK Biobank data frame to include only data from the same cities as the horticulturalists. Secondly, I filtered the horticulturalist data frame to use only those in the 45 to 69 age range to match the cohorts' age ranges. In the resampling tests, I separately assessed the variables cooked vegetables, raw vegetables, fresh fruit, moderate exercise, and vigorous exercise. For the models, I used the variable fruits and vegetable intake, but I used the variables moderate exercise and vigorous exercise separately. Finally, I categorised BMI into 'Healthy, Overweight, and Obese' using cut-points from the NHS.

Unfortunately, due to the differences in the format of the variable 'age' between the survey and the UK Biobank, it was not possible to include it as a confounder. The horticulturalists' survey classified age using blocks of age '18 – 29 years', '30-44 years', '45-69 years', and 'more than 70 years', whilst the UK Biobank reported 'age when attended assessment centre' (**Appendix B; Table B.1**). All the participants in the UK biobank were between 45 to 69 years old, which is the same block as the third block of age from the gardeners' survey, so there was no differentiation that could be applied in the models.

6.3.3 Statistical analysis

Due to the difference in sample size between the two data sets, I used resampling methods and probabilistic models to avoid issues with data imbalance. I tested differences in means for the lifestyle behaviours between the two samples using permutation tests with 10,000 generations, and for the categorical variables, I used a chi-square and permutation test with 10,000 generations.

To further assess the differences in lifestyle behaviours between the two samples, I fitted general linear models for fruit and vegetable intake, hours spent outdoors, moderate exercise, and vigorous exercise. To determine the odds of reporting loneliness (reference = 'No'), and medication intake (reference = 'None of the above'), between horticulturalists and UK Biobank volunteers, I ran logistic general linear models (GLMs). For the health markers BMI (reference = 'healthy'), self-health assessment (reference = 'Poor'), and happiness (reference = 'Extremely unhappy') I used ordinal logistic regression. To avoid issues with degrees of freedom, I only used the variable fruits and vegetable intake. All models were adjusted for confounders gender (reference = 'Female'), highest qualification or education level (reference = 'College of university degree'), and smoking status (reference = 'Never').

6.4 Results

6.5 Descriptive analysis for lifestyle characteristics

Descriptive statistics for lifestyle behaviours and health and well-being markers stratified by 'sample' are provided in **Table 6.1**. The table includes the p value of the permutation tests.

Gender was fairly evenly distributed in the UK Biobank sample (female = 55%, male = 45%). The horticulturalists' group had more females (66%) than males (34%). Both groups have similar values for smoking status (No = 88% vs No = 89%). 76% of horticulturalists were professionals versus 33% of UK Biobank participants **Table 6.1**.

With respect to measures of well-being and physical health, the results showed that horticulturalists report feeling less lonely (urban horticulturalists; yes = 15% vs yes = 19%, p value = 0.003) than UK Biobank participants, lower BMI (urban horticulturalists; healthy = 55% vs UK Biobank participants; healthy = 33%, p value $\leq$ 0.001), and take less medication than UK Biobank participants (urban horticulturalists; yes = 22% vs UK Biobank participants; yes = 32%, p value $\leq$ 0.001). The self-health assessment scores across the two groups were similar, however, horticulturalists appeared to score a bit higher than UK Biobank participants (urban horticulturalists; excellent = 19% vs UK Biobank participants; excellent = 16%, p value = 0.004). However, horticulturalists score lower for levels of happiness (urban horticulturalists; extremely happy = 4.1% vs UK Biobank participants; extremely happy = 10%, p value $\leq$ 0.001) **Table 6.1**.

On average, horticulturalists eat more fruit a day (2.62 vs 2.2, p value $\leq$ 0.001), cooked vegetables (1.59 vs 0.33, p value $\leq$ 0.001), and raw vegetables than UK Biobank participants (0.92 vs 0.13, p value $\leq$ 0.001). Moreover, horticulturalists, on average, meet the recommended intake of five portions of fruits and vegetable (5.15, 3.66, p value $\leq$ 0.001) and they spent fifteen more minutes than UK Biobank participants exercising moderately (65 min per day vs 53 min per day, p value $\leq$ 0.001). However, in contrast they spent fourteen fewer minutes than UK Biobank participants doing vigorous exercise (25 min per day vs 39 min per day, p value $\leq$ 0.001) **Table 6.1; Fig. 6.1**.

Table 6.1: **Descriptive analysis: UK Biobank participants and respondents of the urban horticulturalists' survey** . Lifestyle characteristics (Gender, Highest qualification, Smoking status, Body Max Index, Medication intake, Loneliness, Self-health assessment, Happiness, Moderate physical activity,Vigorous physical activity, Cooked vegetable intake, Raw vegetable intake, Fruit intake, fruit and vegetable intake, and hours spent outdoors) of the UK Biobank participants and of respondents of the urban horticulturalists' survey. For categorical variables, the table shows the count and the percentage of participants in each category, for numerical variables it shows the mean and standard deviation. The p value of the permutation tests when applied is reported.

Characteristic	**Urban horticulturalists n = 391**	**UK Biobank participants n = 429,045**	**p value**
Gender (reference = Female)			
Female (reference)	258 (66%)	231,684 (55%)	NA
Male	133 (34%)	193,070 (45%)	NA
Highest qualification (reference = College or university degree)			
None of the above	5 (1.2%)	72,937 (17%)	NA
Education till 16	22 (5.6%)	115,842 (27%)	NA
18 above no degree	67 (17%)	98,680 (23%)	NA
College or University degree (reference)	297 (76%)	141,584 (33%)	NA
Smoking status, (reference = No)			
No (reference)	344 (88%)	381,850 (89%)	NA
Only occasionally	20 (5.1%)	11,584 (2.7%)	NA
Yes, on most or all days	27 (7.1%)	33,465 (7.8%)	NA
Body Max Index (reference = Healthy			
Healthy (reference)	216 (55%)	141,584 (33%)	
Overweight	117 (30%)	180,198 (42%)	≤ 0.001
Obese	58 (15%)	102,970 (24%)	

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(Continued)

Characteristic	Urban horticulturalists n = 391	UK Biobank participants n = 429,045	p value
Medication intake (reference = None of the above)			
None of the above (reference)	304 (78%)	291,750 (68%)	
Yes	87 (22%)	137,295 (32%)	≤ 0.001
Loneliness			
No (reference)	58 (15%)	81,518 (19%)	
Yes	333 (85%)	347,527 (81%)	0.003
Self-health assessment (reference = Poor)			
Poor (reference)	16 (4.3%)	19,736 (4.6%)	
Fair	78 (20%)	90,099 (21%)	0.004
Good	223 (57%)	248,846 (58%)	
Excellent	74 (19%)	68,647 (16%)	
Happiness (reference = Extremely unhappy)			
Extremely unhappy (reference)	2 (0.3%)	434 (0.3%)	
Very unhappy	8 (1.3%)	1,383 (0.9%)	
Moderately unhappy	42 (6.8%)	6,911 (4.4%)	0.02
Moderately happy	328 (53%)	62,612 (40%)	
Very happy	210 (34%)	69,454 (44%)	
Extremely happy	25 (4.1%)	15,654 (10%)	
Moderate physical activity minutes/day			
	65 (21)	53 (17)	≤ 0.001
Vigorous physical activity minutes/day			
	25 (13)	39 (28)	≤ 0.001
Cooked vegetable intake portions/day			

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(Continued)

Characteristic	Urban horticulturalists n = 391	UK Biobank participants n = 429,045	p value
	1.59 (1.7)	0.3 (0.21)	≤ 0.001
Raw vegetable intake portions/day			
	0.92 (1.5)	0.13 (0.11)	≤ 0.001
Fruit intake portions/day			
	2.62 (1.8)	2.20 (1.61)	≤ 0.001
Fruit and vegetable intake portions/day			
	5.15 (2.61)	3.66 (2.09)	≤ 0.001
Hours spent outdoors hours/day			
	4.15 (2.38)	3.57 (2.49)	≤ 0.001

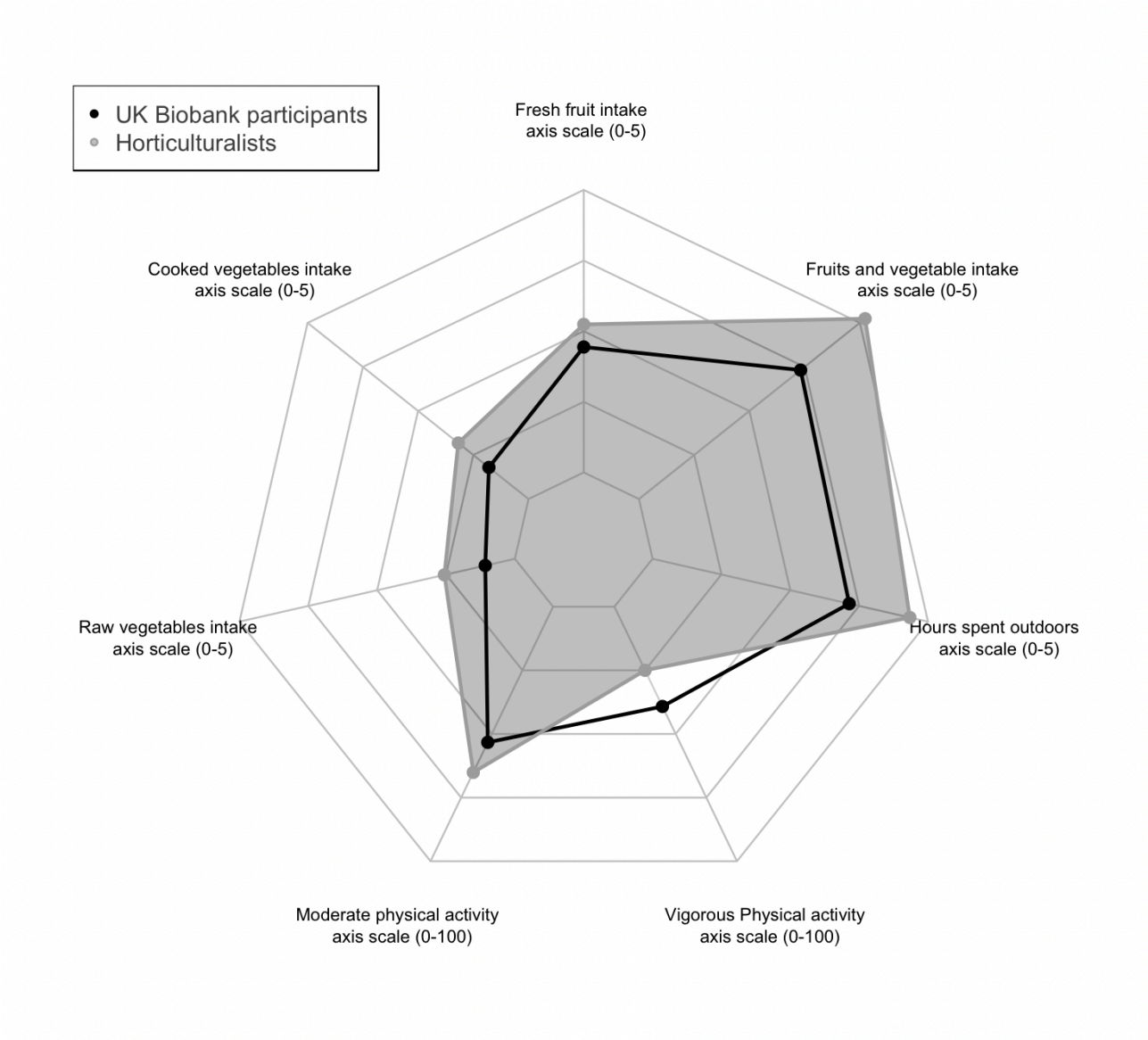

Figure 6.1: Radar chart showing the mean for each lifestyle behaviour (moderate physical activity, vigorous physical activity, cooked vegetable intake, raw vegetable intake, fresh fruit intake, fruit and vegetable intake, and hours spent outdoors) as a comparison between horticulturalists and the UK Biobank participants. The scale for the lifestyle behaviours goes from 1 to 5, except for moderate and vigorous physical activity (1 to 100). Horticulturalists are represented in grey and UK Biobank participants in white with a black line.

6.5.1 Differences in lifestyle behaviours between urban horticulturalists and UK Biobank participants

The results of the GLMs indicate that horticulturalists eat more fruit and vegetables than the UK Biobank participants (β = 30.312, 95% CI = [1.202 – 1.533], p value $\leq$ 0.001), do more moderate physical activity (β = 16.312, 95% CI = [10.147 – 26.476], p value $\leq$ 0.001), and spend more time outdoors in summer (β = 1.043, 95% CI = [0.846 – 1.239], p value $\leq$ 0.001). However, the results of

the GLMs indicated that the UK Biobank participants do more vigorous exercise (β = -9.529, 95% CI = [-11.365 – -7.694], p value $\leq$ 0.001) (**Table 6.2**).

Table 6.2: **GLMs' results: Lifestyle behaviours (Fruit and vegetable intake, Moderate physical activity,Vigorous physical activity, and Hours outdoors in summer); UK Biobank participants vs respondents of the urban horticulturalists' survey**. Differences in lifestyle behaviours between the UK Biobank participants (reference) and respondents of the urban horticulturalists' survey. The table shows the estimated coefficient (β), 95% confidence interval, and the p value. This table only shows the differences in lifestyle behaviours between the two samples (UK Biobank participants and urban horticulturalists), the complete table with the confounders is in **Appendix D**.

Sample	Estimated coefficient (β)	95% CI	p value
	Fruit and vegetable intake portions/day		
Horticulturalist	1.367	1.202, 1.533	$\leq$ 0.001
	Moderate physical activity min/day		
Horticulturalist	16.312	10.147, 26.476	$\leq$ 0.001
	Vigorous physical activity min/day		
Horticulturalist	-9.529	-11.365, -7.694	$\leq$ 0.001
	Hours outdoors in summer hours/day		
Horticulturalist	1.043	0.846,1.239	$\leq$ 0.001

6.5.2 Health and well-being markers differences between horticulturalists and UK Biobank participants

The results indicate that horticulturalists are less likely to take medication (OR = 0.257, 95% CI = [0.250 – 0.264], p value = 0.07) and have a lower BMI than UK Biobank participants (OR = 0.654, 95% CI = [0.555 – 0.770], p value = 0.001). However, they have lower odds of feeling happy (OR = 0.454, 95% CI = [0.388 - 0.530], p value $\leq$ 0.001) and reporting good health (OR = 0.584, 95% CI = [0.495 – 0.688], p value = 0.004). The model for loneliness found no differences between the two samples (OR = 1.001, 95% CI = [0.795 – 1.260], p value = 0.64) **TableD.2**.

Table 6.3: **GLMs' results: Health and well-being markers (Body Mass Index, Medication intake, Loneliness, Happiness, Self-health assessment); UK Biobank participants vs respondents of the urban horticulturalists' survey**. Differences in health and well-being markers between the UK Biobank participants (reference) and the urban horticulturalists. The table shows the odds ratio (OR) 95% confidence interval, and the p value. This table only shows the differences in lifestyle behaviours between the two samples (UK Biobank participants and urban horticulturalists), the complete table with the confounders is in **Annex D.2**

Sample	OR	95% CI	p value
Body Mass Index (reference = Healthy)			
horticulturalist	0.654	0.555, 0.770	≤ 0.001
Medication intake (reference = None of the above)			
horticulturalist	0.257	0.250, 0.264	≤ 0.001
Loneliness (reference = No)			
horticulturalist	1.001	0.795, 1.260	0.64
Happiness (reference = Extremely unhappy)			
horticulturalist	0.454	0.388, 0.530	≤ 0.001
Self-health assessment (reference = Poor)			
horticulturalist	0.820	0.807, 0.834	≤ 0.001

6.6 Discussion

Prior studies have reported on the effectiveness of urban agriculture projects on improving lifestyle behaviours, physical health, and mental well-being in The Global North (Mok et al., 2014; Golden, 2013). However, to assess the potential of interventions based on urban agriculture to promote healthier lifestyles as a public health policy, I need to understand the pathways through which urban agriculture influences healthy behaviours and ultimate physical and mental health of those who practice it. This chapter is novel in that it looked at multiple lifestyle behaviours and health and well-being markers simultaneously whilst also taking advantage of a study design that compared horticulturalists with a large sample of urban dwellers represented by the UK Biobank.

6.6.1 Healthy behaviours' differences between horticulturalists and UK Biobank participants

I find that in comparison to the general population (with similar characteristics in terms of age, city of residence, and smoking and alcohol intake), urban horticulturalists tend to choose healthier lifestyles, supporting the hypothesis that healthier lifestyle choices are one of the potential benefits of practicing urban agriculture. People involved in urban agriculture projects were shown to eat 5.15 portions of fruit and vegetables daily, which goes in line with the recommended amount of five portions a day by the WHO. Moreover, 43% of the horticulturalists sampled met the WHO requirement, compared to 20.1% in the UK Biobank sample. These findings are in line with previous studies, for example, in a cross-sectional survey, Ober Allen et al. (2008) found that, after controlling for confounders, horticulturalists consumed 1.4 times more fruit and vegetables than neighbours not involved in agriculture projects. Similarly, Barnidge et al. (2013) found that being involved in community gardens was associated with higher odds of meeting the daily fruit and vegetable intake recommendation. The results show that the difference between horticulturalists and UK Biobank participants is more pronounced for vegetable consumption than fruit consumption; horticulturalists eat on average 2.67 portions of vegetable a day while UK Biobank participants eat on average 0.46. This is in accordance with Castro et al. (2013), who also reported a higher increase in vegetable intake (33%) than in fruit intake (25%) after an intervention program promoting urban agriculture. This trend might be the result of the availability of produce because horticulturalists are more likely to cultivate vegetables than fruit (Mok et al., 2014; Guitart et al., 2014).

UK recommendations for physical activity state that adults should do 75 min of vigorous exercise a week or 150 min of moderate exercise. I found relatively small although significant differences between urban horticulturalists and the UK Biobank population sample. Horticulturalists spent more time than UK Biobank participants exercising moderately (65 mins a day versus 53 mins a day), but the differences in the two groups for vigorous activity was more marked and in the opposite direction. Overall, 77% of the urban horticulturalists meet the requirements for moderate exercise, compared to 71% of UK Biobank participants, but 81% percent of UK Biobank participants do at least 10 minutes a day of vigorous exercise, versus 52% of horticulturalists. In total 81% of horticulturalists meet the requirements for total exercise (moderate or vigorous), versus 89% of UK Biobank participants. Urban agriculture activities like gardening are considered moderate exercise, and some papers suggest that people join gardening activities to be more active (Kingsley et al., 2009; Soga et al., 2017a). However, the results suggest that there may be a substitution effect, with gardening activities replacing more vigorous forms or other moderate forms of exercise, leading to no net gain in physical activity. These

differences may vary by age group, as indicated in Van den Berg et al. (2010), who found that only horticulturalists over 62 years old were more active than their non-gardening neighbours. Similarly, Poulsen et al. (2014) highlight that the exercise provided by urban agriculture seemed to be more critical for older horticulturalists. Nevertheless, I was not able to investigate such age impacts, as I did not have detailed age data within the 45-69 age range.

Adding to the complexity and uncertainty in comparing physical activity across the two groups is the use of self-reported measures. Current knowledge on physical activity tends to rely on self-reported, rather than objective measures of physical activity (Al-Delaimy and Webb, 2017) and perceptions may vary for each type of activity as to whether it is light, moderate, or vigorous exercise. It is possible therefore that more pleasant types of physical activity, such as gardening, may feel less like exercise than other sports activities and thus levels of exercise may be under-reported.

The results on time spent outdoors suggest that urban horticulturalists spent on average 1.8 more hours outdoors than UK Biobank participants. Previous studies have shown that being outdoors and having a connection to nature was one of the most reported benefits of urban agriculture projects (Armstrong, 2000; Lin et al., 2017; Soga et al., 2017a). Wood et al. (2016) reported that horticulturalists respond that being outdoors was one of the benefits they enjoy the most while gardening. Similarly, Soga et al. (2017a) show that horticulturalists in Tokyo, Japan reported that 'being in contact with nature' was one of the main reasons for participation in allotment gardening. Spending time in nature has been shown in literature on green space as providing a potential range of benefits, including reducing levels of stress, anxiety, and blood pressure (Van den Berg et al., 2015; WHO, 2016). It is possible, therefore, that horticulturalists might be using the time in their allotments or gardens to disconnect from the stress of the city environment and connect with nature (Poulsen et al., 2014; Pitt, 2014; Soga et al., 2017a) and this may have a knock-on effect on their physical and mental health. However, from this study, this can only be suggested but not confirmed.

6.6.2 Health traits' differences between horticulturalists and UK Biobank participants

Whilst I found some measurable differences in some of the health behaviours between urban horticulturalists and the UK Biobank participants, these differences did not always translate into health benefits in the fully adjusted models. Once socio-demographic and lifestyle factors were accounted for, horticulturalists did show better health status as measured by BMI and medication intake, but not with respect to loneliness, self-health assessment and happiness. Previous studies, contrary to the

findings, has shown some indication of well-being and social cohesion benefits of participation, whilst the evidence on BMI or chronic diseases is scant.

