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Beyond the Community Garden
Investigating strategies to reduce the environmental impact of urban areas in New Zealand

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Abstract
The object of this research was to identify and test community gardening strategies that could reduce the environmental impact of urban areas in New Zealand. Two established community gardens were chosen as case studies for this investigation: Island Bay / Berhampore Community Orchard and Stan's Edible Garden. The existing conditions of each case study were mapped and evaluated using metrics established from literature. Case study one used 1.75% and case study two 0.08% of the area of the parks within which they are located. Of this percentage, the existing conditions of case study one meant it was only using 13% for food growing. Similarly case study two was only using 22% of the available community garden area to grow produce. Next, strategies that retained the overall area of each existing CG were mapped to determine how much produce could be grown to supply the local population (within a 400m/5min minute walking zone). Supplying produce locally means that people will collect their fruit and vegetables from their nearest community garden rather than having them supplied conventionally, which means collect them from the nearest supermarket. There is fewer greenhouse gas emissions associated with locally supplied produce as conventional supply has to ship produce from different growing regions around the world, these emissions are called food miles. By maximising efficiency of each case study garden, 85% of the CG area for case study one and 66% for case study two was productive when maximising for vegetables and 96% for case study one and 89% for case study two when maximising for fruit. The strategy "maximum vegetable patches" was able to meet 16.36% of case study one's and 0.59% of case study two's vegetable demands The strategy "maximum fruit trees" was able to meet 10.40% of case study one's and 0.43% of case study two's fruit demands for the local population as defined above. To meet the demands for the whole population within this walking zone, the Island Bay / Berhampore Community Orchard would need to occupy 26.53% of Martin Lucky Park and Stan's Edible Garden would need to occupy 32.99% of Macalister Park.

Next, greenhouse gas emissions reduction strategies were mapped for the total area designated to community gardening within Wellington City, New Zealand to determine the value of net annual stored carbon for each strategy. Converting this total area to lawn stored 0tCO_2-e, converting the same area to maximum fruit and vegetables stored 8.48tCO_2-e, converting to native New Zealand forest stored 23.05tCO_2-e, converting to macrocarpa forest stored 10.94tCO_2-e and converting to radiata pine forest stored 56.09tCO_2-e. These finding suggest that planting urban forests are a more effective strategy at reducing urban environmental impact than cultivating fruit and vegetables to supply produce locally. These findings also suggest that a radiata pine forest is the most effective urban forest for sequestering carbon. What these findings do not consider is the lost social, economic and environmental benefits if the total area designated to community gardening were converted to urban forests. These findings also do not consider the disadvantages, such as loss of biodiversity, associated with converting this area to radiata pine forest.

Preface
This report presents the findings of the joint research project 'Beyond the Community Garden'. The project built on results from a 2018/19 investigation into possible strategies for facilitating community gardens in Wellington, New Zealand.

The current study aims to identify successful methods of 1) assessing the efficiency of community gardening spaces using measurable criteria and 2) determine strategies that are able to effectively reduce urban environmental impact.

Acknowledgments

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Notes

This report is intended to aid designers in incorporating community gardens into future building developments within New Zealand. Having measurable criteria for the efficiency of community gardens will allow designers to design spaces that are able to maximise urban environmental impact reductions.

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Introduction

This research investigates methods of reducing urban environmental impact through community gardening strategies. As the global population increases, more and more people are moving to urban centres. It is anticipated that the percentage of urban populations will grow faster than the total world population (Adhikari et al., 2006). This expansion of urban populations brings an increase in urban environmental impact. Currently 54% of the world's population reside in urban centres and these cities are contributing to 70% of global carbon emissions (habitat, U.N., 2016). There has been a growing interest in urban agriculture as a method of reducing this increasing urban environmental impact. Community gardening, as a subset of urban agriculture, has been cited as providing social, economic and environmental benefits for the surrounding areas in which they are situated (Ackerman et al., 2014, 2014; Artmann & Sartison, 2018; Clair et al., 2018; De la Sota et al., 2019; Hale et al., 2011; Houghton et al., 2001; Patel, 1996; Voicu & Been, 2008). A limiting factor for these spaces being able to provide effective urban environmental impact reduction is the regulations imposed by local councils (Ackerman et al., 2014; Bakshi et al., 2019). This investigation will go beyond what is currently possible and will investigate:

- How community gardens can reduce the urban environmental impact of areas within Wellington City, New Zealand
- If supplying produce locally through community gardening is a more effective strategy at reducing urban environmental impacts than cultivating urban forests

Definitions

Urban Agriculture:

Urban agriculture (UA) is the term used to describe farming activities that happen within urban centres, Enete & Achike (2008:132) describe UA as "The intensive farming of small plots of land available in the urban and peri-urban areas", whereas Opitz et al. (2016:342) simply describe UA as "Food production in urban areas". UA is often the umbrella term used to describe all types of agricultural activities that take place within urban areas. These agricultural activities can consist of; community gardening, allotment gardening, community orchards and urban farms.

Community Garden:

Community garden (CG) is the term used to describe farming activities that are for self-supply of produce managed by a community. Knapp et al. (2016:1) describe CGs as "non-commercial gardens that are collectively managed to produce crops, vegetables, fruit and/or flowers for self-supply. In a New Zealand context, Wellington City Council (WCC, 2019) describe CGs as "a small-scale, low-investment neighbourhood communal gardening venture, where the primary purpose is growing vegetables or fruit". The issue with this definition, as discussed in the previous phase of this research, is that labelling CGs as a "small-scale, low investment venture" limits the potential productivity that these space could have (Bakshi et al., 2019).

Urban Environmental Impact

Urban Environmental Impact (UEI) is the term used to describe the increased energy consumption and carbon emissions that are associated with urbanization. Urban centres have been estimated to contribute to 75% of global carbon emissions and consume 60%-80% of the world's generated energy despite only occupying 3% of the globe (Seto et al., 2014). This is becoming an issue of concern because currently, half of the world's population resides within urban centres and this is projected to increase to 66% by 2050 (UN, 2012b). As urban populations increase, the UEI of these spaces will increase simultaneously.

Greenhouse Gas Emissions:

Greenhouse gas emissions (GHG) is the term used to describe all the atmospheric gasses that absorb and emit heat from the sun and that are contributing to the greenhouse effect. Often GHGs are represented as carbon dioxide equivalents (CO_2-eq) because each type of GHG has different greenhouse effect properties. For example methane will absorb and emit 21 times more heat than carbon dioxide (Houghton et al., 2001). Each GHG is converted to the equivalent amount of carbon dioxide that will have the same greenhouse effect in order to have a consistent unit of measure. Carbon dioxide is used as the equivalence measure as it is the most prevalent atmospheric gas that is contributing to the greenhouse effect.

Background

Previous Phase of Research

As outlined in the previous phase of this research (Bakshi et al., 2019), the regulations imposed by the Wellington City Council (WCC) for CG activities happening within Wellington City were felt to be far too restrictive to allow for efficient and effective use of these spaces. In order for CGs within Wellington to provide UEI reductions they would need to go beyond what is currently possible within current regulations.

UN Sustainable Development Goals

Following decisions made at the Rio+20 United Nations conference of sustainable development, a set of 17 sustainable development goals (SDGs) were developed by an intergovernmental open working group. These SDGs were developed as a framework that countries could use to frame future agendas and policy making so as to match the goals of being a green economy in the context of sustainable development and eradication of poverty (UN, 2012a). The problem with these SDGs is that they are a distilled version of various reports that examine the same problems. They are based on 40 chapters within agenda 21 (UN, 1992), which in turn was based on the initial mandates from the Kyoto protocol (1992), which were based on the Brundtland Commission (UN, 1987), which were based on the original findings from the research that led to *Limits to Growth* (Meadows et al., 1972). The issue of the SDGs is when all the information from these reports are distilled into only 17 goals, there is a loss of scope from that originally outlined in. Although the SDGs do not encompass the full problem and need to, they are still important for ensuring sustainable growth for all countries between the years 2015 – 2030. The built environment is a large contributor to the issues the SDGs are attempting to address. Construction alone will contribute 42.4 billion tons of carbon emissions by 2035 (EIA, 2010). Because of the impact of the built environment, architectural practice has a significant role to play in aligning the future built environment with SDGs. This research will provide methods to help cities within New Zealand better align with SDGs by investigating UEI reduction strategies through community gardening practices.

Benefits of Urban Agriculture

Along with an increase in UEI, urbanization has also been detrimental to the social and environmental aspects of communities. Because of this, interest in UA has been increasing as a solution to addressing these concerns (Kingsley et al., 2019). Various studies have been undertaken on UA to identify the social, economic and environmental benefits of this. What follows is a brief description of some of these benefits. This list may not be comprehensive due to the limited time and resources for this research.

Social Benefits:

A study by Clair et al., (2018) found that CGs had a multitude of social benefits for users including therapeutic effects and increased knowledge of growing produce. Hale et al. (2011) found that users that had hands on experience at a CG contributed meaning to this experience and were therefore more likely to continue engaging with CG activities, which could lead to positive health outcomes. Patel (1996) found a strong correlation between users having experiences of growing food locally and an increase in consumption of fruit and vegetables. UA has also been cited as improving urban communities by connecting the community to a broader social process as well as connecting it to natural processes (Artmann & Sartison, 2018).

Environmental Benefits:

UA and urban forestry were found to be an effective strategy for contributing to climate change mitigation by providing carbon storage and bio-capacity increase (De la Sota et al., 2019). UA may also contribute to bio-diversity by replacing lawns with productive gardens and therefore increasing space for wildlife inhabitation (Artmann & Sartison, 2018). Urban food waste (UFW) is a significant contributor to UEI as food waste that is sent to landfill produces methane (which traps 21 times more heat than carbon dioxide (Houghton et al., 2001)). Studies have shown that a significant reduction in GHG emissions can be achieved when a portion of UFW is diverted to composting facilities located within UA ventures (Adhikari et al., 2006; Ng & Yusoff, 2015; Pai et al., 2019).