The results for loneliness showed that horticulturalists had slightly lower counts of loneliness in urban horticulturalists in the un-adjusted analysis, but once education and other lifestyle factors (possibly indicative of other socio-demographic factors) were accounted for, the association disappeared. The results are surprising because social cohesion is often mentioned as a benefit of urban agriculture. In a literature review, Di Fiore et al. (2021) found that 16 out of 36 studies mentioned socialisation as a motive for participation in urban agriculture programs. People who feel lonely may therefore participate in urban agriculture to gain more opportunities to meet people thus reducing their self-reported 'loneliness scores'. However, loneliness feeling is related to factors such as age, nationality, and ethnicity (Yang and Victor, 2011; Jamieson et al., 2018), so probably these unaccounted factors affected the 'loneliness score' more than urban agriculture. Some studies, for example, found a reduction of loneliness after gardening intervention programs in care homes (Tse, 2010; Brown et al., 2004). Consequently, it is possible that urban agriculture may have a higher impact on loneliness for people in particular situations, such as older adults in care homes where other social activities are limited. Once again, I were unable to capture differences due to age or social situation, which would have allowed me to have disentangled this complex association further.

Self-perceived 'good health' and happiness were negatively associated with the practice of urban agriculture in adjusted analyses, in other words, the UK Biobank participants score better than urban horticulturalists in levels of happiness and self-health assessment. I predicted that health and well-being benefits were likely to result from the healthy behaviours associated with urban gardening, however, evidence for this association is limited. In a scoping review of the health benefits of urban agriculture in countries of the Global North, Cruz-Piedrahita et al. (2020) found 39 articles stating the health benefits of urban agriculture with only four of those papers directly assessing self-perceived health of horticulturalists. One of the studies demonstrates that, compared to their neighbours in the same age range, horticulturalists over 62 had better self- perceived health and well-being, with the opposite holding true for younger participants (less than 62) (Van den Berg et al., 2010). Another study based on qualitative interviews noted that some, but not all, urban horticulturalists felt improvements in health after involvement in urban agriculture (Kingsley et al., 2009). This chapter did not report age differences. Still, I propose that old people might more likely to report well-being benefits from urban agriculture projects than younger ones. I also note that the UK Biobank sample is known to have a healthy volunteer bias, thus offers a high bar for comparison of health measures (Cassidy et al., 2017; Fry et al., 2016).

I only found one paper assessing a physical trait directly linked to chronic disease. Weltin (2013) used participation in community gardens as an intervention program for immigrants in Iowa, some of them with Type II Diabetes. They assessed glycated haemoglobin before and after the intervention and between intervention and control groups. The results show a reduction in glycated haemoglobin for those in the gardening group after 6 months while the control group increased the glycated haemoglobin levels. The results for medication intake for chronic diseases, including among that insulin, go in line with these findings and show that urban agriculture is related to less medication being taken for chronic conditions. I can hypothesise therefore, that healthy lifestyle behaviours in horticulturalists act in synergy improving horticulturalists' physical health, which is reflected in lower BMI and less medication intake.

Overall, I found benefits in health markers that might be considered objective, such as BMI and medication intake, but the reverse in perceived health and well-being such as happiness and self-health assessment, and no differences for loneliness. A possible reason might be that urban agriculture participants do not recognise that their health is better than they perceive it to be, or are more conscious of their limitations concerning their health. Alternatively, the opposite is possible, and people get involved in urban agriculture projects because they need to improve their health and well-being.

6.7 Conclusion

Urban agriculture in the Global North is becoming increasingly popular as a tool to improve people's health and well-being and increase green spaces in cities. Social research has recognised the benefits of urban agriculture for its participants, but most research is qualitative and assesses subjective health and well-being traits. This research is unique because it compares lifestyle behaviours and health markers of horticulturalists with a large sample of urban dwellers, and to my knowledge, this is the first study of this kind.

The research suggests that urban agriculture can be used as a promising tool to address chronic diseases and obesity by facilitating multiple lifestyle changes that positively affect health, such as fruits and vegetable intake, increasing the time outdoors in summer, socialisation, and physical activity. These lifestyle behaviours might cluster and improve horticulturalists' health, so they probably don't need to increase each of them notably or make a lot of efforts that cannot sustain in time. Minor improvements in each behaviour acting together can improve physical health. However, some horticulturalists, especially the younger ones, might not acknowledge the benefits and tend to overlook

them. Therefore, the importance of more quantitative studies assessing the health impact of urban agriculture in different people. I specifically highlight the need for more intervention research to analyse urban agriculture's benefits in different age groups and longitudinal analysis to establish causality and quantify the benefits over time.

Chapter 7

Holistic approach to assess the association between the synergistic effect of physical activity, exposure to greenspace, and fruits and vegetable intake on health and well-being: Cross-sectional analysis of UK Biobank

This chapter relies heavily on the accepted manuscript: 'Holistic approach to assess the combined associations physical activity, exposure to greenspace, and fruits and vegetable intake on health and well-being: Cross-sectional analysis of UK Biobank' (Cruz-Piedrahita et al., 2022). The other authors of the article are the supervisors of this thesis or advisers of the UK Biobank and agreed to use its content here.

References:

*Cruz-Piedrahita, C., Roscoe, C., Howe, C., Fecht, D., & de Nazelle, A. (2022). Holistic approach to assess the association between the synergistic effect of physical activity, exposure to greenspace, and fruits and vegetable intake on health and wellbeing: Cross-sectional analysis of UK Biobank. Frontiers in public health, 10.

CRediT authorship contribution statement:

Catalina Cruz-Piedrahita: Performed data analysis, interpretation, and statistical analysis from the two databases. Wrote the first draft. Wrote the final paper.

Caroline Howe: Review and editing, conceptualization, and, Supervision.

Audrey de Nazelle: Review and editing, conceptualization, and, Supervision.

Charlotte Roscoe: Review and editing, adviser in statistical analysis, cleaning of the data, data analysis.

Daniela Fecht: Review and editing, adviser in statistical analysis.

7.1 What is this chapter about?

This chapter aims to evaluate how the interaction effects of the lifestyle behaviours related to urban agriculture are associated with health and well-being markers. In other words, if the possible benefits of fruit and vegetable intake, physical activity, and greenspace exposure are the result of the added association of each lifestyle independently, or if other benefits are due to interaction effects between the lifestyle behaviours and health and well-being.

In the context of the whole research, this chapter explores the last objective of the thesis:

7.1.1 Objective related to this chapter

Objective III. Assess whether a combined effect of the three main behaviours (fruit and vegetable intake, being physical activity, and being exposed to a green area) associated with urban agriculture improve population health rather than the sum of their separate effects on health. In other words, are city dwellers that have a healthy diet, are physically active and interact with greenspaces, healthier than expected?

For this objective, I will analyse the UK Biobank cohort by comparing single versus joint effects of the behaviours mentioned using General Linear Models (GLMs with bootstrap) with and without interactions between the explanatory variables. The results showed that the three behaviour variables interact regarding their overall impact on health and well-being. However, these interactions are complex, and the direction and effect size varies depending on the values of other explanatory variables.

7.2 Introduction

The findings from the previous chapters suggest that urban horticulturalists are, on average, healthier than the general urban population due to the healthier behaviours they exhibit. However, it is possible that these people may be even healthier than expected due to synergistic effects between the different lifestyle behaviours: fruit and vegetable consumption, physical activity, and hours spent outdoors as a proxy to greenspace exposure (Lahart et al., 2019a; Anderssen et al., 2007).

It can therefore be hypothesised that when people have several healthy lifestyles behaviours their health may be better than expected than when evaluating the impact of each healthy lifestyle habit separately, as the impacts will work in synergy, increasing the level of benefits. Several authors/researchers have previously proposed this argument, relating it to the prevention of non-hereditary diseases: reporting two main types of synergies – positive and negative or antagonistic (Wang et al., 2011). For example, some people eat more food to compensate the extra effort of increasing levels of physical activity (Caudwell et al., 2009). Where there is no change in food quality or the nutritional value of the food consumed, this results in weight gain, or an increased chance of non-inherited diseases as opposed to weight loss. In contrast, when people improve their diet and exercise simultaneously, the health markers increase more than expected when the contributions of exercise and diet are analysed independently (Anderssen et al., 2007).

One possible explanation for the high incidence of non-hereditary diseases in populations of the Global North is the occurrence of synergies between poor health habits (such as smoking and not exercising). If I predict that good health behaviours generate a synergistic effect that improves health, the opposite may also be true in that unhealthy habits will have a synergistic effect that worsens health outcomes. In cities developed nations, people tend to move less in their day to day lives, due to lifestyle and technological facilities that exist in cities (Olabarria et al., 2014; Mamplekou et al., 2010). For example, they use the car instead of walking or riding a bicycle, or take an elevator instead of the stairs. Cities also have an impact on eating patterns (Olabarria et al., 2014; Mamplekou et al., 2010). People are often encouraged to consume food that is unhealthy due to ease *e.g.*, fast food or sandwich lunches grabbed 'on-the-go'. Some authors refer to this phenomenon as the 'foodscape' and relate it to poor eating patterns (Burgoine et al., 2016). Modern cities also tend to have fewer green spaces due to population density (Fuller and Gaston, 2009). Several authors have linked the proximity to greenspace with an increase in physical activity and mental health improvements (Wolch et al., 2014). Consequently, it is likely that people in cities will spend fewer hours outdoors and exercising, which will not only impact their health (Mamplekou et al., 2010), but do so to a greater extent than if they

only undertook one of these behaviours at a time. Whilst horticulturalists, by counter-balancing these unhealthy habits with increased exercise, for example, will, in general, be in better health than their non-gardening peers, and their improved health will be greater than expected if, for example, they only spent time outside or only exercised more.

Although the benefits, in terms of healthy behaviours, of urban agriculture have been tested independently (Soga et al., 2017b), synergies between them have not been explored. The aim of this chapter is to investigate potential synergistic impacts (both positive and negative synergies) between fruit and vegetable intake, levels of physical activity, and exposure to greenspaces, through an assessment of different health markers using the UK Biobank cohort.

7.3 Methods

* ***Chapter 4*** *contains the description of the data used here. For this chapter, I only worked with the UK Biobank participants' data frame, and in this section, I am explaining the specific methods.*

7.3.1 UK Biobank cohort

For this chapter, I only included participants who resided in England at the time they were recruited for participation and had data collected via the touchscreen questionnaire, direct measurements at the assessment centre and had greenspace data available from UK Biobank project 4362 (Roscoe, 2020), which assigned high-resolution Ordnance Survey MasterMap greenspace data in circular distance buffers around participant addresses (N = 204,478).

7.3.2 Explanatory variables

Unlike the previous two chapters, I used two different explanatory variables for this analysis. To assess physical activity, I used questions based on the short form of the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003). I used the UK Biobank variable 'IPAQ activity group', which categorises people into three groups, 'Low', 'Moderate', and 'High', by using the classification processing rules published by the IPAQ (*ibid*). This UK Biobank variable was not part of the original data and it was created as part of the project 3594, the protocol and procedures of that research are

reported elsewhere (Cassidy et al., 2016). IPAQ reports physical activity in weekly Metabolic Equivalent Tasks (METs) (min/week), which relates to the energy expenditure doing moderate activities, vigorous activities, and walking, compared to sitting (Craig et al., 2003; Cassidy et al., 2016).

Based on the hypothesis that people who practice urban agriculture are in constant proximity and interact with nature, I wanted to assess the association of greenspace exposure and health and well-being markers using distance to greenspace instead of time outdoors. Hence, I used data on exposure to greenspace within 100 metres of the participants' residential addresses using data from Ordnance Survey MasterMap Greenspace (UK Biobank project 4362). Methods to calculate greenspace percentage are reported elsewhere (Roscoe, 2020). The percentage of surrounding greenness or greenspace exposure was categorised using quartiles (Q1, Q2, Q3, and Q4) (Roscoe, 2020).

I used the fruits and vegetable intake as a categorical variable by using the WHO recommendation of eating at least five portions of fruits and vegetables as a cut-point. I labelled participants as 'Less than 5 portions' for participants who ate less than five portions a day and '5 portions or more' for those who consumed 5 or more portions a day.

7.3.3 Socio-demographic characteristics and lifestyle factors

For this chapter I changed the confounders for the models, I included sex (Female, Male), age at baseline assessment, ethnicity as a binary variable (two categories): 1) White, 2) Not white (original Biobank categories: 'Mixed', 'Asian or Asian British', 'Black or Black British', 'Chinese', and 'Other ethnic group'), smoking, and Index of Multiple Deprivation (IMD) (**See Table B.1**, **Table B.2**, and **Table B.3** in **Appendix B**).

I defined neighbourhood deprivation using the deciles of the 2010 IMD for England (Lewer et al., 2020). I created the categories 'Low', 'Medium', and 'High Deprivation' by collapsing the national deciles 1-3, 4-7, and 8-10, respectively. The index of multiple deprivation comprises assessments of seven different categories experienced by people: Income Deprivation, Employment Deprivation, Health Deprivation and Disability, Education Skills and Training Deprivation, Barriers to Housing and Services, Living Environment Deprivation, and Crime (DCLG, 2011). I used the category 'smoking' from the UK biobank that splits participants into current smokers, previous smokers, and participants who had never smoked.

7.3.4 Health and well-being markers

I defined health markers BMI (three categories) by collapsing the original UK Biobank variable: 1) Healthy ($\leq$ 24.9), 2) overweight (25 – 29.9), and obese ($\geq$ 30) (Cai et al., 2018), blood pressure (binary): 1) Healthy ($\leq$ 120 systolic; $\succ$ 80 diastolic) and 2) High ($\geq$ 120 systolic; $\geq$ 80 diastolic) (Zhang et al., 2022a; Slark et al., 2014), self-health assessment, and loneliness were considered as outcome variables to assess health and well-being. For this chapter, loneliness was assessed using the questions 'Do you often feel lonely?' (No = 0, Yes = 1) and 'How often are you able to confide in someone close to you?' (0 = almost daily to once every few months; 1 = never, or almost never), participants were defined as lonely if they answered positively to both questions (score 2) (Mutz et al., 2021; Elovainio et al., 2017).

7.3.5 Statistical analysis

Out of the initial 502 664 UK Biobank participants, I excluded participants with missing data in any of the explanatory variables and those who did not meet the inclusion criteria. To avoid losing data I classified NAs of confounders as 'Missing' and used this as a category. To explore if healthy behaviours and exposures related to urban agriculture (fruit and vegetable intake, physical activity, and greenspace exposure) have a synergistic effect on health traits, I conducted Bootstrap General Linear Models (1000 generations) with and without interactions (two-way and three-way) between the explanatory variables. I used logistic regression for blood pressure (reference = healthy) and loneliness (reference = no), and I used ordinal logistic regression to assess self-health assessmet (reference = poor) and BMI (reference = normal), the variable overall health rating is the only variable that uses the unhealthy category (poor) as reference (Mutz et al., 2021). All models were adjusted for age, sex, IMD, ethnicity, highest qualification, and smoking. For each health and well-being marker I first fitted one single exposure model with one of the explanatory variables plus the covariates; secondly, I fitted a multi-exposure confounding model with the three explanatory variables - fruit and vegetable intake, physical activity, and greenspace exposure, plus the covariates without including interactions; finally, I fitted a multi-exposure model with two and three-levels interactions between the explanatory variables plus the covariates.

To account for multiple testing, p values were corrected using the Benjamini & Hochberg method, setting the significance level at $\alpha = 0.05$ and using two-tailed tests (Benjamini and Hochberg, 1995). To relax the distributional assumptions and to calculate the fit of the model and the 95% confidence intervals of the models' coefficients I bootstrapped all the models (1000 generations) (Sherman and

Cessie, 1997; Efron, 1985). The tables in the main text show the outcomes of the exposure model with two and three-levels interactions; outcomes for single exposure and the multi-exposure confounding models (without interactions) are presented in **Appendix E**. I used likelihood ratio test to compare the goodness of fit between the models with interactions and the models without interactions and statistical significance was defined by an $\alpha = 0.05$ and two-tailed tests.

7.4 Results

The final sample size was n = 204,478. Women represented 53% of the participants in the sample (n = 109,339). The sample was biased towards white people, who represented 93% of the sample (n = 190,872), and non-smokers 89% (n = 182,514). The percentage of participants meeting the recommendations for fruits and vegetables was 31.8% (n = 64,999), and 40.5% (n = 82,655) of the participants were classified in the high physical activity category. The percentage of participants classified with healthy BMI was 34% (n = 69,538), 4.0% (n = 8,132) of participants rated their health as poor, 83% (n = 169,802) had healthy blood pressure, and 4.7% (n = 9,624) were classified as lonely **Table 7.1**.

Table 7.1: **Descriptive analysis: UK Biobank England**. Lifestyle characteristics of the UK Biobank participants used in this chapter (Age at baseline, Sex, Ethnicity binary, Index of Multiple Deprivation, Highest qualification, Body Max Index, Smoking, Blood pressure, Loneliness, greenspace (%) at a 100m buffer; quartiles, Physical activity; IPAQ activity group, and Fruits and vegetables intake, binary). For categorical variables, the table show the count and the percentage of participants for each category, for numerical variables it shows the mean and standard deviation.

Characteristic	n = 204,478
Age at baseline (years)	
Years	56 (8)
Sex	
Female	109,339 (53%)
Male	95,139 (47%)
Ethnicity, binary	

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Characteristic	n = 204,478
Not white	13,606 (6.7%)
White	190,872 (93%)
Index of Multiple Deprivation (small-area level)	
Low deprivation	77,366 (38%)
Medium deprivation	79,564 (39%)
High deprivation	47,548 (23%)
Highest qualification	
None of the above	30,139 (15%)
Education till 16	55,142 (28%)
18 above no degree	36,938 (19%)
College or University degree	72,301 (37%)
Smoking	
Never	110,908 (54%)
Previous	71,606 (35%)
Current	21,469 (11%)
Body Max Index (BMI)	
Healthy	69,538 (34%)
Overweight	86,588 (42%)
Obese	48,352 (24%)
Blood pressure	
Healthy	169,802 (83%)
High	34,676 (17%)
Loneliness	
No	194,854 (95.3%)
Yes	9,624 (4.7%)

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Characteristic	n = 204,478
Self-health assessment	
Poor	8,132 (4.0%)
Fair	41,826 (20%)
Good	119,884 (59%)
Excellent	34,636 (17%)
Greenspace (%) at a 100m buffer; quartiles	
1	51,156 (25%)
2	51,093 (25%)
3	51,140 (25%)
4	51,089 (25%)
Physical activity; IPAQ activity group	
Low	37,967 (18.5%)
Moderate	83,856 (41%)
High	82,655 (40.5%)
Fruits and vegetables intake, binary	
Less than 5 portions a day	139,479 (68,2%)
5 or more portions a day	64,999 (31.8%)

7.4.1 Association between lifestyle behaviours and health and well-being

After adjusting for age, sex, ethnicity, highest educational qualifications, smoking, and Index of Multiple Deprivation; single exposure models show, as would be expected that both fruit and Vegetable intake and physical activity are positively associated with overall health rating; physical activity with decreased BMI; both physical activity and fruit and vegetable intake with decreased blood pressure, but the latter only for high levels of physical activity (OR= 0.894, 95% CI = 0.865, 0.924, p adjusted $\leq$ 0.001) (**Table E.1 - E.4; Appendix E**). Physical activity and surrounding greenness were associated with reduced loneliness, except for the 2nd quartile of greenspace exposure that was not statistically

significant (OR= 0.979, 95% CI = 0.924, 1.038, p adjusted = 0.477) (**Table E.1 - E.4; Appendix E**). Contrary to expectations, however, fruit and vegetable intake and surrounding greenness were associated with increased BMI; the quartiles Q2 and Q3 of surrounding greenness with poor health, and with increased blood pressure.

I found similar associations between the explanatory variables and the health outcomes in the multiple-exposure models with no interactions, but all the association were slightly attenuated when compared to the single exposure models **Table E.5 - E.8; Appendix E**.

Multiple-exposure models with two- and three-way interactions show generally similar associations between the explanatory variables and the health outcomes, but with further attenuation. More closely aligned with expectations, Q2 (Q2: OR= 1.049, 95% CI = 0.984, 1.118, p adjusted = 0.249) and Q4 (Q4: OR= 1.049, 95% CI = 0.907, 1.030, p adjusted = 0.372) were no longer significantly associated with increased BMI, but Q3 in comparison with Q1 remained associated with worsened BMI (**Table 7.2**). Also more aligned with expectations, the quartiles Q2 and Q3 were no longer associated with poor health, and in reverse, as would be expected, Q4 became significantly associated with good health (OR= 0.896, 95% CI = 0.825, 0.974, p adjusted $\leq$ 0.032). More aligned with expectation the greenspace exposure quartiles Q2 and Q4 lost their positive associations with blood pressure, but Q3 remained significant (OR= 1.199, 95% CI = 1.097, 1.311, p adjusted $\leq$ 0.001) (**Table 7.2**). Physical activity and greenspace exposure remained significant, showing a beneficial association with loneliness (**Table 7.2**).

Two-way interactions

The results show that the synergistic effect of eating at least five portions of fruits and vegetables whilst being physically active is associated with healthy blood pressure, that is; after controlling for the association between each of the lifestyle variables independently and blood pressure, the effect of the interaction term in the category 'meets the recommended levels of fruit and vegetable' is larger among the individuals with 'high' physical activity (OR= 0.851, 95% CI = 0.763, 0.950, p adjusted = 0.009) (**Table 7.2**) when compared to those individuals with low levels of physical activity, or vice versa.