Economic Benefits:

While economic benefits are attributed to UA, there have been few studies that assess these. A study by Voicu & Been (2008) found that house prices, and subsequently tax revenue, increased as much as 9.4% when located near an UA venture after 5 years of its establishment, making investments into UA activities for local governments worthwhile. UA has been found to contribute to a community's food security while also being able to provide long term employment, offsetting of household incomes, and provision of revenue streams for the community (Ackerman et al., 2011; Ackerman et al., 2014).

Barriers to Success

Ackerman et al. (2014) found that a major barrier to successful UA ventures was the limiting regulations imposed by local councils. The uncertainties over jurisdiction and land unavailability was a limiting factor for UA practices in New York to perform in an effective manner. These findings have been mirrored in the findings from phase one of this research (Bakshi et al., 2019).

Methodology

This research will investigate different UEI reduction strategies based on existing community gardens in Wellington City, New Zealand as case studies. This investigation will be conducted by mapping what is currently on the existing sites of each case study and then mapping UEI reduction strategies for each case study. The existing site and UEI reduction strategies can then be evaluated using metrics established from literature. These measures can then be used to compare each strategy against the other in order to determine the most effective use for these spaces in order to reduce UEI.

Case Studies

This research has focused on community gardens in Wellington City, New Zealand. Wellington was chosen because as the capital city of New Zealand it is to an extent representative of urban centres within New Zealand. Additionally, due to the limited resources and time for this research site visits to community gardens were possible within the time frame. The fact Wellington City already

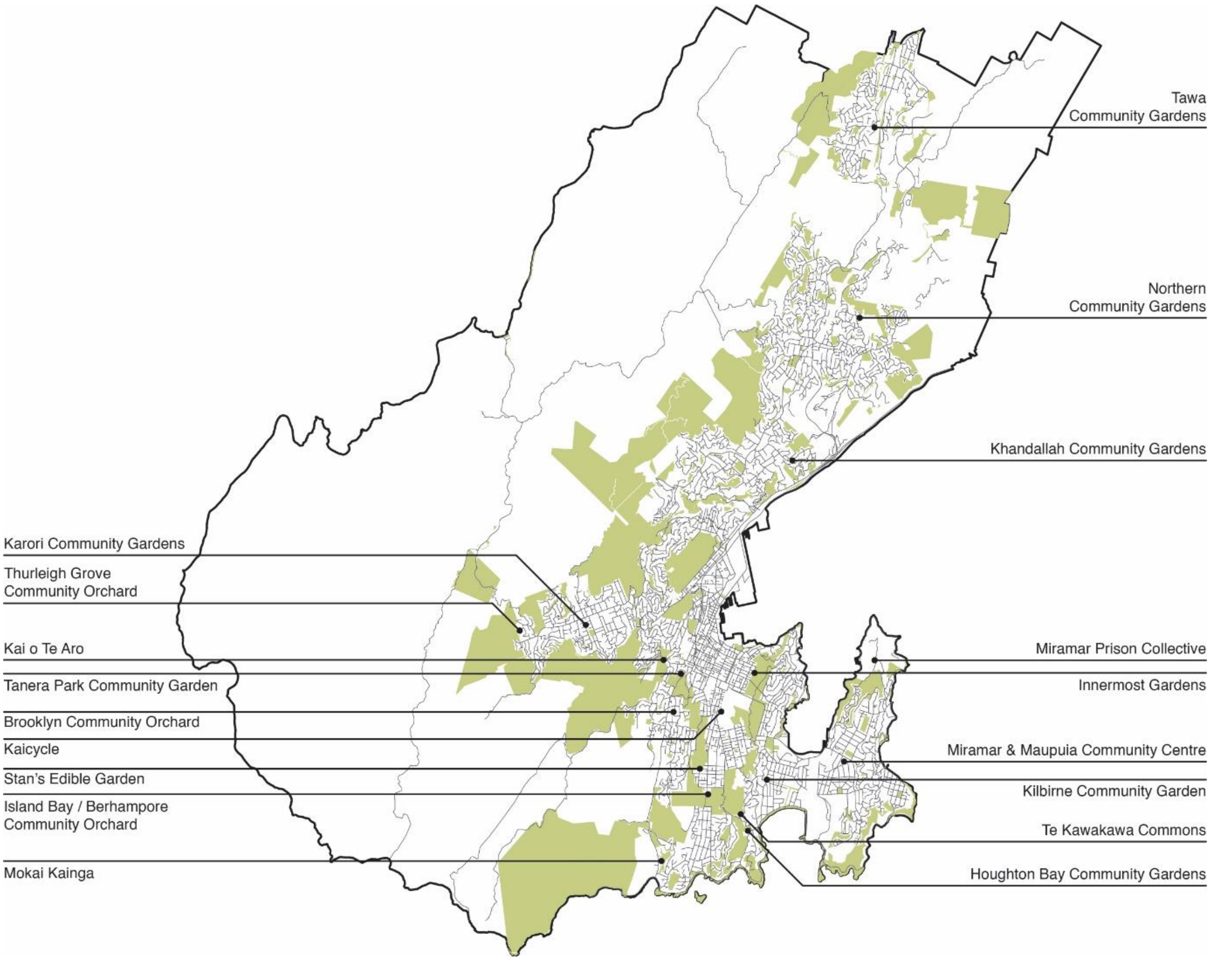


Figure 1

contains 19 established Community Gardens (CGs) means it provides a good basis for investigation, shown in figure 1. Two community gardens from Wellington City were selected as case studies for this research, these being the Island bay / Berhampore community orchard located within Martin Lucky Park on Adelaide Road and Stan's Edible Garden located within Macalister Park, between Palm Grove and Stanley Street. The Island bay / Berhampore community orchard contains both fruit trees and vegetable patches within an area of 4430 square metres. Stan's Edible Garden contains allotment style vegetable patches within an area of 270 square metres. These CGs were selected due to the difference in garden typology and size. Site visits were made to each garden in order to map the areas of vegetable patches, fruit tree patches, composting, circulation space and total area. These areas were mapped using a measuring tape and notebook while on-site and scaling satellite imagery to measure anything that could not be measured on-site. Due to the limited information available for each case study, assumptions, such as boundaries and what was cultivated/un-cultivated, had to be made using observations and pictures taken during site visits.

GIS Mapping

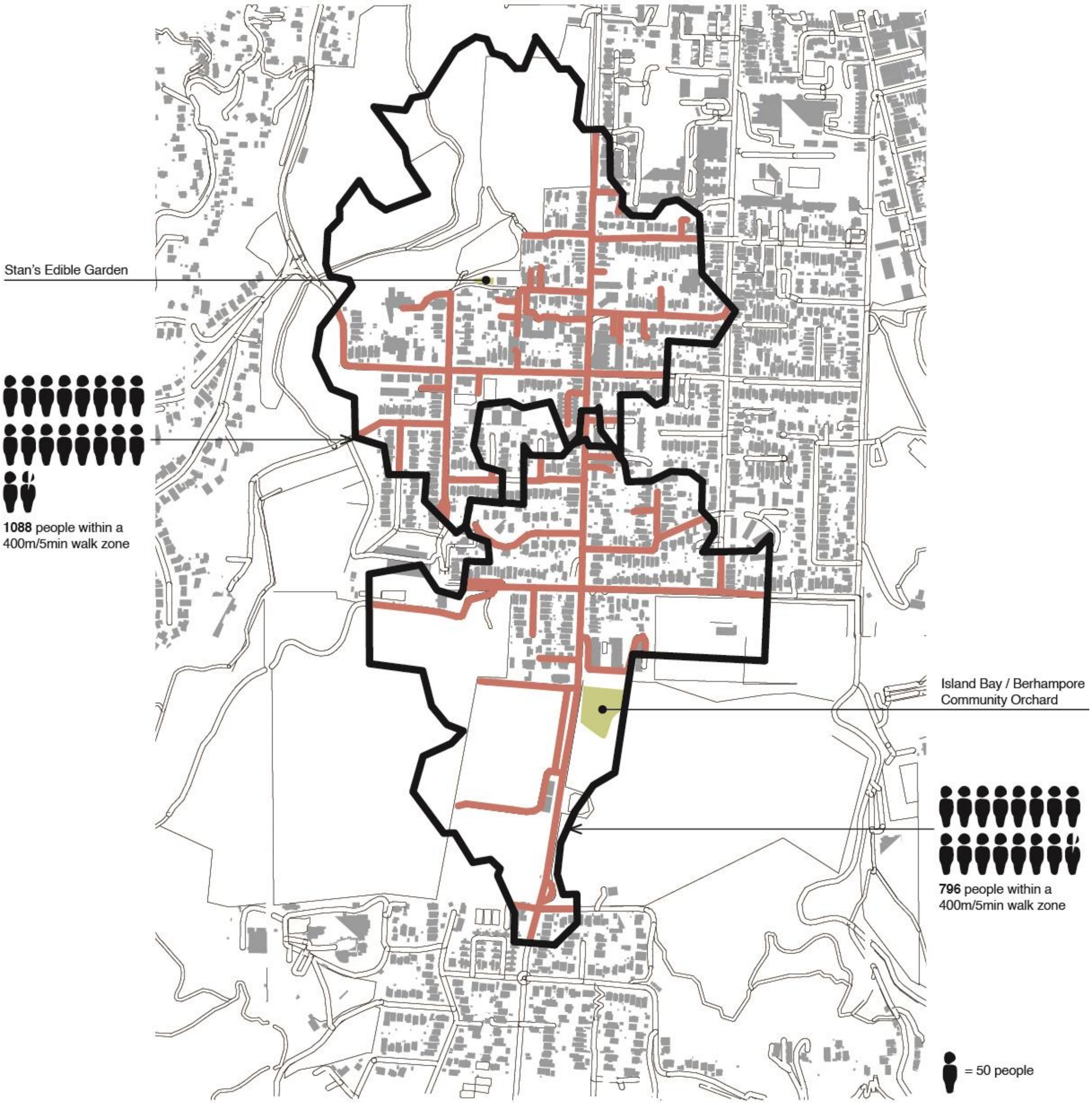


Figure 2

GIS software was used to map a 400m/5min walking distance from each case study garden. Meshblock data from the 2013 New Zealand census was used to estimate the population of residents within this 400m/5min walking distance. As only parts of some Meshblocks fell within these 400m/5min zones, an assumption was made to use a proportion of the population within each Meshblock equal to the proportion of area that fell within these 400m/5min zones, in order to approximate the population surrounding these case study gardens, this is shown in figure 2. Using GIS data supplied by Wellington City Council (WCC) the area of total green space owned by WCC was determined. This allowed the results of the UEI reduction strategies to be applied at a city wide scale.

Produce Production

In order to estimate the produce production potential of these case study gardens, fruit and vegetable yield rates of New Zealand agricultural activities were acquired from the Food and

Agriculture Organization Corporate Statistical Database (FAOSTAT, 2013). An average of different yield rates for all produce grown in New Zealand was taken and categorised into fruit (total) and vegetables (total) in order to approximate New Zealand agriculture activities as a whole. While this data accurately represents New Zealand as a whole in 2013 it will not necessarily represent growing conditions in Wellington City. However, such data is useful in order to be able to compare strategies. The rates of “kg of produce grown per square metre per year” for fruit and vegetables can be used to estimate the existing produce production potential for each case study garden and also future produce production strategies. The total amount of fruit and vegetable consumed within New Zealand has also been acquired from FAOSTAT (2013). These rates of “kg of produce consumed per captia per year”, combined with the population within the 400m/5min walking radius were used to estimate how much produce could be supplied by each case study garden to the surrounding area and how many people it could feed.

Food Miles

When comparing locally and conventionally supplied produce it is useful to use the concept of food miles. Food miles represent the carbon emissions generated from transporting produce from where it is grown to where it is consumed. Conventionally supplied produce is commonly grown on a commercial scale in a rural area and shipped to a supermarket, from which the consumer can then purchase their produce. Locally supplied produce is different as it is grown and supplied to the consumer in the same place, thereby reducing the carbon emissions associated with the food. Assumptions were made when it came to calculating the delivery strategy for produce in this research. Consequently the values used here do not capture the complete impact of each delivery method. However, they are a useful measure for making comparisons between different UEI reduction strategies. For locally supplied produce it was assumed that the population within the 400m/5min zone would gather their produce from their local CG, assuming they would walk there and not drive. This does not take into account any emissions associated with how this produce is then stored, cooked and disposed of. Conventionally supplied produce is assumed to be the same produce but bought from the supermarket nearest to the CG. It was assumed the same people would walk to the supermarket rather than drive there. The fruit supplied is assumed to come from the Cromwell region, Central Otago (where most of New Zealand’s fruit is grown) and the vegetables from the Otaki region, Kapiti (where most of Wellington’s vegetables are grown). The fruit transported from Cromwell first travels 432km from Cromwell to Lyttelton (the nearest port to Cromwell) by truck, it then travels 320km from Lyttelton to Wellington by boat and finally travels another 7km from Wellington’s port to the supermarket nearest to the CG by truck. The vegetables from Otaki travel 78km from Otaki to the supermarket nearest to the CG by truck. A study by Cenek et al. and NZTA (2012) determined the carbon emissions ($kgCO_2/km$) to transport a 20ft container from Wellington to Tauranga by truck and from Wellington to Lyttelton by boat. This study calculated the carbon emissions of a 20ft container whilst the container was empty and did not take into account the weight of the contents. Although this is calculation is not accurate, if anything, the values used in this investigation are conservative considering that produce is currently transported by many smaller truck/vans that are less efficient in CO_2 terms than transportation in a 20ft container. Using these values, the carbon emissions of transporting a container from Otaki to Wellington were calculated to be 0.0395 tCO_2 per container and transporting from Cromwell to Wellington were 0.3121 tCO_2 per container. In order to determine how many containers are needed for each reduction strategy the weight of produced needed to be conventionally supplied was divided by the maximum weight that could be transported in a 20ft container. These values were then multiplied by the carbon emissions of transporting each container in order to measure tCO_2 per kg of conventionally supplied produce.

Carbon Sequestration

In order to estimate the carbon sequestration potential of each case study garden, carbon sequestration rates for tree species, urban agriculture, and lawns were sourced and used to calculate sequestration rates per square metre over time. A study by MAPAMA (2015) determined carbon sequestration rates for different species of tree for a single specimen over time. Rates of carbon sequestration for Radiata Pine (Pinus radiata), Macrocarpa (Cupressus macrocarpa) and Forest Apple Tree (Malus sylvestris) were used in this study combined with the typical tree spacing for each species (Maclaren, 1993; Nicholas, 2007; Zhang et al., 2015) to determine a rate of tCO_2/m^2 for forest plantations of each specie. A study by Schwendenmann & Mitchell (2014) was used to determine a carbon sequestration rate for a native New Zealand forest. This native New Zealand forest is a combination of Titoki (Alectryon excelsa), Taupata (Coprosma repens), Karamu (Coprosma robusta), Karaka (Corynocarpus laevigatus), Kawakawa (Macropiper excelsum), Whitey wood (Melicytus ramiflorus), Mousehole tree (Myoporum laetum), Red matipo (Myrsine australis), Lemonwood (Pittosporum eugenioides), Kohuhu (Pittosporum tenuifolium), Seven-finger (Schefflera digitate) and Puriri (Vitex lucens). Schwendenmann & Mitchell (2014) determined an average rate of 1699.1 kg C ha^{-1} $year^{-1}$ for this native New Zealand forest. This rate was converted into tCO_2/m^2 using a conversion factor of $1tC=3.67tCO_2$ (Ecometrica, 2011). A study by Zirkle et al. (2011) determined a rate of 25.4-114.2 gC/m^2 net carbon per year for lawns (only mowed). An average of this range was taken and converted into tCO_2/m^2 using the Ecometrica (2011) formula. A study by Mota et al. (2011) was used to determine an annual carbon sequestration rate for urban agriculture (UA) activities.

Carbon Emissions

- Carbon emissions of forestry management

Two of the forests used in this investigation (radiata pine and macrocarpa) are primarily grown to be used as timber products at the end of their lifecycle. Because of this there will be emissions associated with the planting, maintenance, harvesting, transporting to the mill and the processing of the trees into usable timber. This investigation will use the emission values associated with the lifecycle of New Zealand forests (from sapling to dressed timber) established by Alcorn (2010). His value of forestry emissions $87{,}229.81gCO_2/m^3$(timber) has been converted into $0.0065tCO_2/m^2$ for radiata pine forests and $0.0002tCO_2/m^2$ for macrocarpa using yield values for m^3(timber)/ha(forest) (Maclaren, 1993; Nicholas, 2007). These values can then be used to subtract against total carbon sequestered to get a value for net carbon sequestered of both radiata pine forest and macrocarpa forest. Since native New Zealand forest is not grown to be used as a timber product it has been assumed that there will be no emissions associated with the management of this forest.

- Carbon emissions of Wellington City

A study conducted by URS (2014) determined a rate of $6.6tCO_{2\text{-}e}$ carbon emissions annually per capita for people living in Wellington City with 1% of that coming from the agricultural sector. As this investigation is focusing on reducing emissions associated with food production a rate of $0.66tCO_2$-e will be used to determine how many people's carbon emissions can be offset by each UEI reduction strategy.

Impact Reduction Strategies Definitions

The investigation method for this research primary features the mapping of existing CG space and the mapping of potential impact reduction strategies. Because of this, it is important to define what each term means when referring to a mapping strategy.

Vegetable Patches:

The amount of square metres dedicated to the growing of vegetables for consumption. Vegetables yield rates (kg/m^2) are assumed to be an average of yield rates for every vegetable that is grown in New Zealand to represent vegetables (total).

Fruit Tree Patches:

The amount of square metres dedicated to the growing of fruit for consumption. Fruit Tree yield rates (kg/m^2) are assumed to be an average of yield rates for every fruit that is grown on trees in New Zealand to represent fruit (total).

Compost:

The total area dedicated to the recycling of food waste and plant matter. In some of the case study gardens there was a combination of traditional composting and vermicomposting. Since this investigation does not focus on the impacts of composting it was assumed that composting was important for each case study garden and would remain the same area for each strategy mapped.

Tool-sheds, Notice Boards, Beehives

The amount of area dedicated to things, such as tool-sheds, notice boards and beehives. It was assumed in this investigation that the areas dedicated to these items were necessary for the running of each case study garden and would remain the same area for each strategy mapped.

Circulation Space:

For this investigation, circulation space refers to the minimum space needed to access all of the garden beds without having to walk over the growing space and compacting the soil. It is important to have adequate circulation space for gardening as compacting the soil around plants can reduce produce yield rates up to 50% (Lane, 2012). For allotment style vegetable gardening it was assumed that 900mm around each garden bed would be required to allow for walking space, as well as space for a wheelbarrow and tools. For raised bed style vegetable gardening it was assumed that 600mm around each garden bed would be required to allow for walking space. For fruit tree gardening it was assumed that no circulation space would be required as there will be adequate space to walk under each tree due to the 4.5m spacing between each tree.

Unused:

The amount of area within each case study garden that was not being used to cultivate produce, nor was dedicated to circulation, composting, tool-sheds, notice boards, or beehives. This is the area within the boundaries that was perceived to be in use in the CG but that was not contributing to its fruit and vegetable productivity.

Mapping Urban Environmental Impact Reduction Strategies

Using the metrics gathered from the literature and the maps made from site visits it was possible to establish the existing food production and carbon sequestration rates per year for each case study. Next, a number of impact reduction strategies were mapped for each case study garden and their effectiveness evaluated based on the previously established metrics. The existing productivity of each case study was then compared with each impact reduction strategy. First, strategies that kept the overall area of each existing CG the same were mapped. This was important in order to determine the breakdown in percentages of the different areas within the CG required by each strategy. The strategies mapped were:

- Maximum Garden Beds
  Garden beds were mapped to be 250m^2 each, and 900mm of circulation space around each vegetable patch was allowed. This was mapped to determine, assuming good management, the maximum weight (kg) of vegetables able to be produced by each case study garden while converting all possible space to allotment style gardens.