Moreover, the effect of the interaction term in the category 'meets the recommended levels of fruit and vegetable' and the categories: moderate and high physical activity levels are larger and negatively associated with health marker loneliness (OR= 0.746, 95% CI = 0.590, 0.943, p adjusted = 0.030) and (OR= 0.695, 95% CI = 0.553, 0.874, p adjusted = 0.004) respectively (**Table 7.2**). I observed

the same outcome for BMI, but in this case, the interaction term was dose-response, meaning that people who meet the required intake of fruit and vegetable and have 'high' levels of physical activity have lower odds of being overweight or obese (OR= 1.166, 95% CI = 1.038, 1.309, p adjusted = 0.019) than those with 'moderate' physical activity (OR= 1.183, 95% CI = 1.055, 1.327, p adjusted = 0.008) respectively (**Table 7.2**).

Although unexpected, after controlling for the association between each of the lifestyle variables independently and overall health rating, the effect of the interaction term in the categories Q1, Q2, and Q3 of greenspace shows an extra negative association only for individuals with 'high' physical activity levels; (OR= 0.903, 95% CI = 0.832, 0.981, p adjusted = 0.030), (OR= 0.920, 95% CI = 0.847, 0.999, p adjusted = 0.041), and (OR= 0.842 , 95% CI = 0.775, 0.915, p adjusted $\leq$ 0.001), respectively (**Table 7.2**).

The effect on the interaction term in the category ´moderate´ physical activity and the fourth quartile of greenspace exposure was large and associated with loneliness (OR= 1.283, 95% CI = 1.071, 1.537, p adjusted = 0.016) (**Table 7.2**). That is, people with moderate levels of exercise that live in areas with high percentage of greenness have higher are more prone to feel alone.

Three-way interactions

The interaction between the three explanatory variables was generally not associated with the health markers. Still, I found that the effect on the interaction term in the categories meeting the recommended intake of fruits and vegetables, moderate physical activity, and the Q2 of greenspace was large and negatively associated with overall health rating (OR= 0.839, 95% CI = 0.713, 0.987, p adjusted = 0.048). This means that people who meet the recommended intake of fruit and vegetable, exercise moderately and live in a slightly greener area than the reference group are more likely to report their health as poor than those in the reference groups.

Participants 'meeting the recommended intake of fruits and vegetable', that exercise 'moderately', and their homes are located in a third quartile of greenspace were more likely to have high blood pressure when compared to the reference groups (OR= 1.317, 95% CI = 1.058, 1.639, p adjusted = 0.043). The effect on the interaction term in the categories 'meeting the recommended intake of fruits and vegetables', 'moderate' physical activity, and the 'Q2 of greenspace' was large and negatively associated with overall health rating (OR= 0.839, 95% CI = 0.713, 0.987, p adjusted = 0.048).

The effect on the interaction term in the category 'high' physical activity, the 'second' and 'fourth' quartiles of greenspace exposure and the category 'meeting the recommended intake of fruits and

vegetables was large and positively associated with loneliness (OR= 1.489, 95% CI = 1.057, 2.096, p adjusted = 0.046), and (OR= 1.468, 95% CI =1.037, 2.078, p adjusted = 0.049), respectively. That is, participants with high levels of exercise living in a greener area than the reference group and eating at least five portions of fruit and vegetables are more likely to feel alone than the reference groups.

Table 7.2: **GLMs' with interactions to assess synergistics effects between healthy behaviour and health and well-being: UK Biobank England**. Odds Ratio (OR) with 95% bootstrap confidence intervals (bCIs), and Benjamini & Hochberg adjusted p value of greenspace exposure at a 100m buffer (reference = Q1), physical activity levels (reference = Low), fruits and vegetables intake (reference = Less than 5 portions), and the interactions between these variables for BMI (reference = Healthy), Self-health assessment (reference = Poor), blood pressure (reference = Healthy), loneliness (reference = No). All models were adjusted for sex, age, highest educational qualification, ethnicity, Index of Multiple Deprivation, and smoking. The table only shows significant exposures, the complete table is in **Appendix E; Table E.9**

Exposure variable (increment)	OR	95% IC	p ajusted
Body Max Index (BMI) (reference = Healthy)			
Fruit and vegetable intake (reference = Less than 5 portions)			
Meets fruit and vegetable	1.169	1.062, 1.287	0.003
Greenspace exposure; 100m buffet (reference = Quartile 1)			
Greenspace Q3	1.077	1.010, 1.149	0.047
Physical activity levels; IPAQ (reference = Low)			
Moderate physical activity	0.639	0.604, 0.675	< 0.001
High physical activity	0.509	0.480, 0.538	< 0.001
Interaction between fruit and vegetable and physical activity			
Meets fruit and vegetable; High physical activity	0.851	0.763, 0.950	0.009
Self-health assessmet (reference = Poor)			
Greenspace exposure; 100m buffet (reference = Quartile 1)			
Greenspace Q4	1.140	1.067, 1.218	< 0.001

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Exposure variable (increment)	OR	95% IC	p ajusted
Physical activity levels; IPAQ (reference = Low)			
Moderate physical activity	1.801	1.700, 1.907	< 0.001
High physical activity	3.009	2.835, 3.193	< 0.001
Interaction between fruit and vegetable and greenspace			
Interaction between fruit and vegetable and physical activity			
Meets fruit and vegetable; Moderate physical activity	1.166	1.038, 1.309	0.019
Meets fruit and vegetable; High physical activity	1.183	1.055, 1.327	0.008
Interaction between greenspace and physical activity			
Greenspace Q2; High physical activity	0.903	0.832, 0.981	0.030
Greenspace Q3: High physical activity	0.920	0.847, 0.999	0.041
Greenspace Q4: High physical activity	0.842	0.775, 0.915	< 0.001
Interaction between fruit and vegetable intake, greenspace and physical activity			
Meets fruit and vegetable; Greenspace Q2; Moderate physical activity	0.839	0.713, 0.987	0.048
Blood pressure (reference = Healthy)			
Greenspace exposure; 100m buffet (reference = Quartile 1)			
Greenspace Q3	1.199	1.097, 1.311	< 0.001
Physical activity levels; IPAQ (reference = Low)			
High physical activity	0.896	0.825, 0.974	0.032
Interaction between fruit and vegetable intake, greenspace and physical activity			
Meets fruit and vegetable; Greenspace Q3: Moderate physical activity	1.317	1.058, 1.639	0.043
Loneliness (reference = No)			

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Exposure variable (increment)	OR	95% IC	p ajusted
Greenspace exposure; 100m buffet (reference = Quartile 1)			
Greenspace Q4	0.736	0.638, 0.849	< 0.001
Physical activity levels; IPAQ (reference = Low)			
Moderate physical activity	0.687	0.611, 0.772	< 0.001
High physical activity	0.679	0.602, 0.766	< 0.001
Interaction between fruit and vegetable and greenspace			
Meets fruit and vegetable; Greenspace Q2	0.729	0.552, 0.963	0.047
Interaction between fruit and vegetable and physical activity			
Meets fruit and vegetable; Moderate physical activity	0.746	0.590, 0.943	0.030
Meets fruit and vegetable; High physical activity	0.695	0.553, 0.874	0.004
Interaction between greenspace and physical activity			
Greenspace Q4: Moderate physical activity	1.283	1.071, 1.537	0.016
Interaction between fruit and vegetable intake, greenspace and physical activity			
Meets fruit and vegetable; Greenspace Q2; High physical activity	1.489	1.057, 2.096	0.046
Meets fruit and vegetable; Greenspace Q3: High physical activity	1.468	1.037, 2.078	0.049

7.5 Discussion

I aimed to explore the potential synergistic effects of health pathways resulting from the practice of urban agriculture through an analysis of a large sample of the urban UK population; the UK Biobank. This chapter is novel in that it looks at the independent, and combined associations of two lifestyle behaviours (fruit and vegetable intake and physical activity), and greenspace exposure on different health and well-being markers (blood pressure, BMI, self-reported loneliness, and self-health assessmet) whilst taking advantage of a large population sample (the UK Biobank).

Main associations between lifestyle behaviours and health and well-being markers

Numerous epidemiological studies have shown associations between unhealthy lifestyle behaviours and life-threatening chronic diseases (CDCP, 2002; Meng et al., 1999; Winkleby and Cubbin, 2004). The current analysis shows that, after controlling for confounders, physical activity and fruit and vegetable intake show positive associations on most health and well-being markers. This is in-line with a large body of literature that demonstrates that being physically active reduces the chances of suffering from chronic diseases including various forms of cancer, high blood pressure problems, cholesterol, cardiorespiratory conditions, mental illnesses, bone and muscular problems, obesity, and sleep complications (McTiernan, 2008; Brymer et al., 2014; Penedo and Dahn, 2005; Warburton et al., 2006). Insufficient intake of fruit and vegetables has been shown to cause 31% of ischemic heart diseases, approximately 19% of gastrointestinal cancers, and 11% of stroke (Aune et al., 2017; Yahia et al., 2017; Alissa and Ferns, 2017) whilst increased intake of vegetables on the other hand significantly reduces the risk of cardiovascular incidents (Aune et al., 2017). Contrary to expectations, however, meeting fruit and vegetable intake recommendations was shown to increase BMI in the analyses. A possible reason for this result is that for the sample, a high intake of fruit and vegetable might reflect a high intake of food in general, and research shows the size of portions is directly linked with high BMI (Livingstone and Pourshahidi, 2014)

In the single exposure models, although greenspace is shown to be associated with reduced loneliness, it was negative associated on health as measured by BMI, blood pressure and overall health rating. Whilst the significance of these associations is mostly removed in the multi-exposure and interaction models, this is still contrary to evidence from the literature. Whilst the significance of these associations is mostly removed in the multi-exposure and interaction models, this is still contrary to evidence from the literature. Greenspace exposure has been shown to be positively associated with mental health benefits (Hunter et al., 2017; Alcock et al., 2014; Beyer et al., 2014), reduction in cardiovascular morbidity (Dalton and Jones, 2020), Type II Diabetes (Maas et al., 2009; Bodicoat et al., 2014), and mortality (Mitchell and Popham, 2008). The reason for this observation in this study could be due to the 100m distance buffer I used to measure greenspace exposure, whilst as most research identifies benefits for buffers of 300m or more. For example, similar to theresults, Zhang et al. (2022b) found a negative association between the percentage of green space and depression symptoms in adolescents at a 100m buffer in adjusted models and no association once the models were corrected for confounders. Hartley et al. (2021) found no significant association between the percentage of green space and several mental issues in kids and adolescents at a 200m buffer. Still, they found a negative association between greenspace and anxiety for buffer distances at 400m and 800m. Moreover, it

has been shown that the benefits of natural spaces to people are not one-dimensional and depend on several factors, such as proximity to the green area, type of greenspace, how often the greenspace is visited, and the time spent in the greenspace (Clayton et al., 2017; Shanahan et al., 2015; Cox et al., 2017).Coleman et al. (2022) for instance demonstrated how air pollution may form part of the equation in the relationships between exercise, greenspace, and mortality. Therefore, further research that includes information on the type of green space and distance is needed. Another possible explanation for that outcome is the presence of a confusing variable not assessed here, such as working status and conditions, marital status and the quality of family relationships (Ganster et al., 2018; Robone et al., 2011; Coombs, 1991; Thomas et al., 2017).

It has been shown that the benefits of natural spaces to people are not one-dimensional and depend on several factors, such as proximity to the green area, type of greenspace, how often the greenspace is visited, and the time spent in the greenspace (Clayton et al., 2017; Shanahan et al., 2015; Cox et al., 2017). Coleman et al. (2022), for instance demonstrated how air pollution may form part of the equation in the associations between exercise, greenspace, and mortality. Therefore, further research that includes information on the type of green space and distance is needed.

Interactions

Beyond these independent benefits of healthy lifestyles, this chapter demonstrated further benefits of combined associations of healthy physical activity levels, fruit and vegetable intake, and greenspace exposure. Models with interactions included showed a better fit to the data than the models that considered the lifestyle behaviours independently. This indicates that the lifestyle behaviours are most likely to act in combination with one another, rather than alone.

Fruit and vegetable intake and physical activity

The results show that the synergistic effect of eating at least five portions of fruits and vegetables whilst being physically active is associated with healthy BMI, a good self-health assessmet, and lower feelings of loneliness. Previous studies have also shown that people who improve their diet, and concurrently increase their levels of physical activity, lose on average more weight than expected than if they had undertaken the behaviours independently (Sparling et al., 2013). Evidence suggests that synergies between these two lifestyle behavours have also been shown to lower levels of blood pressure, cardiovascular diseases, depression, and certain cancers (Sparling et al., 2013; Anderssen et al., 2007; Loprinzi, 2015; Loprinzi et al., 2014). However, contrary to this evidence, I could not find evidence

supporting a synergistic effect on blood pressure of eating at least five portions of fruits and vegetables whilst being physically active. Probably, other aspects of diet are needed besides just the intake of fruit and vegetable, for example portions size, or sugar and saturate fat intake (Ahmad et al., 2020; Hall, 2009).

Physical activity and greenspace exposure

Surprisingly, I found negative synergies between greenspace exposure and high levels of exercise on participants reporting good health. Moderate levels of physical activity and exposure to the highest quartile of greenspace also led to higher odds of feeling alone. None of the other interactions with greenspace were significant. These results contradict previous findings on added benefits for health and well-being of green exercise (WHO, 2016), although the metrics precluded any assessment of where physical activity took place or of how respondents were engaged in greenspace. Other research, however, has found little or no evidence of physical activity being a mediator of green space benefits (Lachowycz and Jones, 2011; De Vries et al., 2013; Dadvand et al., 2016; Richardson et al., 2013; Squillacioti et al., 2022; Coleman et al., 2022). Lahart et al. (2019b) carried out a meta-analysis of the benefits for health and well-being of exercising outdoors versus indoors and reported inconclusive, poorly supported, and contradictory findings overall. Whilst some studies have shown clear benefits from green exercise, lack of conclusiveness in this area may indicate that associations are complex, and evaluations might be limited by poor standardisation of measures of green space exposure. The results of this chapter suggest that despite the proposed association between green exercise and physical health and well-being, the association is not always positive and greener areas are not necessarily associate with higher levels of physical activity and better health and well-being.

Three-way interactions

In general, the three-way interactions show little or no association with the health and well-being markers, and for some specific combinations, indicate potential negative impacts. This is likely to be caused by the dominant negative impact of greenspace on outcomes in this analysis. For example, the interaction between fruits and vegetable intake and physical activity showed a clear positive association with good health rating, but, when greenspace is also considered, the interaction between these three lifestyle behaviours with self-health assessment when physical activity is moderate and greenspace exposure is moderate to low, is negative. Feelings of loneliness showed the same trend, the interaction between fruit and vegetable and physical activity was associated with lower odds of feeling alone, but,

when greenspace is also included the interaction between the three lifestyle behaviours was associated with higher odds of feeling alone. However, three-way interactions are complex, and the significant associations need to be considered with care. Further analysis needs to corroborate the nature and significance of these types of interactions (Dawson and Richter, 2006).

Previous studies indicate the importance of other forms of interactions or synergies, which I were not able to investigate. This suggests that it is likely that multiple factors within a person's environment act together to affect their health. For instance, healthy diets and vegetable intake have been shown to attenuate the detrimental impacts of air pollution (Wang et al., 2022), or vise versa, high levels of air pollution have been shown to attenuate some of the benefits of physical activity (Andersen et al., 2015). Some synergies show a dose-response association between multiple healthy behaviours and health and well-being markers (Loprinzi, 2015; Loprinzi and Mahoney, 2014), whilst for others such as greenspace the association is not dose-response (Richardson et al., 2013). This thesis thus supports a growing body of research that demonstrates how the urban environment contributes in multiple ways to public health (Avila-Palencia et al., 2022; Negev et al., 2022). It also shows how more research focused on holistic approaches that consider the multiple pathways between urban environment, health and well-being is needed. The extra association effects of synergies occurring between different health behaviours are clearly complex; simplistic approaches to public health policies will therefore not necessarily take advantage of positive associations and may, in fact, have unintended adverse effects. It is therefore recommended that a holistic approach to public health be taken rather than targeting one behaviour individually, as has been carried out to date in both research and policy planning in this area.

7.5.1 Interactions and urban agriculture

Returning to the hypothesis that interventions such as urban agriculture can bring more significant benefits to public health than interventions that only seek to address a single healthy lifestyle behaviour: as stated in the introduction, research has shown the benefits of urban agriculture for health and well-being and the association between the practice of urban agriculture and healthy lifestyles (Soga et al., 2017a). These results continue to support the existing literature that multiple-lifestyle behaviours are better than single-focused approaches (Loprinzi et al., 2016). However, more research is needed to understand the association that the different interactions between the urban environment, socio-demographic factors, and lifestyle behaviours have with health and well-being. Nevertheless, and more importantly, there is a need for health authorities to create strategies that motivate the population to engage in healthy behaviours (Dale et al., 2014). According to the results and the literature, urban agriculture could be a helpful tool due its multiple potential contributions to urban

health (Soga et al., 2017b).

7.6 Conclusion

Despite the widespread and known benefits of healthy lifestyles, it remains a challenge to encourage the general population to take many of these behaviours up, particularly in tandem. The WHO estimates that 1.7 million lives could be saved globally by increasing the consumption of fruit and vegetables (WHO, 2020); Saint-Maurice et al. (2022) show that adding 10 minutes of moderate or vigorous exercise could prevent around 110,000 deaths per year in the US. Residential greenness has been shown to lower mortality risk in most of the causes of death analysed (Bauwelinck et al., 2021). Public health gains from these lifestyle factors are undeniable, yet little progress is made on the ground to increase uptakes. Solutions that enable seamless integration of healthy habits in daily lives are needed, and, as I see from this research, solutions that enable the simultaneous uptake of healthy habits are likely to achieve even greater health benefits than tackling each of these behaviour or exposure target one at a time. Physical activity, fruit and vegetable intake, and exposure to greenspace, are three lifestyles that can be achieved jointly through participation in urban gardening. This research provides some of the arguments for the promotion of urban agriculture that go beyond the known independent benefits that have been previously identified in relation to urban agriculture participation. Nevertheless, I can also see from the research how associations between lifestyle behaviours and health and well-being are complex and not necessarily associated as expected. More multi-behaviours research is needed to increase the evidence around the association between lifestyle behaviours combined and health and well-being markers.

Chapter 8

Discussion, limitations, future work, and conclusion

8.1 Discussion

This research provides a contribution to the growing literature on the associations between urban agriculture in countries of the Global North and public health and well-being. It delivered this by investigating the association between ecosystem services provided by urban agriculture and the lifestyle behaviours/exposure of its participants. The overall aim of this thesis was to understand and provide guidance on how urban agriculture might be a useful tool to improve and promote population health and well-being in urban areas of the Global North. The scoping review provided the theoretical basis, represented by the urban agriculture framework (**Chapter 3**). This framework guided the development of the empirical chapters and assessment of hypotheses related to lifestyle behaviours/-exposures (fruit and vegetable intake, physical activity, greeenspace, and social cohesion) and health and well-being benefits (happiness, loneliness, BMI, self-health assessment, blood pressure). **Chapter 5** showed that urban horticulturalists believed they had changed their lifestyle behaviours/exposures due to their participation in urban agriculture projects. Despite a few differences between the type of urban agriculture, lifestyle behaviours, and health and well-being markers, the associations between the former and the latter are constant across the kinds of urban agriculture assessed in this thesis. In the comparison between horticulturalists and a sample of urban dwellers from across the UK, it was found that horticulturalists have better health markers for BMI and medication intake and better lifestyle behaviours (physical activity and fruit and vegetable intake), but the opposite was true for

self-health assessment and happiness, and no differences were found for feelings of loneliness (**Chapter 6**). Finally, it was observed that there are synergistic effects of urban agriculture-related behaviours (fruit and vegetable intake, physical activity, and greenspace exposure) on health markers, however, these effects are not always positive and associations were shown to be complex (**Chapter 7**). On average, reporting healthy lifestyle behaviours/exposures was associated with better health markers, for example, fruit and vegetable intake combined with physical activity was associated with lower BMI or better self-health assessment, exposure to greenspace combined with fruit and vegetable intake was associated with lower odds of loneliness, but exposure to intermediate levels of greenspace combined with physical activity was negatively associated self-health assessment and loneliness.

In the discussion section of each chapter, I provide a discussion on the importance of these results in relation to the specific objectives for the chapter whereas in this chapter, I discuss the entire body of evidence arising from this PhD research. Here I focus on the implications, trade-offs, and limitations, discuss my findings in the context of other forms of nature-based solutions, and evaluate the benefits and drawbacks of urban agriculture as a specific policy focus. I also highlight the limitations of this research and provide recommendations for future research and policy-making.