- Maximum Raised Beds
  Raised beds were mapped to be 1.2m wide and no longer than 7m, with allowance for 600mm of circulation space around each raised bed. This was mapped to determine, assuming good management, the maximum weight (kg) of vegetables able to be produced by each case study garden while converting all possible space to raised bed style gardens.

- Maximum Fruit Trees
  Fruit trees were mapped with a 4.5m spacing tree to tree and all trees spaced 2m from any boundary. This was mapped to determine, assuming good management, the maximum weight (kg) of fruit able to be produced by each case study garden while converting all possible space to fruit trees. It was assumed the fruit trees would be mature.

Next, using the populations gathered from the GIS mapping of a 400m/5min walk zone around each case study garden and fruit and vegetable consumption data from FAOSTAT (2013), a value for how much fruit and vegetable produce a 400m/5min walk zone consumes was calculated. Using these values it was possible to calculate how much area of fruit and vegetable patches would be required to meet the produce demands of the surrounding area for each case study. These strategies were mapped as:

- Meeting vegetable demands
  Expanding the area of the CG into the park within which it is situated in order to produce enough vegetables, assuming good management, to meet the vegetable consumption demands of everyone within 400m/5min walk of the CG. The area needed for circulation space was calculated by using the percentage of areas determined in the “maximum garden beds” strategy.

- Meeting fruit demands
  Expanding the area of the CG into the park within which it is situated in order to produce enough fruit, assuming good management and mature trees, to meet the fruit consumption demands of everyone within 400m/5min walk of the CG. The area needed for circulation space was calculated by using the percentages of areas determined in the “maximum fruit trees” strategy.

- Meeting produce demands
  Expanding the area of the CG into the park within which it is situated in order to produce enough produce (vegetables + fruit), assuming good management and mature fruit trees, to meet the produce consumption demands of everyone within 400m/5min walk of the CG. The area needed for circulation space was calculated by using the percentages of areas determined in “maximum garden beds” and “maximum fruit trees” strategies.

City Scale Mapping

To determine the UEI reduction possible for all of Wellington City, each strategy was mapped at a city-wide scale. First, GIS data was acquired from WCC in order to establish total the green space area owned by WCC. Next, satellite imagery to scale was used to map the total area designated to CGs in Wellington City.

Carbon Sequestration as an UEI reduction strategy

Rather than reducing UEI through food miles reduction, carbon sequestration strategies were mapped to evaluate their effectiveness. Carbon sequestration strategies were mapped by converting the total area designated to CGs in Wellington City into each strategy, assuming good management. The strategies mapped were:

- Maximum Lawn

  The net amount of carbon able to be stored by a lawn (mowed only) if the total area designated to CGs in Wellington City was converted to lawn. It has been assumed that a lawn will not be able to store the carbon it sequesters due to the regular mowing and decomposition of the mown grass. The emissions associated with the mowing and management of this lawn has been assumed to be zero due to the limited time and resources of this investigation.

- Maximum Fruit and Vegetables

  The net amount of carbon able to be stored annually by meeting Wellington Cities produce needs through locally supplied produce. This value includes the amount of carbon sequestered annually by the fruit trees necessary to meet fruit demands. Carbon sequestered was calculated by multiplying the carbon sequestration value of fruit trees per metre squared for 40 years, the metric previously discussed, and divided by 40 to get a value of average carbon sequestered annually.

- Maximum Native New Zealand forest

  The net amount of carbon able to be stored annually by a native New Zealand forest if the total area designated to CGs in Wellington City was to be so planted. This native New Zealand forest is assumed to be a permanent carbon sink and therefore will have no emissions associated with management, harvesting and processing of these trees. The emissions associated with the planting and management of this forest have also been omitted from this investigation but food mile emissions from produce not supplied by this strategy have subtracted from the total amount of carbon sequestered to provide a net carbon value. An annual net carbon value has been calculated by multiplying the carbon sequestration value per metre squared per year, the metric previously discussed, with the area of urban forest and then subtracting the food miles emissions associated with this strategy to get a net carbon value annually.

- Maximum Macrocarpa forest

  The net amount of carbon able to be stored by a Cupressus macrocarpa forest annually if the total area designated to CGs in Wellington City was to be so planted. The emissions associated with the management, harvesting and processing of these trees, along with the food mile emissions from produce not supplied by this strategy, have subtracted from the total amount of carbon sequestered to provide a net carbon value. An annual net carbon value has been calculated by multiplying the carbon sequestration value per metre squared per 40 year lifecycle, the metric previously discussed, with the area of urban forest and then subtracting the emissions associated with harvesting and replanting this forest once every 40 year lifecycle, dividing this by 40(years) and then subtracting the food miles emissions associated with this strategy to get a net carbon value annually.

- Maximum Radiata forest

  The net amount of carbon able to be stored by a Pinus radiata forest annually if the total area designated to CGs in Wellington City was to be so planted. The emissions associated with the management, harvesting and processing of these trees, along with the food mile emissions from produce not supplied by this strategy, have subtracted from the total amount of carbon sequestered to provide a net carbon value. An annual net carbon value has been calculated by multiplying the carbon sequestration value per metre squared per 20 year lifecycle, the metric previously discussed, with the area of urban forest and then subtracting the emissions associated with harvesting and replanting this forest once every 20 year lifecycle, dividing this by 20(years) and then subtracting the food miles emissions associated with this strategy to get a net carbon value annually.

Results

The following section will discuss the results generated from mapping and analysing each strategy. Once the total area of produce patches had been determined for each strategy it was multiplied by the appropriate yield rate to determine the productivity of each strategy (produce in kg). This can then be compared against the produce consumed by the populations within a 400m/5min walk zone of each case study garden. For the Island Bay / Berhampore Community Orchard the population within this zone is 796 persons and they consume 159,442kg of vegetables and 83,719kg fruit annually. For Stan's Edible Garden the population within this zone is 1088 persons and they consume 217,930kg of vegetables and 114,430kg fruit annually. Once each strategy has been mapped and analysed a comparison can be made to determine the efficiency of each.

Case Study: Island Bay / Berhampore Community Orchard

Existing

First, the existing site was mapped to enable a comparison of each UEI reduction strategy against the existing conditions of the site. Figure 3 is a site map of the existing conditions at the Island Bay / Berhampore Community Orchard. In the existing site a fairly small amount of fruit and vegetable patches are sparsely distributed, with a large proportion of the total CG space being unused. This is reflected in figure 4 which shows percentages of total area dedicated to each land use:10% is dedicated to fruit tree patches, 3% to vegetable patches and 67% of the CG is unused. This meant this existing site was able to meet 0.64% of vegetable demands, 1.05% of fruit demands and 0.84% of overall produce demands for the population within a 400m/5min walking zone of the garden.

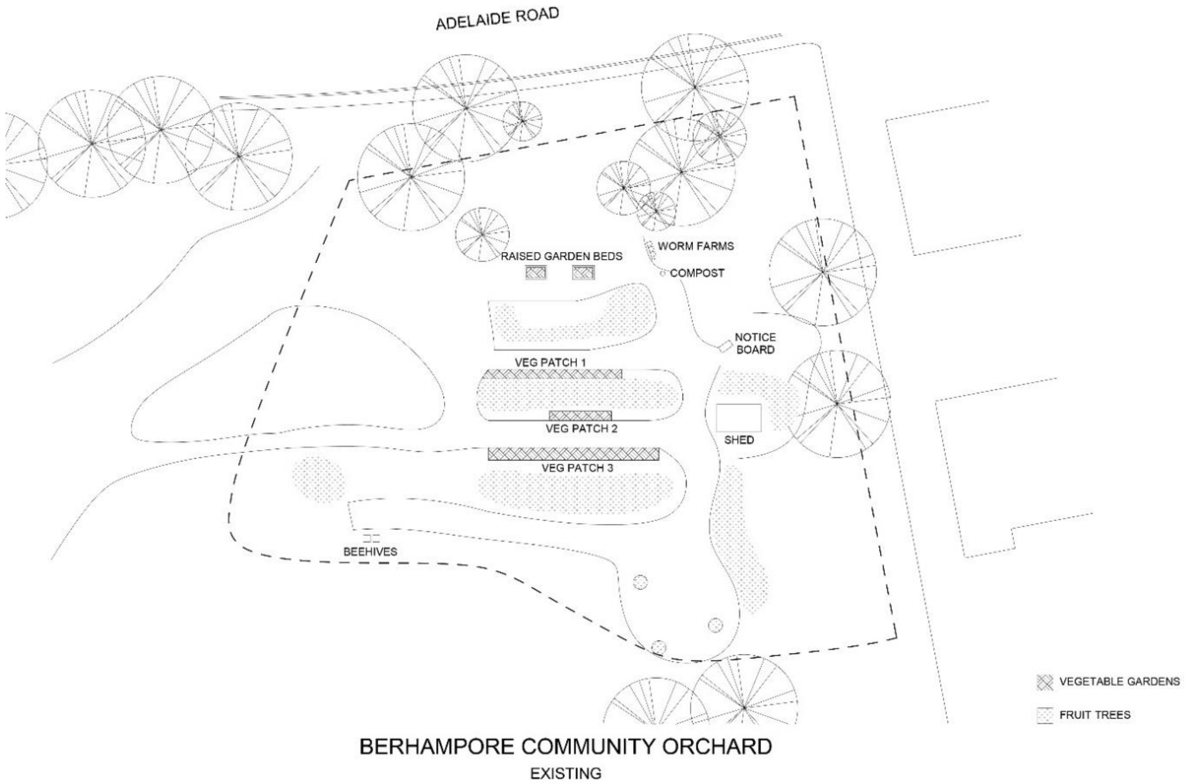
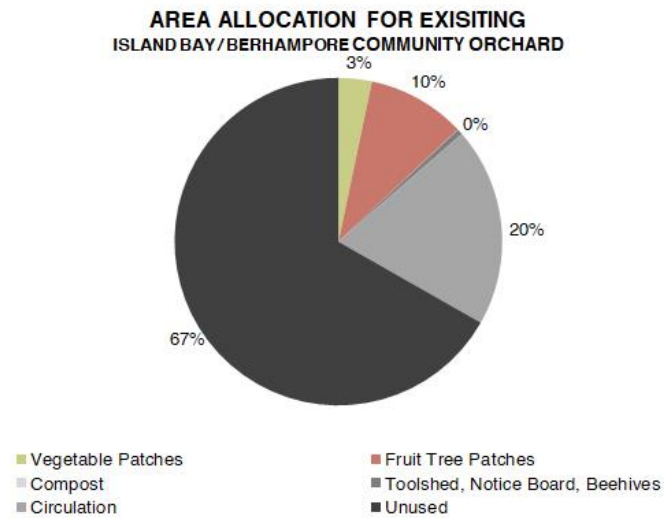


Figure 3



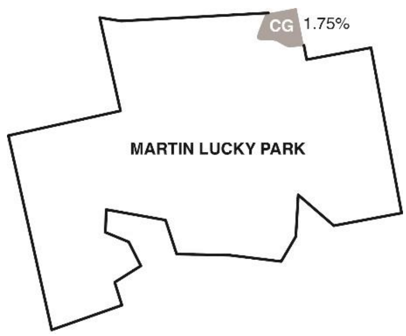


Figure 4

Maximum Garden Beds

Next, the maximum amount of allotment style garden beds was mapped into the area designated to the existing CG and shown in figure 5. This strategy is able to convert more of the CG space into productive areas compared to the existing conditions. This is reflected in figure 6 which shows percentages of area dedicated to each land use: 85% is now dedicated to vegetable patches, 13% to circulation space and only 1% of CG area is unused. This version of the case study was able to meet 16.36% of vegetable demands, 0% of fruit demands and 8.18% of overall produce demands for the population within a 400m/5min walking zone of the garden.

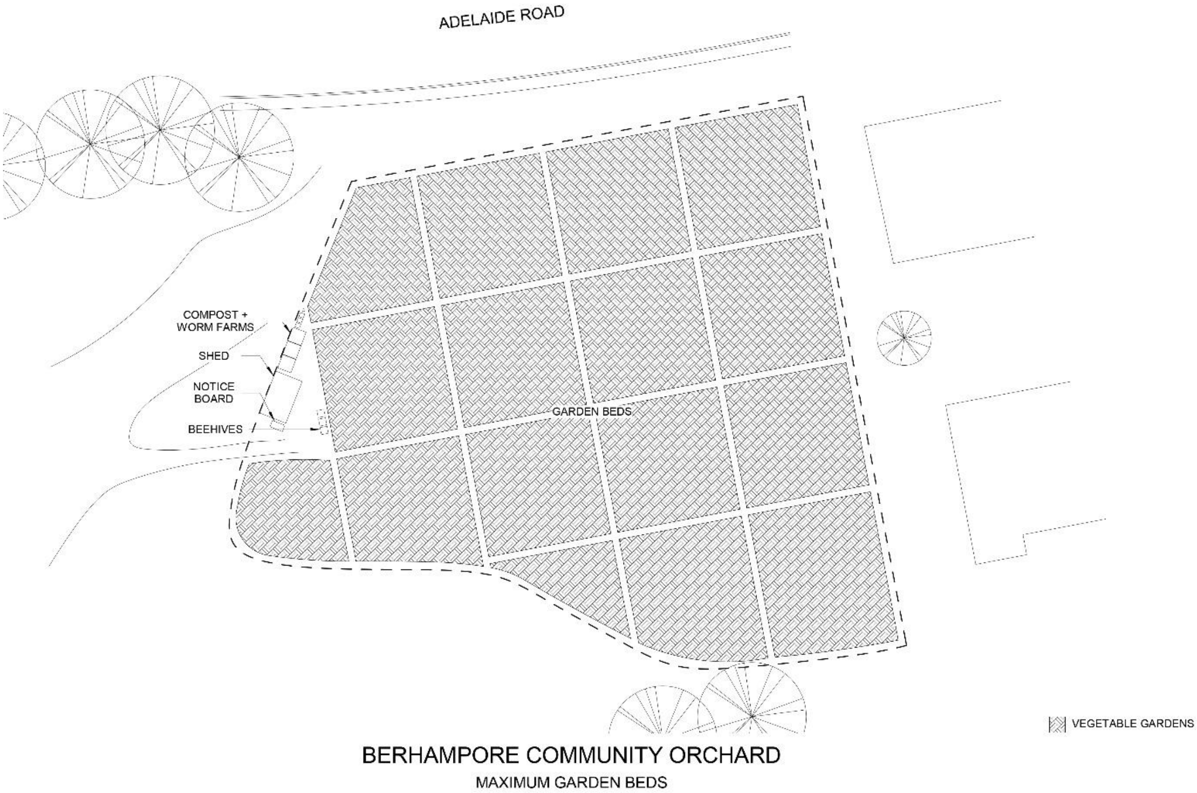


Figure 5

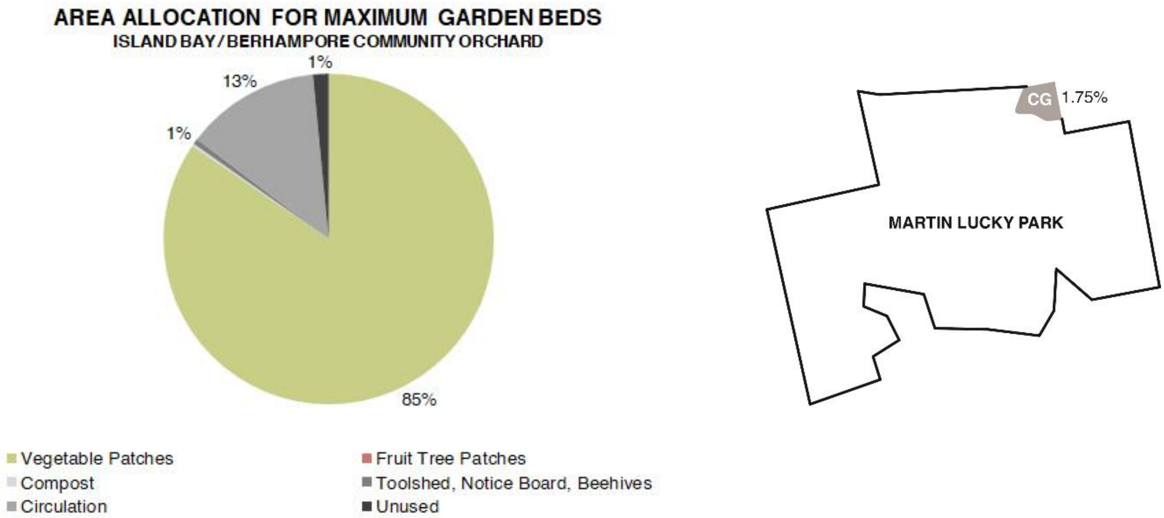


Figure 6

Maximum Raised Beds

Next, the maximum amount of raised bed style garden beds was mapped as shown in figure 7. This strategy was not able to dedicate as much area to productive space compared with the allotment style beds due to the increased need for circulation space. This is reflected in figure 8 which shows percentages of area dedicated to each land use: 60% is dedicated to vegetable patches, 36% to circulation space and 3% of CG area is unused. This version of the case study was able to meet 11.69% of vegetable demands, 0% of fruit demands and 5.84% of overall produce demands for the population within a 400m/5min walking zone of the garden.