8.1.1 Implications for health and well-being: Advantages of urban agriculture projects versus other nature-based solutions

Today, the role of urban agriculture in urban development and design is again coming to the fore. Urban agriculture projects are increasing in number and are being implemented as a social response to different economic and segregation pressures urban dwellers face in cities worldwide (Dieleman, 2017). In the Global North, most epidemiological studies to-date have shown that there is a association between lifestyle behaviours, socio-demographic conditions, and environmental exposures, to an increase in non-communicable diseases, mental health issues, and obesity (Ventriglio et al., 2021; Evans, 2003; Loewen et al., 2019; Rohrer et al., 2005; Ausín et al., 2017). Hence, it is essential to encourage healthy behaviours in urban populations in order to protect public health (WHO-FAO, 2003). Although some policies and programs have shown to have potential to address unhealthy behaviours, as has been shown in the case of cigarette consumption (Alamar and Glantz, 2006), others have not been reflected in changes in population health, such as the consumption of ultra-processed foods (Vandevijvere et al., 2019; Blüher, 2019). Generally, behavioural changes that involve people getting out of their comfort zone, such as using the bike to commute instead of the car, are challenging to implement on a large scale (Kelly et al., 2016; Duckworth et al., 2018). The evidence shows that

people who already have unhealthy behaviours tend to change only for a short period before reverting to their previous lifestyle habits (Duckworth et al., 2018; Marlatt and Kaplan, 1972; Neal et al., 2013). Creating strategies that allow the population to engage in healthy behaviours in the longer-term is therefore crucial to improve population health more broadly (Dale et al., 2014). Based on the results of this thesis, and the related literature, it can be argue that urban agriculture has the potential to be an effective tool in the promotion of population health and well-being in multiple ways.

Based on the definition of urban agriculture we proposed for this thesis "*the definition of urban agriculture used in this project was based on the three previous definitions. Still, I made some changes for the purpose of this thesis. My thesis focuses on plant production, known as horticulture, because it is the most common type of urban agriculture in the Global North, as previous authors have done (Mok et al., 2014; Lin et al., 2017; Gulyas and Edmondson, 2021). I will still be using the broader term of urban agriculture throughout my thesis." it can be argued that urban agriculture can be considered a Nature-Based Solution, which are actions that rely on ecosystems and the services they provide to respond to societal challenges such as climate change, food security or disaster risk (Cohen-Shacham et al., 2016).* However, even though the use of nature-based solutions in the Global North, as a means to tackle urban problems such as air pollution, heat island effects as well as mental health, is rising in popularity (Maes and Jacobs, 2017; Cohen-Shacham et al., 2016; Maes and Jacobs, 2017), natural environments such as green or blue spaces are still becoming rare commodities in urban areas (Fuller and Gaston, 2009). Many urban societies suffer from a disconnect from nature (Clayton et al., 2017), a phenomenon known as 'extinction of experience' (Pyle, 1993). Some nature-based solutions based on green infrastructure projects, such as green walls or green roofs, can provide ecosystem service benefits both directly and indirectly, however,in many of these examples there is little or no interaction with the space itself, and many potential additional benefits are lost (Panagopoulos et al., 2018; Lin et al., 2017; Evans et al., 2022). Miller (2005) argued that although parks and other green areas increases people's exposure to nature, this exposure may not be enough to increase interaction with nature. As explained below (**Chapter 3**), the theoretical evidence compiled here, and the empirical results indicate that urban agriculture may bring greater health and well-being benefits than other forms of nature-based solutions (Sowińska-Świerkosz et al., 2021; Tan et al., 2017), given the closeness and feeling of belonging of its participants. Such as increased fruit and vegetable intake, moderate physical activity (**Chapters 5 and 6**), and even the synergistic effect of those two lifestyle behaviours combined (**Chapter 7**) due to the more complex and complete interactions between the participants and the natural environment it enables (Webber et al., 2015).

Urban agriculture as NBS

In the Global North, cities are densely populated, and on average, they have lower green coverage than that recommended by the WHO (EEA, 2012). Evidence shows a reduction in green spaces in urban areas as population density increases (Fuller and Gaston, 2009). Moreover, it has been suggested that the distribution of green spaces in cities is associated with income, whilst ethnic minorities are often marginalised from green spaces (Saporito and Casey, 2015; Rutt and Gulsrud, 2016), not only due to the increase in property values around green intervention areas (Rutt and Gulsrud, 2016), but also because of gentrification stratified by ethnicity in parks (Cole et al., 2017).

Research has also shown that the benefits of natural spaces to people are not one-dimensional, for example a proximity to greenspace is only one dimension of greenspace benefits to health and well-being, and depends on several factors, for example, type of green space, proximity to the green area, how often the green space is visited, and the time spent in the green space, are all important factors (Clayton et al., 2017; Shanahan et al., 2015; Cox et al., 2017). The complexity of this interaction between the natural space and people might explain the result in **Chapter 7**, as the percentage of greenness around the household was not positively related to the health and well-being markers assessed.

On the other hand, our results show on **Chapter 6** that urban horticulturalists spent more time outside than the population sample and one hour more than the recommended levels, which might indicate interactions with natural environments. More important, horticulturalists believed they spent more time in greenspaces because of urban agriculture projects (**Chapter 6**). These results go in hand with the literature showing that the association of urban agriculture projects with health and well-being might be more beneficial than with other NBS due to a multilevel interrelationship between the horticulturists and the natural space used. Clayton et al. (2017) proposed that interactions with nature when the person is an active participant, such as those in urban agriculture projects, are based on emotions evoked by vivid and sensory experiences, which increases the link between people and greenspaces even further. In urban agriculture projects, people become part of the entire production cycle. Horticulturalists are involved from the planting of the seeds to the harvest. They are both observational and active participants of the production cycle (Langemeyer et al., 2021). Growing plants requires effort, time, and dedication. Psychologists refer to an 'IKEA effect' as the effect of the link that people create with projects that involve an individual effort (Norton et al., 2012), such as the one described above. It is therefore highly probably that some of the well-being benefits of urban agriculture projects are related to a sense of achievement rather than a simple exposure to nature, as reported by Webber et al. (2015), who stated that a sense of achievement and connectedness to

nature might have been the mediating terms of the association between psychological quality of life, well-being and urban agriculture projects.

Urban agriculture and fruit and vegetable intake

Similarly to greenspaces, the IKEA effect has been reported in studies on children involved in gardening activities and an increase in their fruit and vegetable intake. Researchers found that children who participate in gardening activities were more likely to try and eat the vegetables they had grown, in part due to a sense of achievement and involvement in the process (Crary et al., 2022; Heim et al., 2009). By being active participants in both process of growing and cooking the food, children felt a sense of connection with the final product, a sense of achievement more broadly and ultimately were more willing to try it (Crary et al., 2022; Heim et al., 2009; Ratcliffe et al., 2011). The results from this thesis corroborate this existing literature and show that horticulturalists believed urban agriculture projects were partly responsible for their eating more fruit and vegetables (**Chapter 5**). Moreover, they had a higher intake of fruits and vegetables not only than the recommended WHO levels (**Chapter 5**) but than non-horticulturalists (**Chapter 6**). Hence, it can be hypothesised that a deeper connection with their gardens was linked to the belief that they had adopted healthier lifestyles, and the IKEA effect may be linked to the higher intake of fruits and vegetables.

Benefits of urban agriculture as a nature-based solution; more than just a greenspace

There is evidence indicating that food insecurity has increased in developed countries in recent years (Long et al., 2020; Pollard and Booth, 2019). At the same time, health authorities and policymakers in the Global North are implementing a variety of strategies to increase the intake of fruits and vegetables within the population (Dhandevi and Jeewon, 2015; Glanz and Yaroch, 2004). Interventions based on cultivating food shows better results than just increasing exposure to fruits and vegetables (Hartwig and Mason, 2016; Castro et al., 2013), whilst at the same time participants also gain from a more active interaction with the natural space, than, for example, with a green wall. As seen in the results of **Chapters 3, 5, and 6**, urban agriculture projects are associated with a high intake of fruits and vegetables, which might help with the increasing food insecurity in the Global North. Also, as shown in the results of **Chapters 5 and 6**, the association between urban agriculture projects and health traits or markers, such as BMI or lower medication intake, might result from simultaneous multi-level behaviours (fruit and vegetable intake, direct exposure and interaction with nature, and feelings of

achievement, satisfaction, and purpose) obtained during the process. **Chapter 7** further explored this hypothesis by showing synergistic effects between the urban agriculture lifestyle behaviours (fruit and vegetable intake, greenspace exposure, and physical activity) and health and well-being. Reconnecting people with nature and natural processes is vital for nature-based solutions to work at a social level (Clayton et al., 2017; Miller, 2005). Thus, it can be argued that urban agriculture may improve the impact of a exposure to a particular greenspace because it increases the closeness to nature by making the horticulturalist an active member of a process that involves more vivid multi-sensory experiences and emotions, creating a stronger bond with nature (Webber et al., 2015). It may also be argued that urban agriculture might increase fruit and vegetable consumption not only because it increases the availability of fresh food, but due to the effort involved in producing it (Ratcliffe et al., 2011).

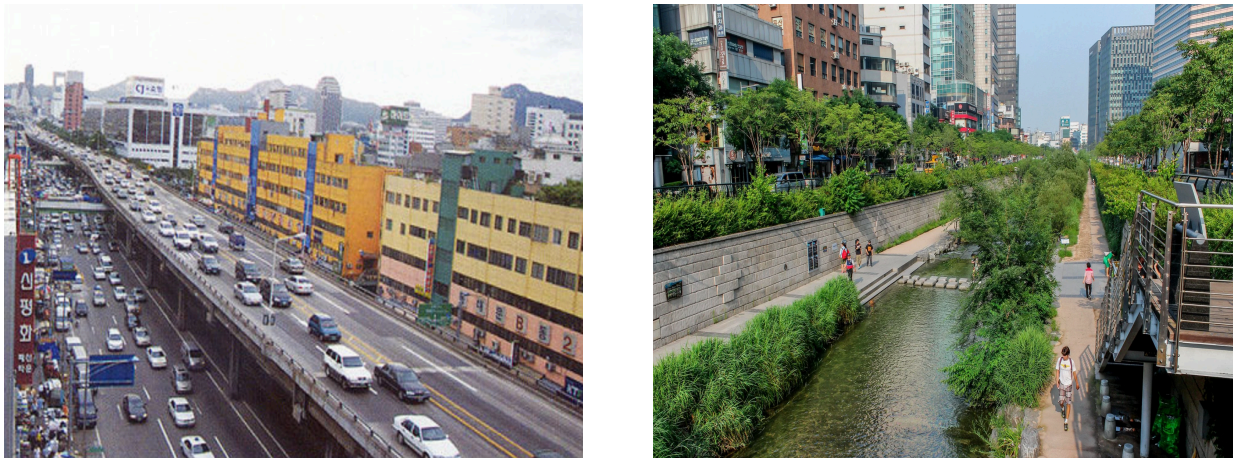
8.1.2 Natured-based solutions, urban agriculture, and the Sustainable Development Goals

In this section I'll show how unlike other NBS commonly implemented by authorities, the results of my thesis goes in hand with available literature that argues that urban agriculture can be multifunctional, support the One Health ideal, and contribute to the circular economy. It does not marginalised vulnerable populations as other NBS initiatives, and does not require high levels of investment to be implemented, in fact most projects are population-based initiatives.

The Sustainable Development Goals were an urgent call to act against ecological and societal challenges and their consequences (Assembly, 2015). Nature-based solutions present an opportunity to address several of these goals within an urban setting: Good Health and well-being (3), sustainable cities and communities (11), climate action (13), and life on land (15) (Rutt and Gulsrud, 2016).

Worldwide, cities have begun to implement some of these solutions with good results (Faivre et al., 2017; Kabisch et al., 2017). For example, in Seoul, Korea (Global North), authorities removed a highway built over a river. The initiative reduced the particulate matter in the city by 35%, the temperature in the city dropped by 3-5 degrees, and they increased urban greenspaces by 400 hectares (Thomas, 2012) (**Fig. 8.1**). As part of the project 'Green Up', the City of Medellin, Colombia (Global South), has replaced 2.3 Km of built areas with green corridors. The city has planted more than 90,000 species of native plants, including 305 trees and 240 palm trees. The city has also built 5000 m^2 of green walls and recovered previous abandoned and contaminated streams (Alcaldia Medellin, 2019; Medellin como vamos, 2022). All these initiatives were intended to improve the air quality of the city, reduce the temperature, create spaces for recreation, increase biodiversity, and build green corridors

across the city to connect natural areas in and out allowing endemic species to migrate across the different environments. Since 2016, the city has created 36 corridors, reduced the average temperature by 2 degrees, and improved air quality (*ibid*); model-based research has also reported a small but positive association of tree coverage and CO2 sequestration (Reynolds et al., 2017) (**Fig. 8.2**).



(a) Before (b) After

Figure 8.1: Restoration of Cheonggyecheon River in Seoul; The left side shows the city before the authorities removed the road and the right side shows the city with the river restored and open as a green and blue area (a) **Photo courtesy of City of Seoul**, (b) **Photo courtesy of Reddit**

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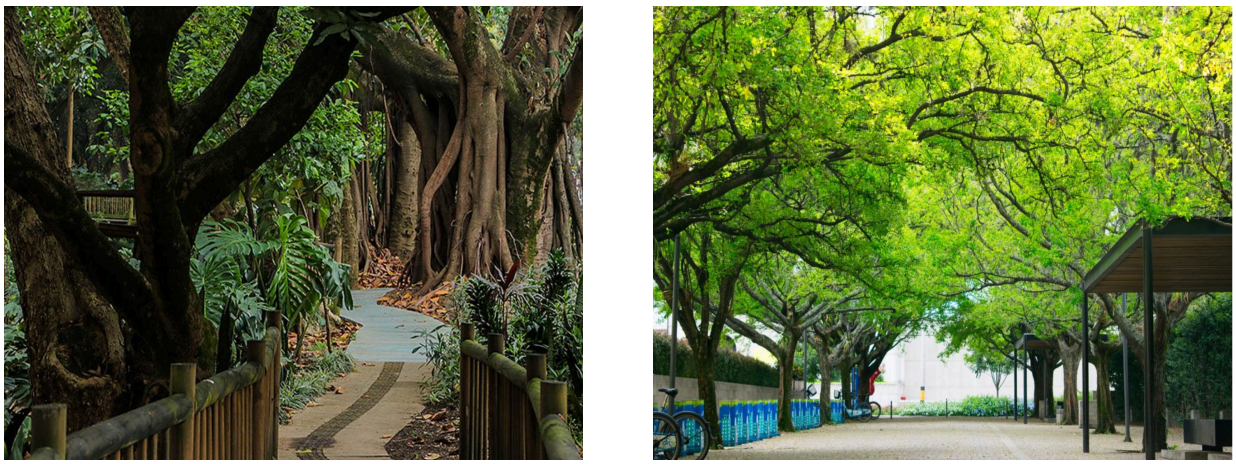
However, all of these examples are top-down approaches that require monetary resources for their implementation and maintenance (Maes et al., 2015), a case which is similar for many nature-based solutions and green infrastructure projects. Due to the cost of these programs, there is often a need for the involvement of the private sector (Baietti, 2013; Baietti et al., 2012), unfortunately the economic goal-oriented focus to these programs which can leave parts of the cities segregated (Sharifi et al., 2021; Anguelovski et al., 2018; Rigolon and Németh, 2020) and poorer areas can become marginalised from these nature-based solution projects (Sharifi et al., 2021; Anguelovski et al., 2018; Rigolon and Németh, 2020). For example, social research has shown that there are gentrification impacts from the two projects mentioned before (Seoul, Korea and Medellin, Colombia) (Lee and Anderson, 2013; Patiño, 2020), because of the increase in value of properties around these projects. In contrast, urban agriculture is often a bottom-up strategy that represents a social movement of participation, empowerment, and involvement of urban dwellers with the environment (Lyson, 2014; Gray et al., 2020; Reynolds and Cohen, 2016; McCabe, 2014). Hence, unlike other urban-green projects, urban agriculture may also contributes to the Sustainable Development Goals: zero hunger (1), gender equality (in developing countries) (5), and in some cases, decent work, and economic growth (8).

This thesis and several authors working on urban agriculture have shown that urban agriculture act as



(a) Walking path (b) Sidewalk

Figure 8.2: Green corridors in Medellin, Colombia; The photos show different parts of the city where authorities have included green infacstructure as part as the urban development, increasing the size and distance of the green corridors. (a), (b), (c) **Photo courtesy Alcaldia de Medellin**, (d) **Photo courtesy of Caracol Radio**

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a different type of NBS because it is a multi-functional strategy that can concurrently tackle ecological, economic, and health challenges (climate change, food security, biodiversity and ecosystem services, agricultural intensification, resource efficiency, urban renewal and regeneration, land management, public health, social cohesion, and economic growth) (Artmann and Sartison, 2018; Kingsley et al., 2021; Van Hullebusch et al., 2021). One essential feature urban agriculture has that the two NBS describe above lack is the potential to be used as a tool to approach One Health in urban areas. One Health is an interdisciplinary concept to approach health, and it explores the interconnectedness and interdependence of environmental, animal, and human health to manage, mitigate, and prevent disease. In urban environments. As argued above, the results of this thesis (**Urban agriculture framework; Chapter 3**) corroborate that urban agriculture connects people to nature deeper than other NBS, the benefits for the environment and people are the results of synergistic people-nature systems improving environmental health, animal health, and ultimately people's health. As highlighted by Kingsley et al. (2021), urban agriculture is a multidimensional approach that enhances food security and restores city socio-ecological identities. Moreover, according to Murray et al. (2022), for the concept of One Health to be correctly applied in urban areas, environmental justice is paramount because, in cities, there is a need to take the bias resulting from systemic racism, classism and other urban structures that have been build during decades. As I will show in the next paragraph, the result of this thesis and the literature show that urban agriculture is better than other NBS in tackling environmental injustice in urban areas.

As explained in their book *'Beyond the Kale: Urban Agriculture and Social Justice Activism in New*

York City', Reynolds and Cohen (2016) argue that urban agriculture is not only a movement to gain access to food, but it is also a tool for cultural expression, social empowerment, social justice, and even an act of rebellion against racial and economic segregation. The authors found evidence of ethnicity and gender empowerment; the last is usually attributed to urban agriculture benefits in the Global South (*ibid*) (**Fig. 8.3**). As supported by the results of the scoping review (**Chapter 3**) and the empirical evidence linking socialisation with urban agriculture (**Chapter 5**), these projects open spaces for socialisation and cultural exchange and even provide social adaptation for immigrants. (McClintock, 2010; Teig et al., 2009; Litt et al., 2015; Agustina and Beilin, 2012; Hartwig and Mason, 2016). As the centre of social and environmental activities, urban agriculture has the potential not only to improve the health and well-being in a similar manner to other green spaces, but it may also allow its participants to have an active role in their relationship with their social-urban environment (McClintock, 2010; Sowińska-Świerkosz et al., 2021; Corcoran and Kettle, 2015; Hale et al., 2011; Teig et al., 2009; Litt et al., 2015; Webber et al., 2015). Having an active participation in their environments helps urban dwellers with additional tools to overcome social and environmental inequalities, which has an added impact on their health and well-being. The 'added-value' of urban agriculture movements make it a different nature-based approach with the potential to address more Sustainable Development Goals than the other top-down NBS projects (Litt et al., 2011; McClintock, 2010; Litt et al., 2011; Hale et al., 2011). Studies have shown that top-down policies are not sufficient to modify urban systems, and often sustainable development goal is not achieved (Swarnakar et al., 2017). Multiple, coordinated actions are required to improve the balance between urban dwellers and the natural environment inside and around the city. Unlike other strategies, the increase in urban agriculture movements in the Global North is a resilience strategy of people living in cities responding to environmental injustice, high food prices, and worldwide issues such as global warming (Hale et al., 2011; Tornaghi and Certomà, 2019; Reynolds and Cohen, 2016). These results are indirectly supported by the the findings in **Chapter 3**, the scoping review showed that the main reasons to practice urban agriculture were food access, socialisation, ecological conscience, and access to greenspace inside city boundaries. Especially as seen above, urban agriculture projects can be used as an NBS to help segregated parts of the population to regain their pride and food sovereignty, which in the long run, can help them reclaim their health and well-being (Cohen-Shacham et al., 2016)

Nevertheless, the involvement of policymakers, urban developers, scientists, and health authorities will contribute to the improvement and regulation of urban agriculture movements by providing access to land, new technologies, knowledge, and ensuring that it is properly regulated (van der Jagt et al., 2017; Fox-Kämper et al., 2018; Golden, 2013; Campbell et al., 2011).

(a) In NY, urban agriculture is used as an empowerment movement for minorities

(b) West Oakland Farms was created to reintegrate inmates to the civil life

(c) Urban agriculture fields in Detroit, a movement started by the comunity

Figure 8.3: The photos show different projects in the US using urban agriculture as a Nature Based Solution for integration, food security, and cultural appropriation. (a), (b), (c) **Photo courtesy Pinterest**

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Disadvantages to urban agriculture projects as nature-based solutions and limits to large-scale implementation

As argued above, urban agriculture can provide social, economic, cultural, environmental, and health benefits that make it an excellent candidate for use as a nature-based solution in Northern Hemisphere cities. However, as shown in results section in **Chapter 3** several adverse effects or dis-services of such practices, and their limitations, must be considered. Most of the issues or disservices related to urban agriculture are caused by a lack of information between the different stakeholders involved. Access to land, lack of regulation and support from local authorities, and social discrimination are the most cited disservices (Lovell, 2010; Castillo et al., 2013; Kim et al., 2014; WHO, 2001). According

to scholars, in order for urban agriculture projects to be done correctly it is necessary to consider social, institutional, economic, technical, geographical and ecological drivers and constraints which requires cross-sectoral stakeholder engagement at international, national and community levels to protect biodiversity and the environment whilst ensuring sustainable and nutritious diets, that are culturally acceptable, accessible, and affordable for all (Artmann and Sartison, 2018; Kingsley et al., 2021; Van Hullebusch et al., 2021).

Horticulturalists have similar views to scholars, as this survey carried out by Castillo et al. (2013) in the city of Chicago shows that the most reported problems by urban horticulturalists were in accordance to those reported by the scholars: Lack of transparent and inclusive ordinances (54% and 28% respectively); regulated use of land (31% and 28%); access to land (28% and 23%); lack of funding (28% by the farmers); lack of preparation by farmers (23% and 8%); lack of water (23% and 20%); difficulty to find insurance (8% and 16%). All these issues could be improved with appropriate involvement of the authorities, as will discussed in the following paragraphs.

Zoning and lack of available land constrains are two of the main barriers to urban agricultural development (McClintock et al., 2012; Spilková and Vágner, 2016; Ghose and Pettygrove, 2014; Wakefield et al., 2007; Saldivar-Tanaka and Krasny, 2004). Urban agriculture projects tend to be practised on vacant land Draus et al. (2014); Morckel (2015); Al-Delaimy and Webb (2017). The lack of ownership of the land can make it difficult to access resources, such as water and electricity (Oberholtzer et al., 2016; Cohen and Reynolds, 2015). In addition, lack of land ownership can result in horticulturalists being evicted at any time. When this occurs they are not provided with help to relocate or they may be moved farther away, resulting in people previously involved being unable to travel there or to lose interest (Mougeot, 2000; Nugent, 2000; Mares and Peña, 2010). The issue of lack of land ownership is related to gentrification which has been reported as an ongoing issue in many urban agriculture projects (Nicklay et al., 2020; Golden, 2013; Draus et al., 2014; Angotti, 2015). In a famous case in New York, the mayor Rudolph Giuliani evicted a group of horticulturalists from an area they had cultivated for 20 years in order to develop urban development projects. Social protests and the legal battle lasted four years (Schmelzkopf, 2002; Angotti, 2015) and in the end, people lost. Nevertheless, this case opened up a debate about the importance of social justice and urban development (Schmelzkopf, 2002). To avoid similar issues in the future, and due to the recent rise in popularity of urban agriculture , many large cities in the US, such as Portland, Denver, Chicago, and Boston, have begun to include urban agriculture projects as part of their policies for land use (Horst et al., 2017). In New York they have increased the taxes on vacant land and provide monetary incentives to urban farmers to use it (*ibid*). In the cities of Vancouver in Canada and Baltimore in the US, land and urban

projects have been designed around urban agriculture (Horst et al., 2017; Young et al., 2018; Mendes et al., 2008).

A common issue in urban agriculture literature is the transfer of heavy metals and organic chemicals (Sharp and Brabander, 2017; McClintock, 2012; Wortman and Lovell, 2013). This phenomenon is related to the above point regarding land tenure and a lack of knowledge (Balotin et al., 2020). In many urban areas, soils have residuals from the previous land uses. Usually, horticulturalists take advantage of abandoned factories or previously industrial sites, but cultivating food in these lots poses a risk of exposure to residual pollutants (Kim et al., 2014; Ferreira et al., 2018; Antisari et al., 2015; Meuser, 2010; Diawara et al., 2006). In other cases, current sources of contaminants, such as traffic (Kim et al., 2014; McClintock, 2012) might contaminate resources and eventually, horticulturalists ingest these contaminants. In some cases, horticulturalists are not aware of this issue and do not take measures to avoid food contamination (Kim et al., 2014). Balotin et al. (2020) found that urban horticulturalists in Atlanta did not have enough knowledge of the topic and did not consider the secondary transfer of pollutants when practising urban agriculture in the city. It has been suggested that importing soil, using raised beds, and cultivating other non-edible plants first to clean the soil may reduce the likelihood of pollutants being transferred to any food grown Brown and Jameton (2000). However, in many cases, urban agriculture initiatives are community driven, and they do not have access to support or guidance from experts, and information on how to prevent transfer of pollutants does not reach them (Aubry and Manouchehri, 2019; Balotin et al., 2020; Brown and Jameton, 2000). On the other hand, unlike industrial agriculture, the use of chemicals and fertilizers inside city boundaries in countries of the Global North is restricted (Cook and Fund, 2019). Using these products is not a common practice in urban agriculture projects. Some studies assessing the concentrations of heavy metals in food from urban agriculture projects show that the levels of contaminants were lower than allowable concentrations for human consumption and did not pose a significant risk to human health (Kim et al., 2017; Lupolt et al., 2021).

Another potential issue resulting from urban agriculture projects in the Global North is marginalisation resulting from social and ethnic disparities in access to urban agriculture projects (Cohen and Reynolds, 2014; Reynolds, 2015; Poulsen, 2017). Most of the cases were reported in the US and involved ethnic or racial discrimination. In *'Beyond the Kale: Urban Agriculture and Social Justice Activism in New York City'* Reynolds and Cohen (2016) found that in urban agriculture projects in New York, social disparities were present in most urban agriculture projects, in particular marginalisation and discrimination against black people by predominately white-middle class people. The authors highlight how the current popularity of urban agriculture projects in the Global North is

associated with young white-middle class and can ignore Black and Asian and other ethnic communities, many of whom have been cultivating food in the cities for decades. It has been found that in organised, high-tech, sponsored projects, primarily white people were in positions of responsibility and decision-making and therefore any paid work in these projects went to them, leaving other ethnic minorities behind (McClintock, 2018; Sbicca, 2019; Carolan, 2020; Horst et al., 2017). Research from Detroit shows a social distrust of urban agriculture projects led by companies that have an economic driver (Draus et al., 2014). These companies are usually start-ups supported by NGOs looking to create sustainable economic growth, including environmental and social development (*ibid*). However, people in these city areas have a history of bad experiences with companies invading their land, so they do not have any reason to believe that there may be positives from working with these companies (*ibid*) and in many cases, they are not happy with such initiatives happening in their neighbourhoods (Draus et al., 2014). Finally, most products from high tech urban agriculture projects are promoted as high quality, organic, and environmentally friendly (Siegner et al., 2018). In many cases, restaurants buy the products in advance (*ibid*) making the vegetables and fruits produced in these urban agriculture projects unaffordable for the local communities, resulting in further marginalisation (*ibid*). Some researchers argue that urban agriculture has become another example of gentrification and it is losing its potential to change societal systems simply because the people in charge of studying it, regulating it, and supporting it are mostly white-middle class people who fail to see social issues from the perspective of the marginalised societies they are trying to help (Siegner et al., 2018; Draus et al., 2014; Reynolds, 2015; Reynolds and Cohen, 2016).

The final limitation of urban agriculture projects relates to a lack of knowledge amongst the different stakeholders involved, as mentioned above. Urban agriculture is a complex term that encompasses many practices with different purposes, technologies, techniques, and locations (Taguchi and Santini, 2019; Weidner et al., 2019; Opitz et al., 2016), each one has pros and cons, and the potential of an urban agriculture project depends on the city where it is being practised (Taguchi and Santini, 2019). Many economic, social, cultural, ecological, geographical, and political gaps are not yet fully understood (Pearson et al., 2010). Furthermore, the benefits and problems of urban agriculture vary depending on, what and/or who, is being assessed (Pearson et al., 2010; Gray et al., 2020), whether it is a person who practices gardening, a person who lives near a gardening project, a community, the ecosystem, the environment, etc (Gray et al., 2020). For example, an allotment area can bring many benefits to those who have access to it, and it can also improve soil quality and increase biodiversity (personal and ecological benefits). Conversely, it can be a problem for those nearby since they are not always attractive places, they have no access, and they may be exposed to chemicals if they are used, and these projects can attract wild animals. These people may prefer a park or a garden as opposed

to allotments. Understanding these trade-offs resulting from urban agriculture projects is necessary to allow urban developers and health authorities to implement urban agriculture based projects that take into consideration and address the different needs of all the stakeholders involved, including those not actively involved in gardening themselves.

Urban agriculture as a Nature-Based Solution for sustainable development in cities: progress and gaps

Although, as evidenced in this thesis, the study of urban agriculture has advanced significantly in the last few decades, further evidence can help improve the case for the appropriate use of urban agriculture by local authorities or urban developers as a tool for sustainable development in urban areas (Mok et al., 2014; Pearson et al., 2010). All the urban agriculture problems mentioned above are linked to the absence of knowledge and control. The risks and benefits must first be established in order to develop policies that can regulate and manage urban agriculture practices with a legal mandate. Many urban agriculture projects that originate as social movements (bottom-up) do not have the necessary supervision and advice (Balotin et al., 2020). Thus, further research in this area and increased knowledge exchange with all urban stakeholders could help to reduce many of the downsides of urban agriculture.

Finally, it is important to highlight the different angles and approaches applied to urban agriculture research, depending on the part of the world in which it is practised. In the Global South, research focuses mostly on the economic potential of urban agriculture projects, whilst in the Global North, research focuses predominately on social cohesion (Gray et al., 2020). Urban agriculture has similar potentials, benefits, dangers, and limitations in developed and developing countries, but researchers have taken different approaches based on the requirements of the urban populations in their regions (Gray et al., 2020; Orsini et al., 2020; Weidner et al., 2019; Opitz et al., 2016). Nevertheless, much of the knowledge generated from research in the Global South can be applied in the Global North and vice-versa (Orsini et al., 2020). In developed countries, inequality is increasing, and urban agriculture is being used as a food security tool (as in the Global South). In many cities in developing countries, population density is decreasing greenspaces, and urban agriculture projects can be used as a green-space (as in the Global North). Research into urban agriculture needs to expand and increase in global reach in order to generate a more holistic understanding of the concept than is currently available. Defining and classifying the different expressions of urban and peri-urban agriculture is necessary to establish the different benefits, limitations, problems, and potentials that all these practices have (Gray et al., 2020; Orsini et al., 2020; Weidner et al., 2019; Opitz et al., 2016). Once that knowledge

is generated, implementing policies, regulations and investments in urban agriculture -based projects will be more feasible and efficient.

8.2 Limitations of this research

This study presents a novel approach to assessing the benefits of urban agriculture projects by comparing a sample of urban horticulturalists with a large sample from the general population that these horticulturalists are drawn from. It attempts to explore the multiple impact pathways of urban agriculture on physical and mental health via changes in lifestyle behaviours. The study, however, suffered from several limitations. Firstly, for the literature review, I only used papers written in English, which will have resulted in a language bias (Tricco et al., 2008). For example, urban agriculture is very popular in Japan, and exposure to greenspaces is used as an intervention tool for public health and well-being. Still, the scoping review only provides limited information about urban agriculture in Japan because most papers were from the US, Australia, Canada and UK, English native speaking countries. Despite this limitation, it is important to consider that English is the language of preference for scientific reports (Morrison et al., 2012), so it is safe to assume that English-written papers would include most of the essential information published on the topic explored here.

Budget was another limitation in this research. For example, no incentive was provided for the horticulturalists' survey, so I relied on people who wanted to answer. Previous research has shown that people are more willing to participate in a survey if they are interested in the topic (Groves et al., 2004), which supports the large response rate in this case. However, surveys with monetary incentives receive between two to five times more responses than those without it (Göritz, 2014). Moreover, economic responses increase the number of people finishing the survey (Yu et al., 2017). Consequently, the lack of monetary incentive for my survey might have reduced the number of people answering and the number of people completing the survey. I lost more than 250 surveys because people answered less than 10% of the questions. With an incentive, it is likely that more people would have finished the survey and thus, the statistical analyses possible with a larger sample size would have differed and it may have been possible to draw stronger conclusions.

In terms of the survey, there was a bias in response rate from allotment horticulturalists. The survey received a disproportionate number of answers from allotment horticulturalists compared to practitioners of other types of urban agriculture. This outcome might be a result of under-coverage (Bethlehem, 2010) because allotments associations have more presence on the internet than other gardening activities. According to the UK Natural Capital Report, 29% of the green areas in cities across the UK

are private backyards or gardens (Brownbill and Dutton, 2019), and non-official data indicates that around 35% of the British population grow food as part of their gardening activities in their private gardens (YouGov, 2021). However, it is not possible to establish what portion of these gardens are used for horticultural activities, although, it is possible to assume that most people cultivating food in the city are doing it in backyards rather than in allotments or community gardens (Loram et al., 2007). Several private/backyard horticulturalists filled in the survey but at a much lower number than allotment horticulturalists suggesting that backyard horticulturalists were under-sampled, possibly due to the difficulty of identifying and reaching them. Due to small sampling bias, the lack of enough participants in categories other than allotment gardens are likely to be underrepresented and may not be sufficient to give an accurate statistical description of the situation for allotment gardens (Bethlehem, 2010).

Another significant limitation is response rate bias (Fincham, 2008). I could not establish the response rate for the survey since I did not know how many horticulturalists in total read the message asking for their participation in the survey. For the UK Biobank, the response rate was only 5%, with evidence of a bias towards healthy respondents, hence for some healthy behaviours or health markers, the UK Biobank will not be representative of the British population (Fry et al., 2016; Cassidy et al., 2017).

I also used self-reported data, which is known to lead to a possible social desirability bias, whereby people tend to over-report traits in questionnaires. Patterns of this behaviour have been reported in dietary data, physical activity, self-health assessment and well-being markers (Subar et al., 2015; Latkin et al., 2017; Dyrstad et al., 2014; Wojcik and Ditto, 2014). As the Biobank sample also included self-reporting data, it is possible that this bias could have been equal across the two samples, thus limiting any biases in our analysis comparing the two samples. Nevertheless, the variable vigorous exercise in the UK Biobank data set has many NAs. Hence the desirability bias might be more substantial for this variable, and the values of vigorous exercise for the UK Biobank participants may be higher than the population average (Subar et al., 2015).

This work had difficulties with assessing self-reporting subjective traits related to well-being. The lack of a standardised unit of measure or a reference value for comparison can result in a lack of consistency, making these measures more susceptible to the interpretation of the person answering (Lucas, 2018; Pavot and Diener, 1993; Wojcik and Ditto, 2014). People tend to score themselves higher than peers in several self-reported subjective measures varying from driving skills to relationships (Wojcik and Ditto, 2014). Moreover, subjective measures are prone to other factors affecting the respondent, such as their mood when answering the questionnaire (Pavot and Diener, 1993). Therefore, assessing these traits carries an added difficulty that objective measures of health do not have. In our case, the

questions related to weight, physical activity, and mental health may be altered; however, this bias affects the two samples equally, so it does not significantly change the inter-specific comparison.

Another limitation related to the survey was the inability to assess the percentage of greenspace at 100m 300m, and 500m buffers from individual households. The survey informed participants that we asked for their postcode to order assess greenspace around the household, but they were free to leave the question unanswered for anonymity reasons. Most participants (68%) did not answer, so I used the time spent outdoors in summer as a proxy for greenspace exposure instead. There is no recommended time spent outdoors for adults, so I had to use the suggested time for children to be outdoors as a proxy. Moreover, being outside does not necessarily mean being in a green space. Consequently, no direct conclusions could be made with respect to greenspace, only extrapolations. For the last chapter, in which I only used the UK Biobank cohort, I was able to use greenspace exposure using the percentage of green areas from the household at 100m buffer, 300m buffer, and 500m buffer. However, the last two variables of green space (300m and 500m) had a high percentage of missing values, so I was only able to use the 100m buffer for the statistical analysis, so any information assessing the distance-related changes of the association between greenspace and health could not be carried out.

For the chapter comparing horticulturalists and the UK Biobank participants, I was not able to adjust for age. The UK Biobank asked for year of birth, whilst the survey asked for an age range. In developed countries, age is the leading risk factor for the prevalence of chronic diseases and other diseases (Niccoli and Partridge, 2012). To counter this, I used horticulturalists of the same range as UK Biobank participants (45-69 years) in order to limit any biases within the comparison. Nevertheless, I acknowledge that age is an important confounder, and the age range was 24 years. Some of the results within that chapter may have been associated with age, as similar studies have found that age modifies the association between urban agriculture projects and health and well-being. As a consequence, I might have lost important results because of this issue.

Moreover, there was the impossibility of assessing the ecosystem services provided by urban agriculture because they varied depending on the type of urban agriculture, the demographics of the participants, and even the city landscape. For example, the two samples use here have similar demographics which allows me to rely on the results comparing both samples. However, other demographic aspects not assessed here could have been very different between the two populations, for example, marital status, number of kids, or even working status. Studies have shown that loneliness and happiness are highly influenced by these conditions and they were not measured here (Ganster et al., 2018; Hank and Wagner, 2013; Shapiro and Keyes, 2008).

The variable used for assessing total physical activity levels (Daily exercise) depended on the time

spent undertaking vigorous physical activity. For the UK Biobank data set, that variable had around 50% missing data. The variable happiness for the UK Biobank data had similar issues. Still, I could not use other variables because the survey of urban horticulturalists had the same ones, and I needed to compare them. So, in **Chapter 6** the model for happiness had around 75% fewer data than the other models. I tried to contra rested this issue by evaluating vigorous and moderate exercise separately in the models instead of using Daily exercise as the physical activity variable. Fortunately, the UK Biobank sample was large enough to fit the model, but the results should be considered with care due to the large number of NAs, so for vigorous exercise and happiness, the desirability bias might be higher than for other variables in the UK Biobank (Davis et al., 2010; Little et al., 2014). To avoid similar issues, for the last empirical chapter (**Chapter 7**), I used the IPAQ activity group instead of Daily exercise, and I removed happiness from the analysis.

Finally, due to the cross-sectional nature of this study, I cannot discard the possibility of reverse causality (Levin, 2006; Giordano and Lindström, 2016) in any of the empirical work. For example, it is not possible to ensure that people started to enjoy greenspaces more because they began urban agriculture projects. The same happens with fruit and vegetable intake. People who like to eat healthily might try urban agriculture because they want to produce healthy food. As seen above, many people claim that worrying about the environment and guaranteeing access to healthy food were among their primary reasons for starting urban agriculture projects. So the results in the empirical chapters of this thesis can be the outcome of healthy people doing these activities because they have a healthy lifestyle and not necessarily that unhealthy people have changed their habits because of urban agriculture. However, evidence from a few well-designed experimental studies (pre-post intervention) supports a causal interpretation of some of our results. Especially, several authors have shown that fruit and vegetable intake increases after being involved in urban agriculture projects (Evans et al., 2012; Weltin, 2013; Gatto et al., 2017; Tse, 2010; Brown et al., 2004; Castro et al., 2013).

8.3 Future work

This work provides an initial theoretical and experimental exploration, and it proposes some bases for understanding the association between urban agriculture projects and public health in urban populations, the main benefits being an increase in urban greenspace, increased production and consumption of healthy foods and increased physical activity. However, the type of ecosystem services delivered vary depending on the type of urban agriculture practiced, the city where it is undertaken, and the demographics of the participants. For this reason, further research should focus on better understand-

ing these variables and their interactions in order to optimise the implementation of urban agriculture projects in cities of the Global North. This will require a more extensive and more varied global population sample than the one in this project, which focused specifically on the UK. Future projects will also need to study the combination of natural spaces, for example, what happens when you have urban agriculture projects within a park or next to a forest and how this may influence the resulting outcomes.

Concerning the limitation of this work, several improvements for future work can be made. Firstly, the sample size of horticulturalists should include a wider variety of people practising different types of urban agriculture. Differences in the health benefits and ecosystem services delivered by different types of urban agriculture can be explored further with other methods rather than an internet-only survey. For example, paper surveys posted via the mail could be an excellent alternative to reaching more people who focus on backyard gardening. Random in-person interviews may be used to reduce the effect of social desirability bias.

In general, the measures for greenspace used in this study are inaccurate. Time spent outdoors does not guarantee that the time is spent in natural environments (**Chapters 5 and 6**). Similarly, the percentage of greenspace does not ensure the greenspace is used (**Chapter 7**). Furthermore, adults tend to work in a different location to the one they live in, and they spend most of their day in these locations. Therefore, future research should focus on understanding the multiple ways in which green spaces can contribute to improved physical and mental health (*e.g.*, percentage of greenness around the working place, time spent in green areas, or the purpose of visiting them), rather than taking a one-dimensional approach, such as distance to green space which is usually applied. Further research should take a more holistic approach to assess the ecosystem services provided by green areas and how those services may be affected by both the characteristics of greenspaces and people's level of exposure, for example, quality of the greenspace, size, type of activities related to the area, barriers of access, distance, and so on.

Our results suggest that urban agriculture might have added benefits to health and well-being due to a synergistic effect between different healthy behaviours, hence urban agriculture projects can bring more significant benefits to public health than interventions that only seek to address a single healthy lifestyle behaviour. Our results support the existing literature that multiple-lifestyle behaviours are better than single-focused approaches (Loprinzi et al., 2016). However, more research is needed to understand the impacts (positives or negatives) that the interactions between the city environment, socio-demographic factors, and lifestyle behaviours have on health and well-being. Nevertheless, authorities need to develop strategies that motivate the public to engage in healthy behaviours (Dale

et al., 2014). According to our results and the literature, urban agriculture could be a helpful tool due to its multiple potential contributions to urban health (Soga et al., 2017b). For urban agriculture specifically, future research should assess the benefits of the interaction between the horticulturalists and the urban agriculture project considering the effect confounders, such as; age, gender, or income, have on these interactions. For example, future research could be focused on establishing if the percentage of green areas around the household affects the perception a person has on the benefits of gardening, and if this perception is different from those living in areas with lower access to greenspaces.