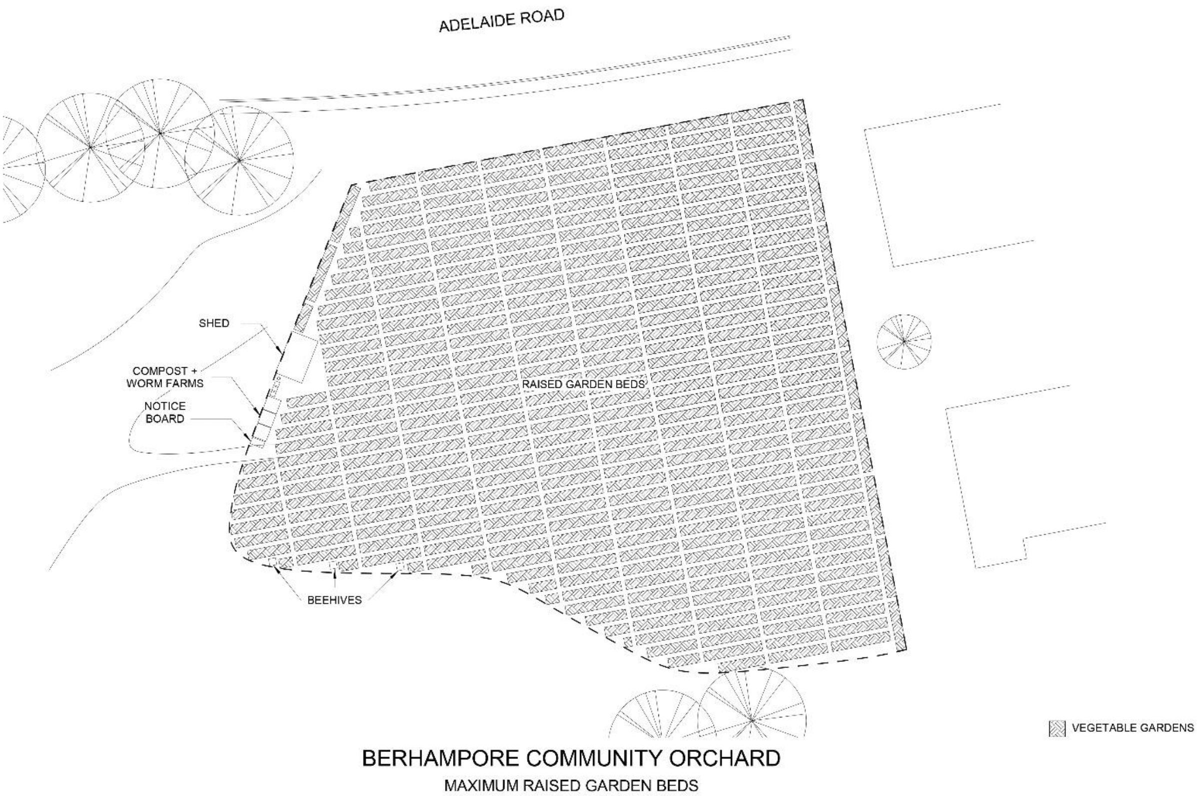


Figure 7

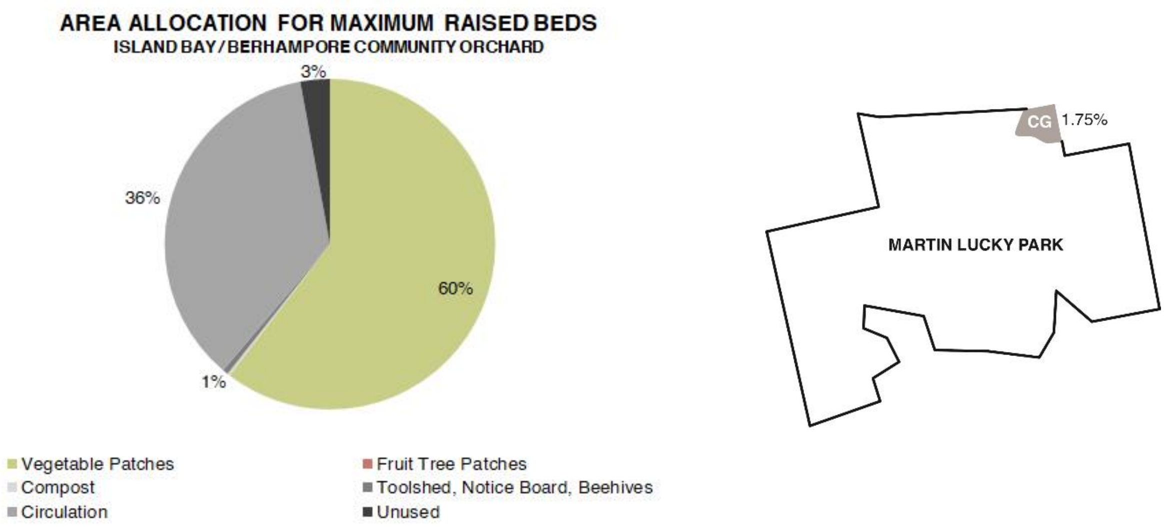


Figure 8

Maximum Fruit Trees

Next, the maximum amount of fruit trees was mapped as shown in figure 9. This strategy was able to dedicate the most amount of area to productive space due to the circulation space being integrated within the orchard type layout. This is reflected in figure 10 which shows percentages of area dedicated to each land use: 96% is dedicated to fruit trees, 0% is dedicated to circulation space and 3% of CG area is unused. This version of the case study was able to meet 0% of vegetable demands, 10.40% of fruit demands and 5.20% of overall produce demands for the population within a 400m/5min walking zone of the garden.

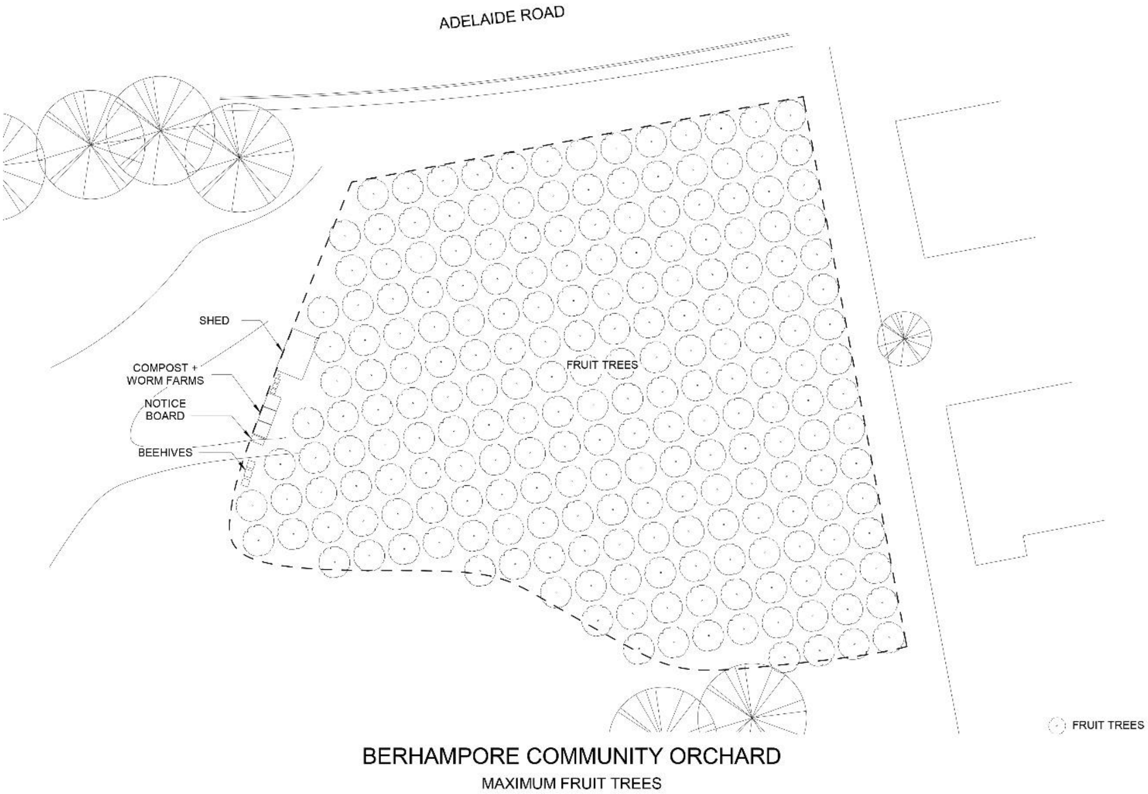


Figure 7

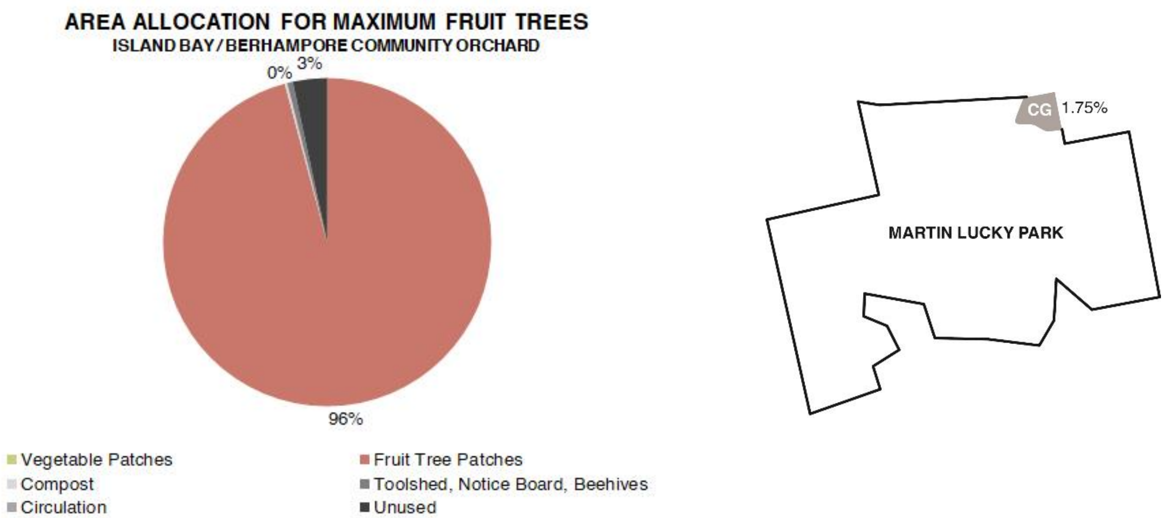


Figure 8

Case Study: Stan's Edible Garden

Existing

The existing site was mapped for Stan's Edible Garden, as shown in figure 11, and then analysed. Stan's Edible Garden is an allotment style gardening block with no fruit tree patches and a larger compost area than in the previous case study. This is reflected in figure 12 which shows percentages of area dedicated to each land use: 22% is dedicated to vegetable patches, 7% to circulation space, 4% to composting space and 67% of the CG is unused. Once analysed, it was determined that this existing site was able to meet 0.19% of vegetable demands, 0% of fruit demands and 0.10% of overall produce demands for the population within a 400m/5min walking zone of the garden. This case study garden is smaller than the previous case study and there are more people within the 400m/5min walk zone so it meets less of the overall produce demands of the surrounding area.