Despite it being reported as a health benefit of urban agriculture, I found that research on physical activity to date has relied on anecdotal, rather than epidemiological, evidence. More research is required to assess the physical activity levels of horticulturalists compared to their peers and evaluate if horticulturalists show evidence of a trade-off between moderate and vigorous activity because they use their spare time for gardening rather than more vigorous activities such as playing sport, for example. When exploring social interactions, I found that the differences in the percentage of self-reported loneliness between horticulturalists and non-horticulturalists were not significant when other confounders were considered. Another study on allotment gardens found a negative association between time spent in an allotment and lower social quality of life, although authors mentioned that the results might be related to the type of urban agriculture (allotments) (Webber et al., 2015), which as explained above (**see limitations of this research**) was over-sampled. Consequently, future research should focus on an exploration of the social benefits of urban agriculture and how these vary depending on the type of urban agriculture practiced. Following on from this, additional research could compare the social benefit of urban agriculture versus other group activities and other lifestyle factors such as marital status, age, and immigration status.

As mentioned multiple times in this work, the empirical evidence of this thesis is cross-sectional; although this study demonstrates an association between urban agriculture and public health, it was not possible to established causality between urban agriculture projects and health and well-being. Future work should focus on experimental intervention-based projects and observational longitudinal studies to assess for causality and to evaluate research questions such as: How much time is required from the moment a person becomes involved in urban agriculture projects and obtaining health and well-being benefits? What health and well-being benefits are immediate, and which ones take time to be observed? Are the changes in lifestyle behaviours well adopted? After stopping urban agriculture activities, how long does someone retain lifestyle behaviours related to the practice of urban agriculture? Are the lifestyle behaviours more noticeable in horticulturalists that have been involved in urban agriculture for longer? These questions are essential and cannot be answered with

cross-sectional designs, hence more intervention-based research, natural experiments, and longitudinal analysis are required. These methods are complicated and expensive to apply at population level, but a combination of these approaches can help elucidate the causality between urban agriculture projects and public health and well-being (Crane et al., 2020; Craig et al., 2017, 2012).

This work focused on public health, but the importance of urban agriculture movements as a social tool to reduce urban inequalities and as an expression of social resilience and empowerment needs further exploration. Additionally, the importance of urban agriculture projects in reducing the environmental impact of cities was observed throughout. Future work should study the different mechanisms by which urban agriculture may be able to reduce the environmental impact of cities. Finally, future work is also required to find the similarities and differences between urban agriculture projects in different regions of the world to facilitate and optimise their implementation at a global scale.

8.4 Conclusion

The purpose of this thesis was to provide a comprehensive understanding of the pathways by which urban agriculture may improve public health by assessing and elucidating, amongst others, the direct and indirect links between urban agriculture and public health (represented by both physical and psychological health markers such as BMI or happiness). Previous studies linking public health and the environment have focused on single pathway studies (e.g., does improving one behaviour improving a particular health marker). As the reality between different health behaviours and outcomes is highly complex, previous studies fail to elucidate the whole picture. This work improves on the current way of approaching research area by increasing the number of behaviours measured simultaneously and the different impacts these behaviours might have on a series of health markers, either acting together or individually, and finds that the behaviours related to urban agriculture projects do affect health by acting synergistically on both self-assessed and non-self-assessed health outcomes. Moreover, the results also demonstrate the nature of the synergies and how they vary depending on the different values, and the type of, health behaviour and outcomes measured. Finally, this work concludes that one of the main benefits of urban agriculture is that it provides ecosystem services that act simultaneously, creating win-win scenarios between healthy environments and public health, suggesting that, with the appropriate strategy and planning, it can improve both the environment and people's well-being simultaneously.

Urban agriculture has many issues that need to be considered before talking of it as population-based solution, and it is not the ultimate solution to many of the health, social, ecological, and cultural issues

in cities, but it can be a good help if applied correctly. Urban agriculture is a nature-based alternative to traditional urban planning that allows for the continued development, and growth of, a city whilst improving the health of urban dwellers. Globally, cities are the only growing ecosystems, and they have an environmental impact ten times greater than their size by area. Consequently, it is essential to understand the interactions between humans and nature when proposing nature-based solutions. In other words, to keep in mind the human-nature relationship when proposing projects seeking to benefit the natural environment and people's quality of life. Currently, development projects seek to make cities more self-sustainable, and an essential part of these projects seeks to integrate GE within urban areas as part of sustainable development. In general, urban agriculture projects are an excellent alternative since they increase GE in the city, can be adapted to different urban designs, and can be a basis for building self-sustaining cities proposals.

If well designed, urban agriculture has the potential to enhance food security, as well as providing an incentive to increase PA. Moreover, it brings nature to the city, increasing exposure to GE and improving people's interactions with natural environments, including for those not directly involved in urban agriculture projects. Finally, urban agriculture also promotes a sense of community and social cohesion. Together, the health (both physical and psychological) and social traits provide urban dwellers with an enhanced sense of belonging to an area, increasing their likelihood of maintaining and improving their local environment.

Due to the different ecosystem services urban agriculture provides, it can provide a range of benefits to both horticulturalists as well as other urban residents. It improves the urban environment as it can be used to recover abandoned and degraded places, enhances soil quality, and increases biodiversity. The adaptability and diversification of urban agriculture projects is also of interest. Any person can cultivate fresh food at home, even those lacking a garden or access to GE. New techniques such as vertical farming allow people to take advantage of walls or other vertical spaces that would otherwise be empty. Roof gardening practices enable residents to use these spaces in cities where land is scarce. Finally, an urban agriculture project can also serve as a source of education, for example the development of school gardens as teaching facilities.

It is important to bear in mind the potential negative impacts of urban agriculture , such as the transfer of pollutants due to contamination of the soil. To achieve a safe and successful urban agriculture culture in cities, residents should be encouraged to become active participants in urban agriculture and local planning, whilst local government should ensure that they provide the necessary resources, help and guidelines, as well as regulating these practices to avoid a potential negative side-effect. In conclusion, urban agriculture is not a new strategy for reducing the environmental impact of cities

and improve public health, but a forgotten and now, often overlooked one. It does not require modern technological techniques, although these can be applied in the case of vertical farming. However, at its heart, urban agriculture is about going back to basics, reconnecting with nature, and claiming control of our urban environments resulting in benefits for the planet and ourselves.

Appendices

Appendix A

Relevant information complementing Chapters 1 and 2

A.1 Important definitions and concepts for this thesis that are not related to urban agriculture

I developed most of the definitions I used in this document by combining different sources of information, and I cite the original sources when needed.

Biophilia hypothesis

One of the most important hypotheses relating human health and well-being with green spaces was proposed by Edward Wilson and it was named Biophilia Hypothesis (Wilson, 1984). It is defined as the innate affinity for everything living, the need to affiliate with other forms of life, the sense of connection with nature and the emotional connection with other living systems, with the habitat and with the environment (Kellert and Wilson, 1993). From an evolutionary perspective, this hypothesis holds that man evolved over thousands of years in natural environments and therefore humans have an innate need for natural spaces (*ibid*). According to this precept, the absence of nature in the environment can have health and mental consequences for people.

Ecopsychology

Ecopsychology is a current within psychology that focuses on understanding and improving the relationship of human beings with the environment (Roszak et al., 1995). It combines ecology and

psychology and is aimed at identifying how the physical, mental, emotional, and spiritual aspects of human beings are influenced by the environment. The term was proposed by Roszak (1992), ever since psychologists have spent several decades studying the interaction between humans and the natural environment and the effects it has on people's mental health.

The Attention restoration theory

The Attention restoration theory (ART) is a proposal from cognitive psychology that was proposed by Kaplan and Kaplan (1989) and maintains that the ability to concentrate could be improved or even restored through exposure to natural environments. This theory has been tested in psychology studies using treatment-control designs and finding differences in attention functions (Ohly et al., 2016a,b), major depression (Berman et al., 2012), or attention deficit hyperactivity disorder (Faber Taylor and Kuo, 2009).

Biophilic design

In a generic way, biophilic design is a current of architecture, interior design and urban planning that seeks to incorporate elements of nature in urban or interior spaces to evoke nature with the aim of improving the well-being of people and society (Ryan and Browning, 2020; Kellert et al., 2011). Biophilic design can be used in individual or closed spaces, as well as in open spaces and entire cities (Kellert et al., 2011).

Definition of authorities for this thesis

In the thesis, I refer to authorities in several locations. Because most of the thesis discussion is related to urban agriculture in the UK, when I use the term local authorities, I'm referring to councils or borough authorities, which generally oversee urban agriculture projects such as allotments. I also use the terms city authorities. In that case, I'm referring to authorities that can regulate practices all over the city (Mayors, for example).

Definition of Non-Governmental organisations for this thesis

Non-Governmental organisations are organisations (NGOs) that operate independently from the governments, but they can receive funding from private donations or even governments (Martens, 2002). For this thesis, I refer to NGOs involved directly or indirectly in urban agriculture projects, for example, the Resource Centre for Urban Agriculture & Forestry (RUAF) foundation or FAO.

Urban planning and urban planners

When referring to urban planning or urban planners in the thesis, I'm talking about the different stakeholders in charge of the planning and design of cities development. Hence, I am not referring to a profession or the city authorities, rather than a general mention of stakeholders in charge of the urban development.

Policy

Refers to a set of actions, regulations, laws, guidelines, procedures, initiatives and voluntary practices from private institutions or governments to encourage behaviour and penalise others (Wies, 1994). For health, several policy techniques are used by governments, private sectors, and NGOs. For example, taxation of junk food, teaching nutrition to kids at school, or incentives for cycling to commute. In this thesis, when I talk about policies, I can refer to the existing policies in different countries or as a term that embraces various regulations, guidelines, or laws that can be applied to improve public health or increase exposures to natural environments (such as urban agriculture spaces).

The recommendations given in this work on policy do not have a defined sector but are based on creating a series of recommendations based on both theoretical and applied evidence so that different stakeholders take it into account as a public strategy tool.

Lifestyle/healthy behaviours

It is a set of behaviours and habits, individual and social that contribute directly or indirectly to health and well-being. Healthy behaviours refer to those that promote health and improve people's quality of life. In this thesis, I use lifestyle or healthy behaviours as a term to describe the behaviours to promote health. More likely, fruits and vegetable intake, physical activity, greenspace exposure, and social cohesion.

Health traits/markers

I use the term health markers or health traits to refer to a set of physical and well-being markers used by health professionals to assess the health of a person. For example, blood pressure, BMI, or happiness.

Health authorities

Health authorities refer to the different people responsible for providing strategies to improve health and identifying the healthcare issues and needs of its resident population. These people can be from the government, researchers, civilians, private sector, NGOs, and the combination of all.

Health

According to WHO, health is *'the condition of every living being who enjoys absolute well-being physically, mentally, and socially'* **page 1** (WHO, 2011). The concept of health not only accounts for the non-appearance of diseases or conditions but goes beyond that. Health is a complex term that includes environmental health, physical health, family health, social health, mental health, personal health, public health, etc. In this thesis, I used four types of health:

1. Personal health. When talking about personal health, I'm talking about the overall health of a single individual in terms of physical and mental health.

2. Public health: Public health in this thesis refers to the science in charge of studying the health of entire populations (Rothstein, 2002). I also refer to public health as the general health and well-being of more than one individual.

3. Physical health: Here, I use the term physical health as the well-being of the body and the optimal functioning of the organs of individuals. In order words, it refers to having a good physical condition and not suffering from any disease.

4. Mental and emotional health: The simplest definition of mental health is the absence of mental illness. In contrast, emotional health refers to a person's feelings. Depending on the context, emotional health can be included in mental heal (Galderisi et al., 2015). Here I use mental health when talking about other authors' work because it is the term they are using. Sometimes the term physical health includes mental and emotional well-being, but I separate the health of the body (not including mental or emotional health) and name it physical health. For psychological and emotional health, I used the term well-being.

Well-being

There is no consensus on the definition of well-being. Still, it usually refers to the positive emotions a person experience, the absence of negative feeling or mental illness, and the life satisfaction a person has (Eid and Larsen, 2008). Well-being is susceptible because not everybody has the same standards, but it is widely used in public health and psychology to measure mental and emotional health (*ibid*).

In this thesis, I use the term well-being instead of mental health or emotional health because it encompasses some of the measured variables in this research, such as self-reported happiness, loneliness, and happiness with own health. All these variables are subjective and might not directly be linked with mental health, but all are related to well-being.

Synergy

The word synergy comes from the Greek word meaning 'cooperation' (dictionary, 2016). The concept is used to name two or more causes that generate an effect that has a greater significance than simply the sum of its parts (dictionary, 2016). A synergy is usually considered to involve integrating parts or systems to create a new object or effect. Therefore, the analysis of this new object (or effect) differs from the study of each of the components separately.

UK Biobank Cohort

It is a major cohort developed in the UK that seeks to improve prevention, diagnoses, and treatment of common diseases. It contains the information of $\sim$ 500,000 volunteer participants around the UK. The information includes health records, biological samples, DNA samples, daily activities, and mental health. For more information visit `https://www.ukbiobank.ac.uk/`.

United Nations concept of cities

The definition of urban areas lacks a common worldwide consensus. It varies from country to country. Hence, in this thesis I decided to use the definition used by the United Nations. According to United Nations (2015), population, area of the city, population density, access to essential services, presence of education, and health services are common traits when defining an urban area. For this project, cities were defined as places with more than 250,000 inhabitants.

Countries in Global North and Global South

Global North refers to countries with advanced economies including Australia, New Zealand, and some countries in North America, Western Europe, and Asia (dictionary, 2016). Global South refers to middle or low-income countries in South America, Asia, East Europe, and Africa. Both terms are often used to replace previous definitions like 'Developed', or 'Developing', or 'Third World'.

A.2 Types of urban agriculture

The following section introduces the types of urban agriculture developed in different cities and complements the information found in **Chapter 2**. The classification and definition of the different kinds of urban agriculture vary depending on the source consulted, the materials used, and the intended purpose of the garden. For example, backyard gardens might include vertical gardens. Here I introduce and classify the most common types of urban agriculture I found in the literature. Also, I highlight the types of agriculture I'm using for this research. First, I split urban agriculture into two main categories. The first one is the type of agriculture that focuses on animals, and the second one is

the type of agriculture that focuses on plants (horticulture). Then I describe the most common types of urban horticulture.

A.2.1 Animal husbandry

The term refers to different urban agriculture practices that focus on raising animals within the city's limits for their use, either for consumption, protection or as an educational tool. Keeping animals can pose a risk to the population due to the transmission of diseases. Therefore, this type of urban agriculture has special legal requirements that change depending on the city. Within this category are urban farms and beekeeping.

A.2.2 Urban horticulture

Backyard gardens

Probably the most common type of urban agriculture. The term refers to private gardens cultivated inside the owners' patios, front yards, or backyards. Depending on the available space, these can be vertical gardens, pots, crops directly in the ground or raised beds. Usually, the products obtained are consumed in the same house or shared with family and friends.

Balcony/terrace gardens

Some people without access to backyards or open spaces inside their houses/flats use their balconies or terraces to cultivate food or ornamental plants using different techniques like vertical farming, hydroponics, and pots.

Private gardens with economic purposes

These gardens are private, and the products are sold to private customers, restaurants, or consumer groups. Within this type of urban agriculture are hydroponics or aquaponics, crop factories and restaurants' gardens.

Orchards/allotments

The word orchard usually refers to areas where trees are mainly grown. However, public urban orchards relate to areas destined for the practice of urban agriculture in the city. People interested in growing their food can rent plots inside these spaces. Usually, they are owned and managed by local

authorities. This same system is known as allotments in the UK and has a historical and cultural connotation.

Community gardens

Community gardens are typically located on public lands. They are free and freely accessible spaces where the residents of the area work to take them forward thanks to teamwork and bearing in mind the agro-ecological techniques to obtain food. These spaces are used as social hubs for the community.

Rooftop gardens

This type of agriculture is practised in cities where land is sparse. As the name indicates, people use the roofs of buildings or houses to grow up food. The definition of rooftop agriculture is based on the garden's location rather than its social or economic purpose. Hence, this practice can be communal, for teaching or private.

Vertical farming and green walls

Refers to the practice of growing food or ornamental plants vertically, usually related to hydroponic crops for commercial purposes. In cities, vertical farming is also commonly used for decorative and environmental goals and is frequently called green walls.

Therapeutic gardens

Therapeutic gardens are specifically designed spaces to improve the health and well-being of patients in hospitals, nursing homes, and mental hospitals. The whole purpose of these gardens is to use them as a therapy to improve the recovery process of patients or to improve the mental health and well-being of patients with special needs.

Teaching gardens

These gardens are specifically designed to teach their participants the importance of healthy eating by introducing the process of food production and consumption. The most common type of teaching gardens are school gardens, and they are used to teach kids about nutrition, food production and nature. But universities, NGOs, and health authorities also use teaching gardens for different purposes.

Hydroponics/aquaponics

These definitions are based on the technology used to produce food rather than its location, social purpose, or economic goal. The goal of these techniques is to grow food in the absence of land and are based on water cycles, and for the case of aquaponics, it involves the use of freshwater fishes.

Hydroponics and aquaponics are versatile types of agriculture and can be used indoors or in outer spaces.

Appendix B

Variables used for this thesis

This appendix complements the information in **Chapter 4** by including the tables of the original variables used for the statistical analysis (**Table B.1**), the variables created from the original variables that I subsequently used in the analysis (**Table B.2**), and the variables with the categories collapsed (**Table B.3**).

Table B.1: **Variables used from UK Biobank and survey of horticulturalists**. The table shows the question related to the variable, the answer' options, the source of the question (UK Biobank questionnaire or survey of horticulturalists), the data base where the variable is used, the variable's name, the type of variable and the measurement units. Some of the UK Biobank variables were not in the questionnaire because they were taken at the assessment centre using direct measures. Those variables are at the beginning of the table. Questions from the UK Biobank questionnaire that I used only in the UK Biobank database have a grey background. Questions used for the UK Biobank and the urban horticulturalists' data base have a white background. Questions included in the urban horticulturalists' survey that are not from the UK Biobank are in orange.

Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
NA	NA	Age when attended assessment centre	Numerical: Discrete
NA	NA	Sex	Nominal
NA	NA	Body Mass Index (BMI)	Continuous
NA	NA	Assessment centre	Nominal
NA	NA	Diastolic blood pressure automated reading	Continuous mmHg
NA	NA	Systolic blood pressure automated reading	Continuous mmHg

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Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
What is your ethnic background?	· British · Irish · Any other white background · White and Black Caribbean · White and Black African · White and Asian · Any other mixed background · Prefer not to answer	Ethnicity background	Nominal
NA	NA	IPAQ activity group	Ordinal
NA	NA	Index of Multiple Deprivation (England)	Continous
How often are you able to confide in someone close to you?	· Almost daily · 2− 4 times a week · About once a week · About once a month · Once every few months · Never or almost never · Do not know · Prefer not to answer	Able to confide (England)	Ordinal

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Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
Which of the following qualifications do you have?	· College or University degree · A levels/AS levels or equivalent · levels/GCSEs or equivalent CSEs or equivalent · NVQ or HND or HNC or equivalent · Other professional qualifications eg: nursing, teaching · None of the above · Prefer not to answer	Qualifications	Nominal
How many minutes did you usually spend doing moderate activities on a typical day?	· Enter a number · Do not know · Prefer not to answer	Minutes a day doing moderate exercise	Continuous $\frac{minutes}{day}$
How many minutes did you usually spend doing vigorous activities on a typical day?	· Enter a number · Do not know · Prefer not to answer	Minutes a day doing vigorous exercise	Continuous $\frac{minutes}{day}$

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Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
About how many pieces of fresh fruit would you eat per day? (Count one apple, one banana, 10 grapes etc as one piece; put '0' if you do not eat any)	· Enter a number · Less than one · Do not know · Prefer not to answer	Daily intake of fresh fruits	Discrete $\frac{portions}{day}$
On average how many heaped tablespoons of cooked vegetables would you eat per day? (Do not include potatoes; put '0' if you do not eat any)	· Enter a number · Less than one · Do not know · Prefer not to answer	Daily intake of cooked vegetables	Discrete $\frac{tablespoons}{day}$
On average, how many heaped tablespoons of salad or raw vegetables would you eat per day? (Include lettuce, tomato in sandwiches; put '0' if you do not eat any)	· Enter a number · Less than one · Do not know · Prefer not to answer	Daily intake of raw vegetables	Discrete $\frac{tablespoons}{day}$
Do you often feel lonely?	· Yes · No · Do not know · Prefer not to answer	Loneliness	Nominal

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Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
In general, how happy are you?	· Extremely happy · Very happy · Moderately happy · Moderately unhappy · Very unhappy · Extremely unhappy · Do not know · Prefer not to answer	Happiness	Ordinal
In general, how would you rate your overall health?	· Excellent · Good · Fair · poor · Do not know · Prefer not to answer	Self− health assessment	Ordinal
Do you regularly take any of the following medications? (You can select more than one answer)	· Cholesterol lowering medication · Blood pressure medication · Insulin · None of the above · Do not know · Prefer not to answer	Medication intake	Nominal
In a typical day in summer, how many hours do you spend outdoors?	· Enter a number · Less than an hour a day · Do not know · Prefer not to answer	Hours spent outdoors in summer	Discrete $\frac{hours}{day}$

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Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
Do you smoke tobacco now?	· Yes, on most or all days · Only occasionally · No · Prefer not to answer	Smoking status	Ordinal
NA	· Current · Previous · Never ·Prefer not to answer	Smoking	Ordinal
Your age?	· 18− 29 · 30− 40 · 45− 69 · more than 70	Age	Ordinal
Gender?	· Male · Female	Gender	Nominal
What is your weight in Kg? (please be very sincere with this answer, we need it for the BMI index)	· Enter a number	Weight	Continuous Kg
What is your height in cm? (please be very sincere with this answer, we need it for the BMI index)	· Enter a number	Hight	Continuous cm

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Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
City of residence?	· Birmingham · Bradford · Edinburgh · Glasgow · Leeds · Liverpool · London · Manchester · Newcastle · Sheffield · Other	City	Nominal
What type of agriculture do you practice? (You can select more than one answer)	· Allotment · Community garden · City farm · Public gardens: non− edible plants like flowers · Backyards gardens: non− edible plants and flowers · Backyards gardens: fruits and vegetable, non− edible plants like flowers	Type of urban agriculture	Nominal
Has your diet changed since you started practising UA?	· Yes · No	Diet changed due urban agriculture	Nominal

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Question	**Answers' options**	**Variable's name**	**Type of variable and measurement units**
If your previous answer was affirmative, what mainly describes the change?	· Mostly positive · Somehow positive · Somehow negative · Mostly negative	Type of change; diet	Ordinal
Have your levels of physical activity changed since you started practising UA?	· Yes · No	Physical activity changed due urban agriculture	Nominal
If your previous answer was affirmative, what mainly describes the change?	· Mostly positive · Somehow positive · Somehow negative · Mostly negative	Type of change; physical activity	Ordinal
Do you interact more with others since you started practising UA?	· Yes · No	Interaction changed due urban agriculture	Nominal
Do you think you are in contact with green spaces more often since you started practising UA?	Greenspace exposure changed due urban agriculture	Nominal	

Table B.2: **Created variables**. The following variables were created using original variables from the UK Biobank and/or the urban horticulturalists' survey. The table shows the variable's name, the original variables used to create them, the formula, and measurement units.

Variable's name	Original variables used	Formula	Measurement units
Body mass index (BMI)	· Height (cm) · Weight (Kg)	$\frac{H}{W^2} = BMI$	$\frac{Kg}{m^2}$
Portions of cooked vegetables	Daily intake of cooked vegetables	$(\frac{DCV}{3})$	$\frac{portions}{day}$
Portions of raw vegetables	Daily intake of raw vegetables	$(\frac{DRV}{4})$	$\frac{portions}{day}$
Daily fruits and vegetable intake (F&V)	· Portions of cooked vegetables · Portions of raw vegetables · Daily intake of fresh fruits	$DICV + DIRV + DIFF = F\&V$	$\frac{portions}{day}$
Daily minutes of exercise (DailyExer)	· Minutes a day exercising moderately · Minutes a day exercising vigorously	$(\frac{MME + MVE}{2})$	$\frac{minutes}{day}$

Table B.3: **Collapsed variables**. The following variables were used in some empirical chapters with the categories collapsed. The table shows the variable's name, the original variables used to create them, original categories, and the categories created.

Variable's name	Original variables used	Original categories	Categories created
Highest qualification (Four categories)	Qualifications	· College or university degree (1) · A levels/AS levels or equivalent (2) · NVQ or HND or HNC or equivalent (2) · Higher National Certificate (HNC) or equivalent, other professional qualifications (2) · CSEs or equivalent (3) · O levels/GCSEs or equivalent (3) · None of the above (4)	(1) College or University Degree (2) Education to age 18 (3) Education until age 16 (4) None of the above
Happiness binary (two categories)	Happiness	· Extremely happy (1) · Very happy (1) · Moderately happy (1) · Moderately unhappy (2) · Very unhappy (2) · Extremely unhappy (2)	(1) Happy (2) unhappy

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Variable's name	Original variables used	Original categories	Categories created
Medication intake (two categories)	Medication intake	· None of the above (1) · Cholesterol lowering medication (2) · Blood pressure medication (2) · Insulin (2)	(1) None of the above (2) Yes
Type of UA (six categories)	Medication intake	· Allotment (1) · Community garden (2) · City farm (2) · Public gardens: non− edible plants like flowers (2) · Backyards gardens: non− edible plants and flowers (3) · Backyards gardens: fruits and vegetable, non− edible plants like flowers (3) · Missing answer (4)	(1) Allotments (1,3) Allotments and Backyards (2) Community garden or other (3) Backyards or other (1,2,3) Three types of urban agriculture (4) Unknown

Appendix C

Relevant information complementing Chapter 5

This appendix complements the information in **Chapter 5** by including the tables with the results of the statistical analyses performed.

Table C.1: **Lifestyle behaviours and BMI of respondents of the urban horticulturalists' survey vs recommended values by WHO**. The table compares horticulturalists' fruit and vegetable intake (portions/day), physical activity (min/day), time spend outdoors (hours/day), and BMI with the health authorities' recommendations (5 portions of fruit and vegetable, 20 minutes of physical activity, 3 hours outdoors, less than 25). It shows the mean, the 95% interval, and the p value.

Observed mean	95%CI	p value
Fruit and vegetable intake (recommended value = 5 portions/day)		
5.10	4.84, 5.37	0.410
Physical activity (recommended value = 20 minutes/day)		
76.12	71.64, 80.58	≤ 0.001
Time spent outdoors (recommended value = 3 hours/day)		
4.094	3.92, 4.25	≤ 0.001
Body Mass Index (BMI) (recommended value $\leq$ 25)		

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Observed mean	95%CI	p value
24.50	24.16, 25.44	0.53

Table C.2: **Healthy behaviour changes reported by participants of the urban horticulturalists' survey**. Table shows horticulturalists self−reported change in lifestyle behaviours compared to a reference value of change (20%). I reported the percentage of change, the 95% interval, and the p value.

Percentage of self−reported change	95%CI	p value
Fruit and vegetable intake changed after participation in urban agriculture		
53%	49%, 55%	≤ 0.001
Physical activity changed after participation in urban agriculture		
71%	67%, 75%	≤ 0.001
Socialising more after participation in urban agriculture		
68%	64%, 72%	≤ 0.001
Interacting more with greenspaces after participation in urban agriculture		
80%	76%, 84%	≤ 0.001

Table C.3: **Healthy behaviour changes reported by participants of the urban horticulturalists' survey**. Table shows if the type of urban agriculture is associated with self−reported change in lifestyle behaviours. I included the 95% interval, and the p value of the chi−square test

Self−reported change	**Allotments**	**Allotments and backyards**	**Backyards**	**Community garden or other**	**Three types of urban agriculture**	**Unknown**	**p value**
	n = 283	n = 77	n = 62	n = 40	n = 35	n = 128	
Fruit and vegetable intake changed after participation in urban agriculture							
Yes	137 (51%)	43 (56%)	36 (54%)	24 (56%)	17 (51%)	85 (52%)	0.172
Physical activity changed after participation in urban agriculture							
Yes	180 (67%)	54 (70%)	42 (69%)	25 (64%)	24 (69%)	98 (80%)	0.084
Socialising more after participation in urban agriculture							
Yes	169 (64%)	53 (69%)	44 (73%)	26 (67%)	27 (77%)	82 (67%)	0.210
Interacting more with greenspaces after participation in urban agriculture							
Yes	217 (82%)	63 (82%)	48 (80%)	29 (74%)	24 (69%)	95 (77%)	0.104

Table C.4: **GLMs' results: Lifestyle behaviours and health and well-being markers by type of agriculture (Complete table) reported by participants of the urban horticulturalists' survey** . The table shows the results of the models for lifestyle behaviours and health and well-being markers by type of agriculture (BMI, fruits and vegetable intake, time spent outdoors, self−health assessment, happiness, medication intake, and loneliness). Each model has the R^2, the estimated coefficient (β), or the estimated odds ratio (OR) for the logistic and ordinal logistic models, the 95% confidence interval, and the p value.

	Estimated coefficient	**95% CI**	**p value**
BMI (R^2 = ***0.44***)			
Type of agriculture (reference = Allotments)			
Allotments and backyards	2.3160	0.129, 4.503	0.0387
Backyards	−0.5735	−2.879, 1.732	0.6262
Community garden or other	−1.1949	−4.243, 1.854	0.4429
Three types of urban agriculture	−2.3589	−5.322, 0.604	0.1196
Unknown	−0.1454	−2.011, 1.720	0.8787
Highest educational qualifications (reference = None of the above)			
18 above no degree	1.1506	−3.600, 5.901	0.6353
College or university degree	−0.9610	−5.490, 3.568	0.6778
education until 16	1.2633	−3.703, 6.230	0.6184
Age (reference = 18−29)			
30−44	−0.2569	−3.570, 3.056	0.8793
45−69	0.7535	−2.284, 3.791	0.6272
More than 70	−0.8539	−4.218, 2.510	0.6192
Gender (reference = Female)			
Male	0.87	0.403, 2.171	0.02
Smoker (reference = Never)			
Only occasionally	−1.6243	−4.823, 1.574	0.3203

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	Estimated coefficient	95% CI	p value
Yes, on most or all days	0.5458	−1.790, 2.882	0.6473
Self−health assessment (R^2 = NA)			
Type of agriculture (reference = Allotments)			
Allotments and backyards	(OR) 0.988	0.503, 1.939	0.972
Backyards	(OR) 0.679	0.308, 1.494	0.336
Community garden or other	(OR) 1.889	1.301, 2.625	0.0315
Three types of urban agriculture	(OR) 2.297	1.500, 4.557	≤ 0.001
Unknown	(OR) 0.717	0.402, 1.279	0.260
Highest educational qualifications (reference = None of the above)			
18 above no degree	(OR) 1.054	0.250, 4.439	0.943
College or university degree	(OR) 1.343	0.343, 5.268	0.672
education until 16	(OR) 0.631	0.140, 2.841	0.548
Age (reference = 18−29)			
30−44	(OR) 2.851	1.050, 7.741	0.040
45−69	(OR) 1.668	0.682, 4.077	0.262
More than 70	(OR) 2.788	1.013, 7.669	0.047
Gender (reference = Female)			
Male	(OR) 1.226	0.782, 1.923	0.374
Smoker (reference = Never)			
Only occasionally	(OR) 0.785	0.276, 2.234	0.650
Yes, on most or all days	(OR) 0.265	0.131, 0.536	0.001
Happiness (R^2 = NA)			
Type of agriculture (reference = Allotments)			
Allotments and backyards	(OR) 0.566	0.503, 1.939	0.972

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	Estimated coefficient	95% CI	p value
Backyards	(OR) 0.519	0.308, 1.494	0.336
Community garden or other	(OR) 0.610	0.405, 2.439	0.988
Three types of urban agriculture	(OR) 1.177	0.452, 2.855	0.786
Unknown	(OR) 0.858	0.402, 1.279	0.260
Highest educational qualifications (reference = None of the above)			
18 above no degree	(OR) 0.764	0.183, 3.196	0.713
College or university degree	(OR) 1.306	0.292, 5.841	0.727
education until 16	(OR) 0.792	0.168, 3.738	0.768
Age (reference = 18−29)			
30−44	(OR) 0.850	0.300, 2.406	0.759
45−69	(OR) 1.084	0.418, 2.812	0.868
More than 70	(OR) 2.542	0.885, 7.301	0.083
Gender (reference = Female)			
Male	(OR) 1.297	0.821, 2.048	0.265
Smoker (reference = Never)			
Only occasionally	(OR) 0.434	0.153, 1.236	0.118
Yes, on most or all days	(OR) 0.520	0.248, 0.901	0.048
Loneliness*(R^2 *= 0.53)			
Type of agriculture (reference = Allotments)			
Allotments and backyards	(OR) 0.692	0.241, 1.989	0.49
Backyards	(OR) 1.479	0.557, 3.929	0.43
Community garden or other	(OR) 0.899	0.228, 3.537	0.87

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	Estimated coefficient	95% CI	p value
Three types of urban agriculture	(OR) 0.059	0.107, 2.863	0.78
Unknown	(OR) 1.607	0.738, 3.498	0.23
Highest educational qualifications (reference = None of the above)			
18 above no degree	(OR) 0.794	0.209, 3.009	0.73
College or university degree	(OR) 1.088	0.470, 2.520	0.84
education until 16	(OR) 0.829	0.218, 3.860	0.88
Age (reference = 18−29)			
30−44	(OR) 0.749	0.192, 2.916	0.67
45−69	(OR) 0.820	0.234, 2.870	0.75
More than 70	(OR) 0.214	0.040, 1.154	0.07
Gender (reference = Female)			
Male	(OR) 0.540	0.263, 1.108	0.09
Smoker (reference = Never)			
Only occasionally	(OR) 1.101	0.274, 4.433	0.89
Yes, on most or all days	(OR) 1.578	0.627, 3.974	0.33
Medication intake(R^2 = 0.66)			
Type of agriculture (reference = Allotments)			
Allotments and backyards	(OR) 0.854	0.325, 2.246	0.74
Backyards	(OR) 1.083	0.399, 2.938	0.87
Community garden or other	(OR) 1.006	0.293, 3.458	0.99
Three types of urban agriculture	(OR) 0.642	0.184, 2.235	0.48
Unknown	(OR) 0.820	0.368, 1.828	0.62
Highest educational qualifications (reference = None of the above)			

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	Estimated coefficient	95% CI	p value
18 above no degree	(OR) 3.724	0.359, 5.646	0.27
College or university degree	(OR) 1.266	0.592, 2.711	0.54
education until 16	(OR) 0.590	0.209, 1.668	0.31
Age (reference = 18−29)			
30−44	(OR) 1.478	0.123, 3.819	0.75
45−69	(OR) 0.312	0.039, 2.499	0.27
More than 70	(OR) 2.89	1.310, 3.317	0.02
Gender (reference = Female)			
Male	(OR) 0.541	0.300, 0.978	0.04
Smoker (reference = Never)			
Only occasionally	(OR) 1.862	0.211, 6.413	0.57
Yes, on most or all days	(OR) 1.442	1.181, 2.080	0.03
Fruit and vegetable intake (R^2 = 0.52)			
Type of agriculture (reference = Allotments)			
Allotments and backyards	0.54	−0.562, 1.652	0.33
Backyards	0.67	−0.520, 1.867	0.26
Community garden or other	1.894	1.413, 3.376	0.012
Three types of urban agriculture	2.074	1.092, 3.413	0.032
Unknown	0.69	−0.249, 1.641	0.14
Highest educational qualifications (reference = None of the above)			
18 above no degree	0.92	−1.824, 3.680	0.50
College or university degree	0.14	−0.805, 1.086	0.77
education until 16	−0.42	−1.848, 0.992	0.55
Age (reference = 18−29)			

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	Estimated coefficient	95% CI	p value
30−44	2.28	0.603, 3.969	0.04
45−69	1.28	−0.252, 2.828	0.10
More than 70	1.46	0.246, 3.171	0.03
Gender (reference = Female)			
Male	0.11	−0.613, 0.843	0.75
Smoker (reference = Never)			
Only occasionally	0.30	−1.314, 1.923	0.71
Yes, on most or all days	−0.03	−1.217, 1.152	0.95
Physical activity (R^2 = 0.52)			
Allotments and backyards	0.54	−5.581, 2.971	0.916
Backyards	0.67	−0.347, 4.050	0.248
Community garden or other	1.89	−3.174, 3.781	0.621
Three types of urban agriculture	−0.07	−4.677, 4.077	0.297
Unknown	0.69	−4.969, 3.452	0.143
Highest educational qualifications (reference = None of the above)			
18 above no degree	0.92	−6.692, 6.921	0.771
College or university degree	0.14	−3.768, 2.155	0.543
education until 16	−0.42	−4.683, 5.098	0.098
Age (reference = 18−29)			
30−44	2.28	−1.969, 2.302	0.678
45−69	1.28	−9.883, 3.476	0.935
More than 70	1.46	−8.855, 4.161	0.730
Gender (reference = Female)			
Male	17.44	12.38, 30.530	0.02

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	Estimated coefficient	95% CI	p value
Smoker (reference = Never)			
Only occasionally	−24.52	−37.446, −15.267	0.037
Yes, on most or all days	−22.03	−42.656, −13.041	0.042
Time outdoors in summer (R^2 = 0.51)			
Allotments and backyards	0.54	−0.575, 0.891	0.67
Backyards	0.67	−0.741, 0.856	0.88
Community garden or other	1.89	−1.185, 0.952	0.83
Three types of urban agriculture	0.237	0.148, 1.032	0.048
Unknown	0.69	−0.710, 0.555	0.81
Highest educational qualifications (reference = None of the above)			
18 above no degree	0.92	−0.268, 4.043	0.08
College or university degree	0.14	−0.570, 0.729	0.81
education until 16	−0.42	−0.102, 1.771	0.08
Age (reference = 18−29)			
30−44	2.28	−1.538, 0.883	0.59
45−69	1.28	−1.326, 0.879	0.69
More than 70	1.46	−1.311, 1.114	0.87
Gender (reference = Female)			
Male	0.11	−0.677, 0.319	0.48
Smoker (reference = Never)			
Only occasionally	1.12	0.43, 1.824	0.27
Yes, on most or all days	−0.03	0.047, 1.657	0.03

Appendix D

Relevant information complementing Chapter 6

This appendix complements the information in **Chapter 6** by including the complete tables obtained from the GLMs.

Table D.1: **GLMs' results: Lifestyle behaviours (Fruit and vegetable intake, Moderate physical activity,Vigorous physical activity, and Hours outdoors in summer); UK Biobank participants vs respondents of the urban horticulturalists' survey (Complete table)**. Differences in lifestyle behaviours between the UK Biobank participants (reference) and the urban horticulturalists. The table show the estimated coefficient, the 95% confidence interval, and the p value.

Characteristic	Estimated coefficient	95% CI	p value
Fruit and vegetable intake portions/day			
Sample (reference = UK Biobank participants)			
Horticulturalists	1.367	1.202, 1.533	< 0.001
Sex (reference = Female)			
Male	−0.460	−0.472, −0.449	< 0.001
Highest qualification (reference = College or university degree)			

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Characteristic	Estimated coefficient	95% CI	p value
None of the above	−0.150	−0.167, −0.132	< 0.001
Education until 16	−0.250	−0.265, −0.235	< 0.001
18 above no degree	−0.129	−0.145, −0.114	< 0.001
Smoking status (reference = No)			
Only occasionally	−0.200	−0.235, −0.165	< 0.001
Yes, on most or all days	−0.864	−0.886, −0.842	< 0.001
Moderate physical activity min/day			
Sample (reference = UK Biobank participants)			
Horticulturalists	16.312	10.147, 26.476	< 0.001
Sex (reference = Female)			
Male	5.965	5.468, 6.462	< 0.001
Highest qualification (reference = College or university degree)			
None of the above	29.932	29.160, 30.703	< 0.001
Education until 16	19.830	19.192, 20.468	< 0.001
18 above no degree	15.859	15.201, 16.517	< 0.001
Smoking status (reference = No)			
Only occasionally	−0.308	−1.814, 1.197	0.688
Yes, on most or all days	8.888	7.909, 9.868	< 0.001
Vigorous physical activity min/day			
Sample (reference = UK Biobank participants)			
Horticulturalists	−9.529	−11.365, −7.694	< 0.001
Sex (reference = Female)			
Male	6.237	5.877, 6.598	< 0.001
Highest qualification (reference = College or university degree)			

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Characteristic	Estimated coefficient	95% CI	p value
None of the above	13.546	12.963, 14.129	< 0.001
Education until 16	7.183	6.723, 7.642	< 0.001
18 above no degree	4.959	4.486, 5.432	< 0.001
Smoking status (reference = No)			
Only occasionally	1.202	0.119, 2.285	0.030
Yes, on most or all days	5.901	5.130, 6.673	< 0.001
Hours outdoors in summer hours/day			
Sample (reference = UK Biobank participants)			
Horticulturalists	1.043	0.846,1.239	< 0.001
Sex (reference = Female)			
Male	0.780	0.767, 0.794	< 0.001
Highest qualification (reference = College or university degree)			
None of the above	1.221	1.201, 1.241	< 0.001
Education until 16	0.723	0.706, 0.741	< 0.001
18 above no degree	0.607	0.589, 0.625	< 0.001
Smoking status (reference = No)			
Only occasionally	0.136	0.095, 0.177	< 0.001
Yes, on most or all days	0.280	0.254, 0.305	< 0.001

Table D.2: **GLMs' results: Health and well-being markers (Body Mass Index, Medication intake, Loneliness, Happiness, Self-health assessment); UK Biobank participants vs respondents of the urban horticulturalists' survey (Complete table)**. Differences in health and well−being markers between the UK Biobank participants (reference) and the urban horticulturalists'. The table show the odds ratio (OR) 95% confidence interval, and the p value.