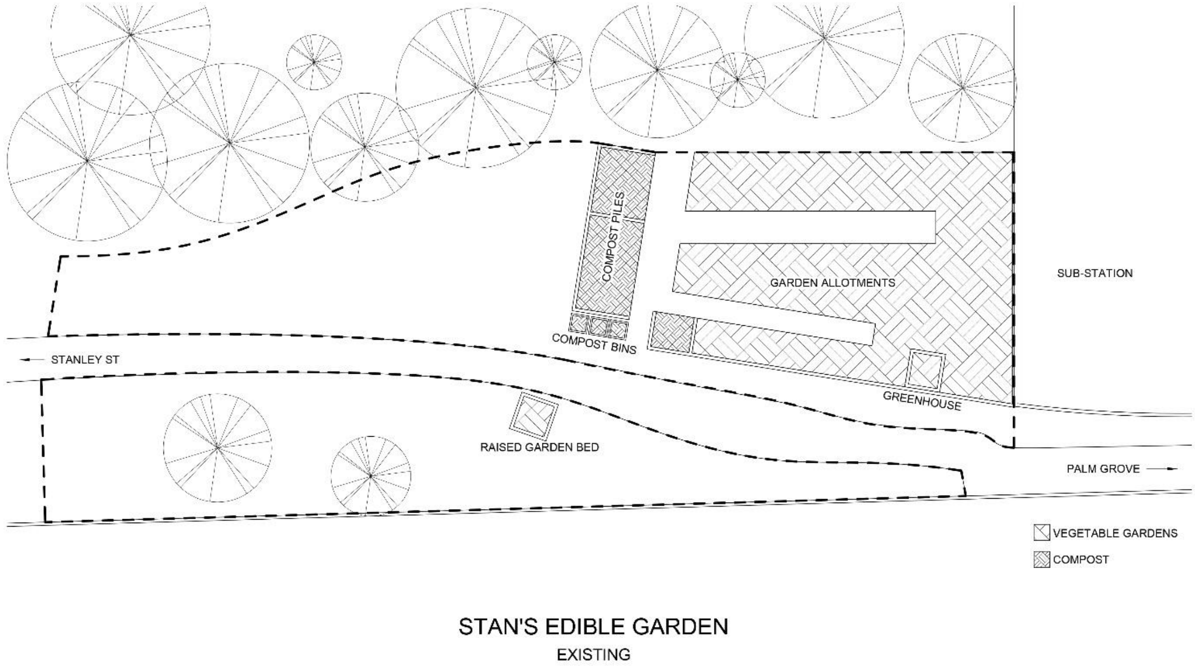


Figure 11

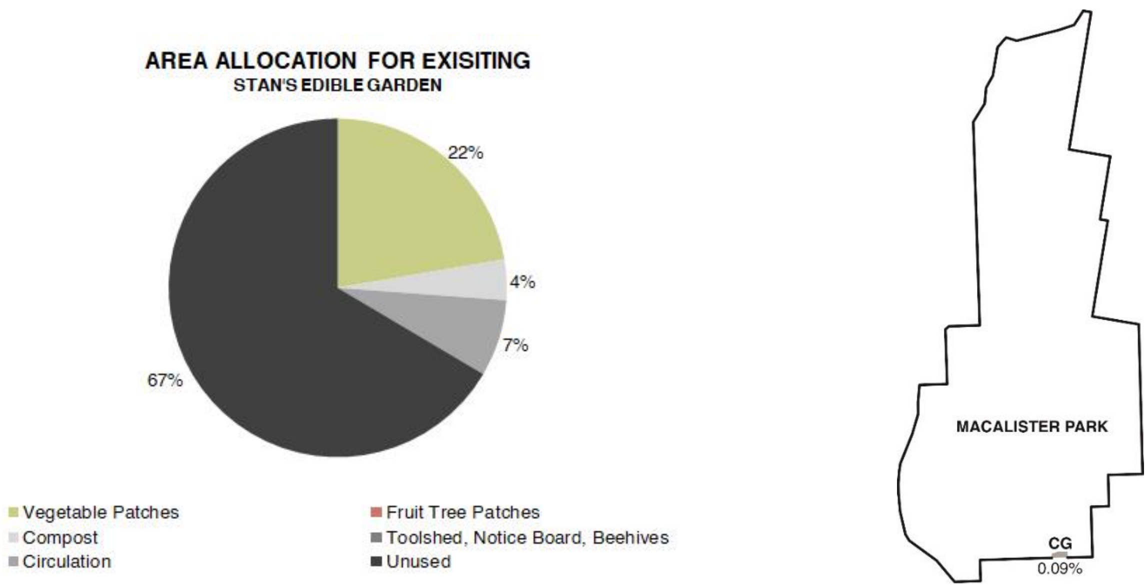


Figure 12

Maximum Garden Beds

Next, the maximum amount of allotment style garden beds was mapped as shown in figure 13. This strategy is able to convert more of the CG space into productive areas as 68% is now dedicated to vegetable patches, 27% to circulation space, 5% to composting and 0% of CG area is unused. This version of the case study was able to meet 0.59% of vegetable demands, 0% of fruit demands and 0.29% of overall produce demands for the population within a 400m/5min walking zone of the garden.

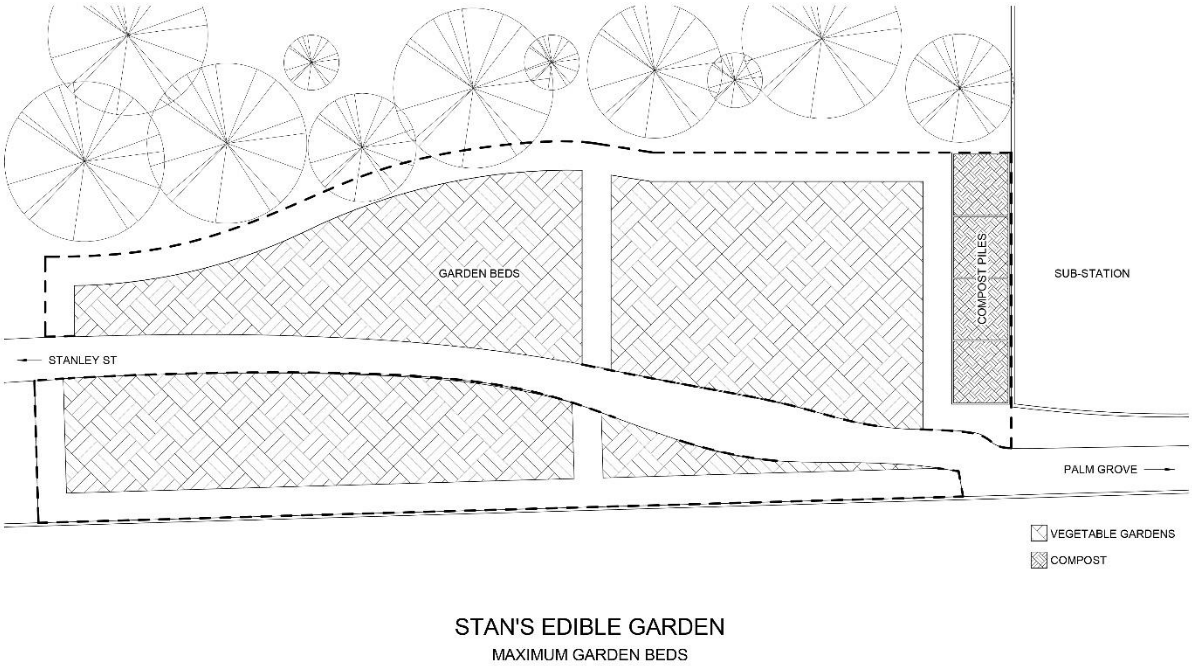


Figure 13

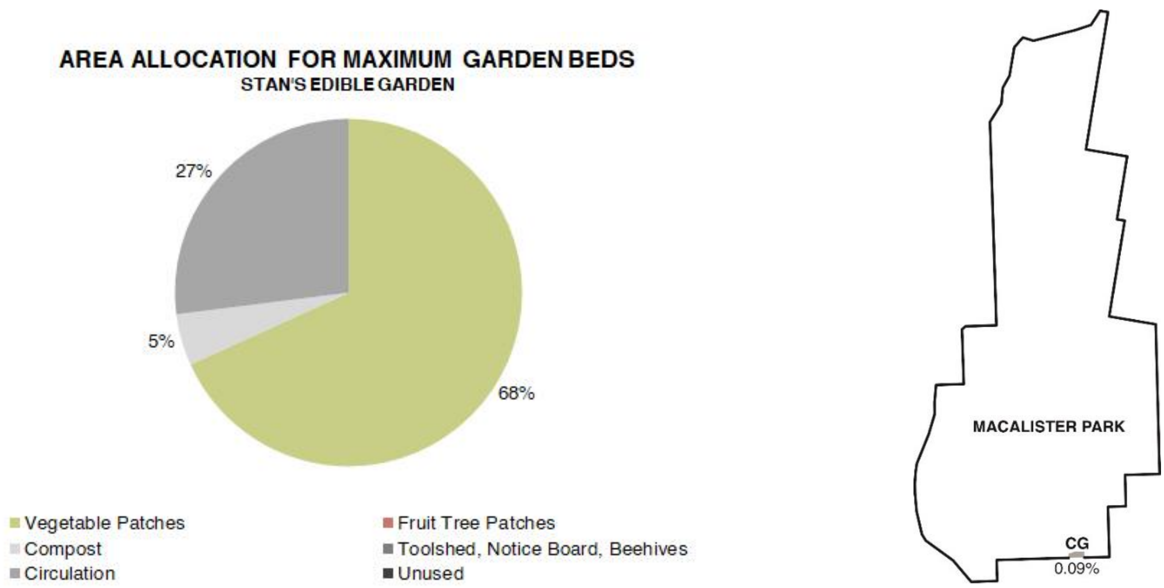


Figure 14

Maximum Raised Beds

Next, the maximum amount of raised bed was mapped as shown in figure 15. As before, this strategy was not able to dedicate as much area to productive space compared with allotment style gardening due to the increased need for circulation space. This is reflected in figure 16 which shows percentages of area dedicated to each land use: 52% is dedicated to vegetable patches, 43% to circulation space, 5% to composting and 0% of CG area is unused. This version was able to meet 0.45% of vegetable demands, 0% of fruit demands and 0.23% of overall produce demands for the population within a 400m/5min walking zone of the garden.