Characteristic	OR	95% CI	p value
Body Mass Index (reference = Healthy)			
Sample (reference = UK Biobank participants)			
Horticulturalists	0.654	0.555, 0.770	< 0.001
Sex (reference = Female)			
Male	1.810	1.782, 1.838	< 0.001
Highest qualification (reference = College or university degree)			
None of the above	1.995	1.945, 2.046	< 0.001
Education until 16	1.557	1.527, 1.588	< 0.001
18 above no degree	1.485	1.456, 1.514	< 0.001
Smoking status (reference = No)			
Only occasionally	1.014	1.007, 1.018	< 0.001
Yes, on most or all days	0.985	0.919, 0.992	< 0.001
Fruit and vegetable intake portions/day	1.018	10003, 1.105	< 0.001
Moderate physical activity min/day	1.014	0.970, 1.060	0.533
Vigorous physical activity min/day	1.032	1.028, 1.045	< 0.001

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Characteristic	OR	95% CI	p value	
Time spent outdoors in summer hours/day	0.777	0.752, 0.803	< 0.001	
Medication intake (reference = None of the above)				
Sample (reference = UK Biobank participants)				
Horticulturalists	0.257	0.250, 0.264	< 0.001	
Sex (reference = Female)				
Male	1.048	1.029, 1.068	< 0.001	
Highest qualification (reference = College or university degree)				
None of the above	1.995	2.161	2.100, 2.223	< 0.001
Education until 16	1.557	1.215	1.187, 1.244	< 0.001
18 above no degree	1.485	1.350	1.319, 1.383	< 0.001
Smoking status (reference = No)				
Only occasionally	0.800	0.756, 0.846	< 0.001	
Yes, on most or all days	0.830	0.798, 0.863	< 0.001	
Fruit and vegetable intake portions/day	1.037	1.032, 1.041	< 0.001	
Moderate physical activity min/day	1.182	0.872, 1.249	0.291	
Vigorous physical activity min/day	0.698	0.432, 0.975	< 0.001	
Time spent outdoors in summer hours/day	1.034	1.011, 1.048	< 0.001	

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Characteristic	OR	95% CI	p value
Loneliness (reference = No)			
Sample (reference = UK Biobank participants)			
Horticulturalists	1.001	0.795, 1.260	0.64
Sex (reference = Female)			
Male	0.654	0.540, 0.669	< 0.001
Highest qualification (reference = College or university degree)			
None of the above	1.534	1.481, 1.589	< 0.001
Education until 16	1.252	1.217, 1.288	< 0.001
18 above no degree	1.172	1.138, 1.207	< 0.001
Smoking status (reference = No)			
Only occasionally	1.449	1.364, 1.539	< 0.001
Yes, on most or all days	1.845	1.771, 1.921	< 0.001
Fruit and vegetable intake portions/day	0.987	0.982, 0.992	< 0.001
Moderate physical activity min/day	0.921	0.721, 1.084	0.098
Vigorous physical activity min/day	0.717	0.609, 0.921	< 0.001
Time spent outdoors in summer hours/day	0.982	0.680, 0.995	< 0.001
Happiness (reference = Extremely unhappy)			
Sample (reference = UK Biobank participants)			
Horticulturalists	0.454	0.388, 0.530	< 0.001

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Characteristic	OR	95% CI	p value
Sex (reference = Female)			
Male	1.011	0.986, 1.038	0.391
Highest qualification (reference = College or university degree)			
None of the above	1.315	1.240, 1.395	< 0.001
Education until 16	1.145	1.108, 1.184	< 0.001
18 above no degree	1.078	1.043, 1.113	< 0.001
Smoking status (reference = No)			
Only occasionally	0.812	0.749, 0.881	< 0.001
Yes, on most or all days	0.554	0.518, 0.593	< 0.001
Fruit and vegetable intake portions/day	1.048	1.031, 1.065	< 0.001
Moderate physical activity min/day	0.940	0.740, 1.159	0.288
Vigorous physical activity min/day	0.839	0.617, 1.131	0.106
Time spent outdoors in summer hours/day	1.077	1.020, 1.083	< 0.001
Self−health assessment (reference = Poor)			
Sample (reference = UK Biobank participants)			
Horticulturalists	0.584	0.495, 0.688	< 0.001
Sex (reference = Female)			
Male	0.820	0.807, 0.834	< 0.001
Highest qualification (reference = College or university degree)			

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Characteristic	OR	95% CI	p value
None of the above	0.415	0.404, 0.426	< 0.001
Education until 16	0.622	0.610, 0.635	< 0.001
18 above no degree	0.681	0.667, 0.696	< 0.001
Smoking status (reference = No)			
Only occasionally	0.762	0.727, 0.799	< 0.001
Yes, on most or all days	0.428	0.414, 0.443	< 0.001
Fruit and vegetable intake portions/day	1.048	1.031, 1.065	< 0.001
Moderate physical activity min/day	1.167	1.108, 1.212	< 0.001
Vigorous physical activity min/day	1.006	1.002, 1.036	< 0.001
Time spent outdoors in summer hours/day	1.077	1.038, 1.103	< 0.001

Appendix E

Relevant information complementing 7

E.1 Model 1: Single exposure models

This appendix complements the information in **Chapter 7** by including the complete tables obtained from the GLMs. Due to the length of the tables with interactions, these tables do not show the outcomes for the confounders.

E.1.1 Body Max Index (BMI)

Table E.1: **Single exposure model: BMI**. Single association between physical activity, fruit and vegetable intake, and greenspace exposure and BMI (n = 204,478). Categories were Healthy, Overweight, and Obese (reference = Healthy

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	0.662	0.647, 0.678	≤ 0.001
High	0.522	0.510, 0.535	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			

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Exposure variable (increment)	**OR**	**95% CI**	**p adjusted**
5 or more portions of fruit and vegetable	1.040	1.022, 1.059	≤ 0.001
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	1.126	1.100, 1.154	≤ 0.001
Quartile 3	1.146	1.118, 1.174	≤ 0.001
Quartile 4	1.057	1.031, 1.083	≤ 0.001

E.1.2 Self-health assessment

Table E.2: **Single exposure model: Self-health assessment**. Single association between physical activity, fruit and vegetable intake, and greenspace exposure and self-health assessment (n = 204,478). Categories were Poor, Fair, Good, and Excellent (reference = Poor).

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	1.795	1.751, 1.840	≤ 0.001
High	2.877	2.805, 2.950	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			
5 or more portions of fruit and vegetable	1.275	1.250, 1.299	≤ 0.001
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	0.921	0.898, 0.945	≤ 0.001
Quartile 3	0.934	0.910, 0.958	≤ 0.001
Quartile 4	1.003	0.977, 1.030	0.869

E.1.3 Blood pressure

Table E.3: **Single exposure model: Blood pressure**. Single association between physical activity, fruit and vegetable intake, and greenspace exposure and blood pressure (n = 204,478). Categories were Healthy, High (reference = Healthy).

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	0.979	0.947, 1.012	0.226
High	0.894	0.865, 0.924	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			
5 or more portions of fruit and vegetable	0.960	0.935, 0.985	0.003
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	1.093	1.055, 1.131	≤ 0.001
Quartile 3	1.133	1.094, 1.173	≤ 0.001
Quartile 4	1.069	1.031, 1.108	≤ 0.001

E.1.4 Loneliness

Table E.4: **Single exposure model: Loneliness**. Single association between physical activity, fruit and vegetable intake, and greenspace exposure and loneliness (n = 204,478). Categories were No, Yes (reference = No).

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	0.732	0.693, 0.773	≤ 0.001
High	0.687	0.650, 0.726	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			
5 or more portions of fruit and vegetable	0.876	0.836, 0.919	≤ 0.001
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	0.979	0.924, 1.038	0.477
Quartile 3	0.936	0.881, 0.994	0.036
Quartile 4	0.888	0.833, 0.945	≤ 0.001

E.2 Model 2: Multi-exposure confounding model, no interactions between explanatory variables

E.2.1 Body Max Index (BMI)

Table E.5: **Multi-exposure confounding model: BMI**. Multi-exposure association between physical activity, fruit and vegetable intake, and greenspace exposure and BMI, without interactions (n = 204,478). Categories were Healthy, Overweight, and Obese (reference = Healthy).

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	0.660	0.645, 0.676	≤ 0.001
High	0.515	0.503, 0.527	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			
5 or more portions of fruit and vegetable	1.110	1.089, 1.130	≤ 0.001
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	1.117	1.090, 1.144	≤ 0.001
Quartile 3	1.136	1.109, 1.164	≤ 0.001
Quartile 4	1.045	1.019, 1.071	0.001

E.2.2 Self-health assessment

Table E.6: **Multi-exposure confounding model: Self-health assessment**. Multi-exposure association between physical activity, fruit and vegetable intake, and greenspace exposure and self-health assessment, without interactions (n = 204,478). Categories were Poor, Fair, Good, and Excellent (reference = Poor).

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	1.780	1.737, 1.824	≤ 0.001
High	2.814	2.744, 2.886	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			
5 or more portions of fruit and vegetable	1.155	1.133, 1.178	≤ 0.001
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	0.936	0.912, 0.959	≤ 0.001
Quartile 3	0.949	0.925, 0.974	≤ 0.001
Quartile 4	1.025	0.999, 1.052	0.065

E.2.3 Blood pressure

Table E.7: **Multi-exposure confounding model: Blood pressure**. Multi-exposure association between physical activity, fruit and vegetable intake, and greenspace exposure and blood pressure, without interactions (n = 204,478). Categories were Healthy, High (reference = Healthy).

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	0.983	0.951, 1.016	0.326
High	0.899	0.870, 0.930	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			
5 or more portions of fruit and vegetable	0.973	0.947, 0.999	0.050
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	1.091	1.054, 1.130	≤ 0.001
Quartile 3	1.132	1.093, 1.172	≤ 0.001
Quartile 4	1.067	1.029, 1.106	0.001

E.2.4 Loneliness

Table E.8: **Multi-exposure confounding model: Loneliness**. Multi-exposure association between physical activity, fruit and vegetable intake, and greenspace exposure and loneliness, without interactions (n = 204,478). Categories were No and Yes (reference = No).

Exposure variable (increment)	OR	95% CI	p adjusted
Physical activity (reference = Low)			
Moderate	0.734	0.695, 0.775	≤ 0.001
High	0.696	0.658, 0.735	≤ 0.001
Fruit and vegetable intake (reference = Less than 5 portions)			
5 or more portions of fruit and vegetable	0.904	0.861, 0.948	≤ 0.001
Greenspace exposure in quartiles (reference = Quartile 1)			
Quartile 2	0.971	0.916, 1.029	0.322
Quartile 3	0.928	0.874, 0.986	0.018
Quartile 4	0.878	0.825, 0.936	≤ 0.001

E.3 Model 3: Multiple-exposure with interactions between the explanatory variable

Table E.9: **Multi-exposure model with interactions, n = 204,478 (Complete table)**. Odds Ratio (OR) with 95% bootstrap confidence intervals (bCIs), and Benjamini & Hochberg adjusted p value of greenspace exposure at a 100m buffer (reference = Quartile 1), physical activity levels (reference = Low), fruits and vegetables intake (reference = Less than 5 portions), and the interactions between these variables for BMI (reference = Healthy), self-health assessment (reference = Poor), blood pressure (reference = Healthy), loneliness (reference = No). All models were adjusted for sex, age, highest educational qualification, ethnicity, Index of Multiple Deprivation, and smoking.

Exposure variable (increment)	OR	95% CI	p ajusted
Body Max Index (BMI) (reference = Healthy)			
Fruit and vegetable intake (reference = Less than 5 portions)			
Meets fruit and vegetable	1.169	1.062, 1.287	0.003
Greenspace exposure; 100 m buffet (reference = Quartile 1)			
Greenspace Q2	1.049	0.984, 1.118	0.249
Greenspace Q3	1.077	1.010, 1.149	0.047
Greenspace Q4	0.967	0.907, 1.030	0.372
Physical activity levels; IPAQ (reference = Low)			
Moderate physical activity	0.639	0.604, 0.675	< 0.001
High physical activity	0.509	0.480, 0.538	< 0.001
Interaction between fruit and vegetable and greenspace			
Meets fruit and vegetable; Greenspace Q2	1.005	0.880, 1.148	0.973
Meets fruit and vegetable; Greenspace Q3	1.031	0.903, 1.178	0.738
Meets fruit and vegetable; Greenspace Q4	0.998	0.874, 1.139	0.975
Interaction between fruit and vegetable and physical activity			

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Exposure variable (increment)	OR	95% CI	p ajusted
Meets fruit and vegetable; Moderate physical activity	0.937	0.838, 1.047	0.335
Meets fruit and vegetable; High physical activity	0.851	0.763, 0.950	0.009
Interaction between greenspace and physical activity			
Greenspace Q2; Moderate physical activity	1.056	0.977, 1.141	0.280
Greenspace Q3: Moderate physical activity	1.046	0.968, 1.130	0.335
Greenspace Q4: Moderate physical activity	1.071	0.992, 1.157	0.146
Greenspace Q2; High physical activity	1.049	0.969, 1.135	0.335
Greenspace Q3: High physical activity	1.023	0.945, 1.108	0.689
Greenspace Q4: High physical activity	1.077	0.995, 1.166	0.130
Interaction between fruit and vegetable intake, greenspace and physical activity			
Meets fruit and vegetable; Greenspace Q2; Moderate physical activity	1.018	0.871, 1.189	0.898
Meets fruit and vegetable; Greenspace Q3: Moderate physical activity	1.005	0.861, 1.175	0.973
Meets fruit and vegetable; Greenspace Q4: Moderate physical activity	1.037	0.888, 1.211	0.738
Meets fruit and vegetable; Greenspace Q2; High physical activity	1.108	0.950, 1.292	0.303
Meets fruit and vegetable; Greenspace Q3: High physical activity	1.096	0.941, 1.278	0.335
Meets fruit and vegetable; Greenspace Q4: High physical activity	1.099	0.943, 1.280	0.335
Self-health assessmet (reference = Poor)			
Fruit and vegetable intake (reference = Less than 5 portions)			

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Exposure variable (increment)	OR	95% CI	p ajusted
Meets fruit and vegetable	1.030	0.932, 1.138	0.637
Greenspace exposure; 100 m buffet (reference = Quartile 1)			
Greenspace Q2	0.980	0.917, 1.046	0.629
Greenspace Q3	1.006	0.941, 1.074	0.869
Greenspace Q4	1.140	1.067, 1.218	< 0.001
Physical activity levels; IPAQ (reference = Low)			
Moderate physical activity	1.801	1.700, 1.907	< 0.001
High physical activity	3.009	2.835, 3.193	< 0.001
Interaction between fruit and vegetable and greenspace			
Meets fruit and vegetable; Greenspace Q2	1.135	0.988, 1.303	0.122
Meets fruit and vegetable; Greenspace Q3	1.028	0.895, 1.180	0.728
Meets fruit and vegetable; Greenspace Q4	1.068	0.929, 1.228	0.425
Interaction between fruit and vegetable and physical activity			
Meets fruit and vegetable; Moderate physical activity	1.166	1.038, 1.309	0.019
Meets fruit and vegetable; High physical activity	1.183	1.055, 1.327	0.008
Interaction between greenspace and physical activity			
Greenspace Q2; Moderate physical activity	0.985	0.909, 1.067	0.728
Greenspace Q3: Moderate physical activity	0.980	0.905, 1.062	0.682
Greenspace Q4: Moderate physical activity	0.951	0.878, 1.031	0.308
Greenspace Q2; High physical activity	0.903	0.832, 0.981	0.030
Greenspace Q3: High physical activity	0.920	0.847, 0.999	0.041
Greenspace Q4: High physical activity	0.842	0.775, 0.915	< 0.001
Interaction between fruit and vegetable intake, greenspace and physical activity			

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Exposure variable (increment)	OR	95% CI	p ajusted
Meets fruit and vegetable; Greenspace Q2; Moderate physical activity	0.839	0.713, 0.987	0.048
Meets fruit and vegetable; Greenspace Q3: Moderate physical activity	0.918	0.781, 1.080	0.377
Meets fruit and vegetable; Greenspace Q4: Moderate physical activity	0.864	0.734, 1.017	0.124
Meets fruit and vegetable; Greenspace Q2; High physical activity	0.897	0.764, 1.053	0.264
Meets fruit and vegetable; Greenspace Q3: High physical activity	0.916	0.780, 1.074	0.360
Meets fruit and vegetable; Greenspace Q4: High physical activity	0.880	0.749, 1.034	0.179
Blood pressure (reference = Healthy)			
Fruit and vegetable intake (reference = Less than 5 portions)			
Meets fruit and vegetable	1.095	0.958, 1.253	0.241
Greenspace exposure; 100 m buffet (reference = Quartile 1)			
Greenspace Q2	1.088	0.994, 1.190	0.120
Greenspace Q3	1.199	1.097, 1.311	< 0.001
Greenspace Q4	1.045	0.954, 1.145	0.388
Physical activity levels; IPAQ (reference = Low)			
Moderate physical activity	1.023	0.945, 1.108	0.603
High physical activity	0.896	0.825, 0.974	0.032
Interaction between fruit and vegetable and greenspace			
Meets fruit and vegetable; Greenspace Q2	0.830	0.687, 1.003	0.114
Meets fruit and vegetable; Greenspace Q3	0.850	0.706, 1.024	0.134
Meets fruit and vegetable; Greenspace Q4	0.884	0.732, 1.068	0.252

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Exposure variable (increment)	OR	95% CI	p ajusted
Interaction between fruit and vegetable and physical activity			
Meets fruit and vegetable; Moderate physical activity	0.835	0.713, 0.979	0.067
Meets fruit and vegetable; High physical activity	0.862	0.737, 1.008	0.120
Interaction between greenspace and physical activity			
Greenspace Q2; Moderate physical activity	0.964	0.864, 1.076	0.562
Greenspace Q3: Moderate physical activity	0.912	0.818, 1.016	0.142
Greenspace Q4: Moderate physical activity	0.974	0.873, 1.087	0.654
Greenspace Q2; High physical activity	1.062	0.949, 1.189	0.358
Greenspace Q3: High physical activity	0.926	0.828, 1.036	0.241
Greenspace Q4: High physical activity	1.026	0.916, 1.150	0.654
Interaction between fruit and vegetable intake, greenspace and physical activity			
Meets fruit and vegetable; Greenspace Q2; Moderate physical activity	1.248	0.999, 1.559	0.114
Meets fruit and vegetable; Greenspace Q3: Moderate physical activity	1.317	1.058, 1.639	0.043
Meets fruit and vegetable; Greenspace Q4: Moderate physical activity	1.226	0.982, 1.532	0.123
Meets fruit and vegetable; Greenspace Q2; High physical activity	1.187	0.953, 1.479	0.179
Meets fruit and vegetable; Greenspace Q3: High physical activity	1.211	0.975, 1.505	0.134
Meets fruit and vegetable; Greenspace Q4: High physical activity	1.275	1.023, 1.589	0.074
Loneliness (reference = No)			

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Exposure variable (increment)	OR	95% CI	p ajusted
Fruit and vegetable intake (reference = Less than 5 portions)			
Meets fruit and vegetable	1.161	0.966, 1.394	0.150
Greenspace exposure; 100 m buffet (reference = Quartile 1)			
Greenspace Q2	0.952	0.836, 1.085	0.525
Greenspace Q3	0.858	0.749, 0.983	0.047
Greenspace Q4	0.736	0.638, 0.849	< 0.001
Physical activity levels; IPAQ (reference = Low)			
Moderate physical activity	0.687	0.611, 0.772	< 0.001
High physical activity	0.679	0.602, 0.766	< 0.001
Interaction between fruit and vegetable and greenspace			
Meets fruit and vegetable; Greenspace Q2	0.729	0.552, 0.963	0.047
Meets fruit and vegetable; Greenspace Q3	0.799	0.602, 1.062	0.160
Meets fruit and vegetable; Greenspace Q4	0.911	0.679, 1.222	0.567
Interaction between fruit and vegetable and physical activity			
Meets fruit and vegetable; Moderate physical activity	0.746	0.590, 0.943	0.030
Meets fruit and vegetable; High physical activity	0.695	0.553, 0.874	0.004
Interaction between greenspace and physical activity			
Greenspace Q2; Moderate physical activity	1.068	0.902, 1.264	0.523
Greenspace Q3: Moderate physical activity	1.134	0.953, 1.349	0.196
Greenspace Q4: Moderate physical activity	1.283	1.071, 1.537	0.016
Greenspace Q2; High physical activity	0.995	0.837, 1.183	0.957
Greenspace Q3: High physical activity	1.059	0.886, 1.266	0.567
Greenspace Q4: High physical activity	1.181	0.980, 1.423	0.120

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Exposure variable (increment)	OR	95% CI	p ajusted
Interaction between fruit and vegetable intake, greenspace and physical activity			
Meets fruit and vegetable; Greenspace Q2; Moderate physical activity	1.402	0.989, 1.988	0.089
Meets fruit and vegetable; Greenspace Q3: Moderate physical activity	1.253	0.877, 1.791	0.262
Meets fruit and vegetable; Greenspace Q4: Moderate physical activity	1.042	0.720, 1.507	0.854
Meets fruit and vegetable; Greenspace Q2; High physical activity	1.489	1.057, 2.096	0.046
Meets fruit and vegetable; Greenspace Q3: High physical activity	1.468	1.037, 2.078	0.049
Meets fruit and vegetable; Greenspace Q4: High physical activity	1.367	0.955, 1.955	0.124

[a] Cells in white were significant

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