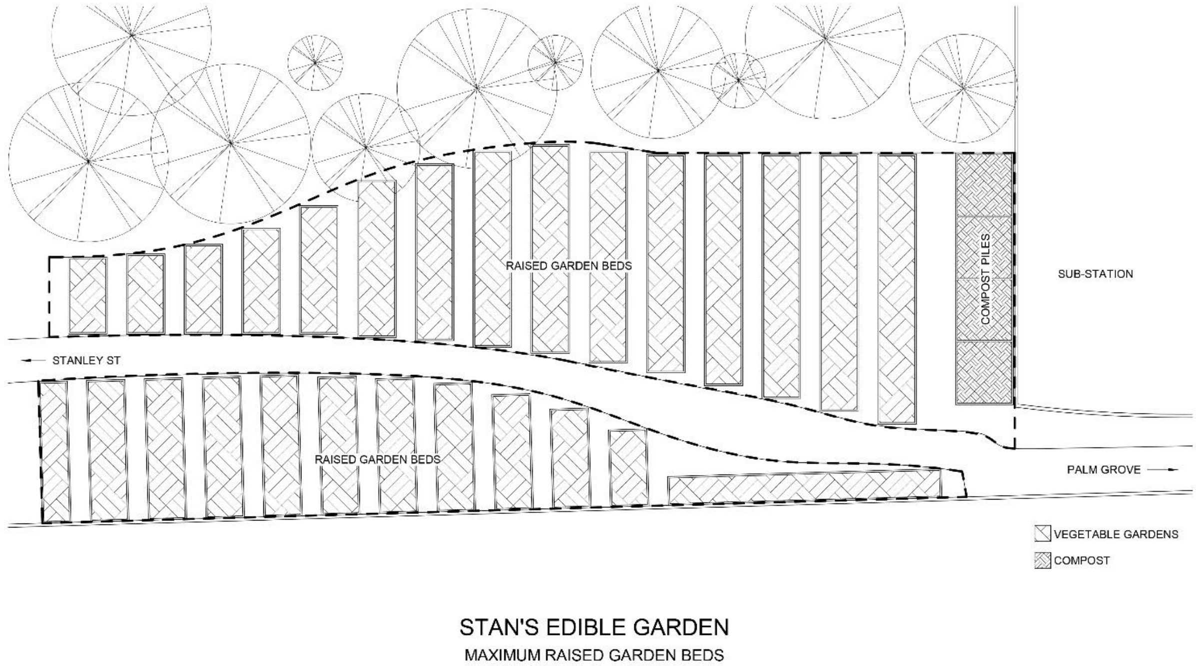


Figure 9

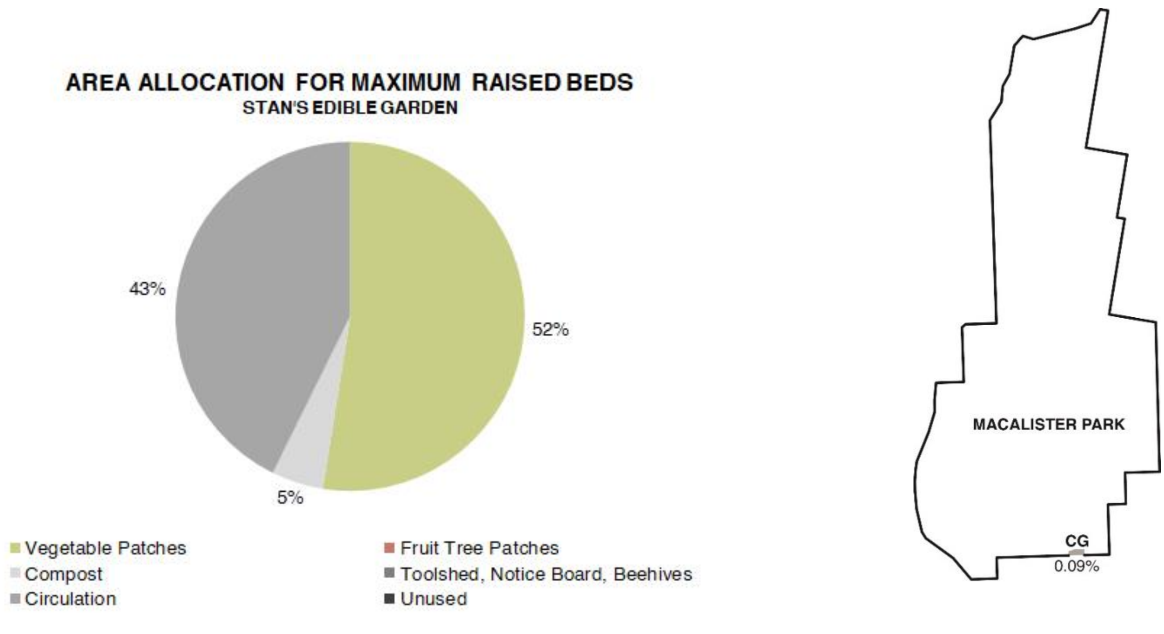


Figure 10

Maximum Fruit Trees

Next, the maximum amount of fruit trees was mapped as shown in figure 17. This strategy was able to dedicate the most amount of area to productive space as circulation happened between the trees. This is reflected in figure 18 which shows percentages of area dedicated to each land use: 89% is dedicated to fruit trees, 5% to composting, 3% to circulation space and 3% of CG area is unused. This version was able to meet 0% of vegetable demands, 0.43% of fruit demands and 0.22% of overall produce demands for the population within a 400m/5min walking zone of the garden.

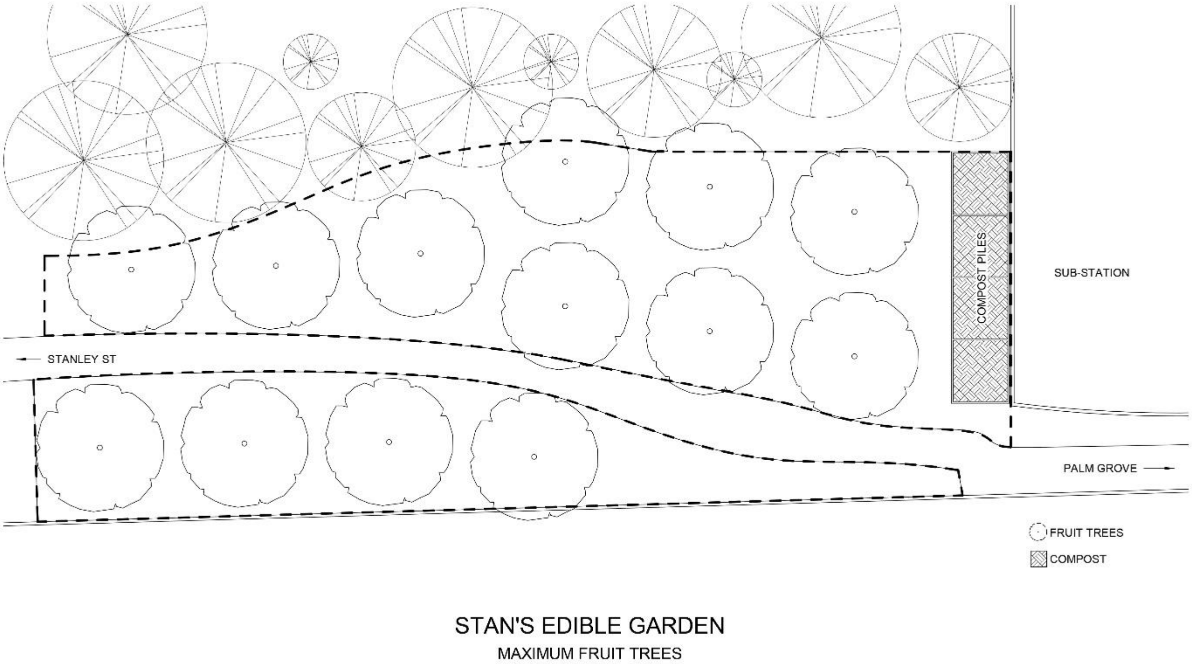


Figure 11

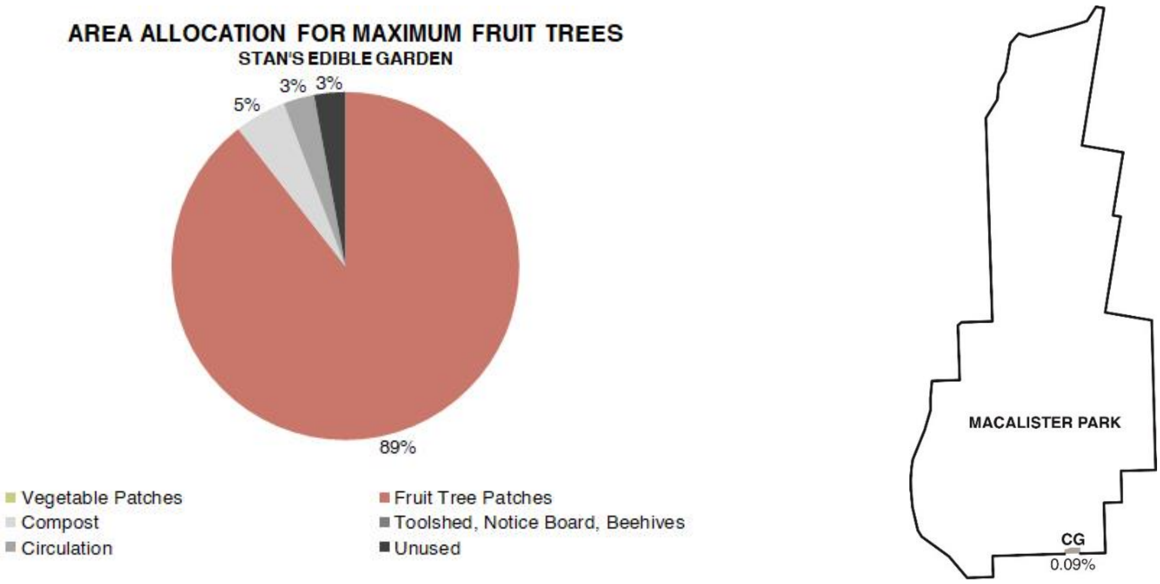


Figure 12

Meeting Produce Demands

The strategies "meeting vegetable demands", "meeting fruit demands" and "meeting produce demands" were mapped next to determine the percentage of CG space that would be needed in each park within which the case study gardens are located in order to meet these demands. Raised style garden beds were found to be less productive than allotment style garden beds. Because of this, allotment style gardening will be used to map "meeting vegetable demands" for the following calculations.

- Island Bay / Berhampore Community Orchard: Meeting Vegetable Demands

In order to meet just the vegetable demands of the surrounding population, this CG would need to increase from the current 1.75% of Martin Lucky Park to 10.46%, thus being 6.0 times larger than the existing CG.

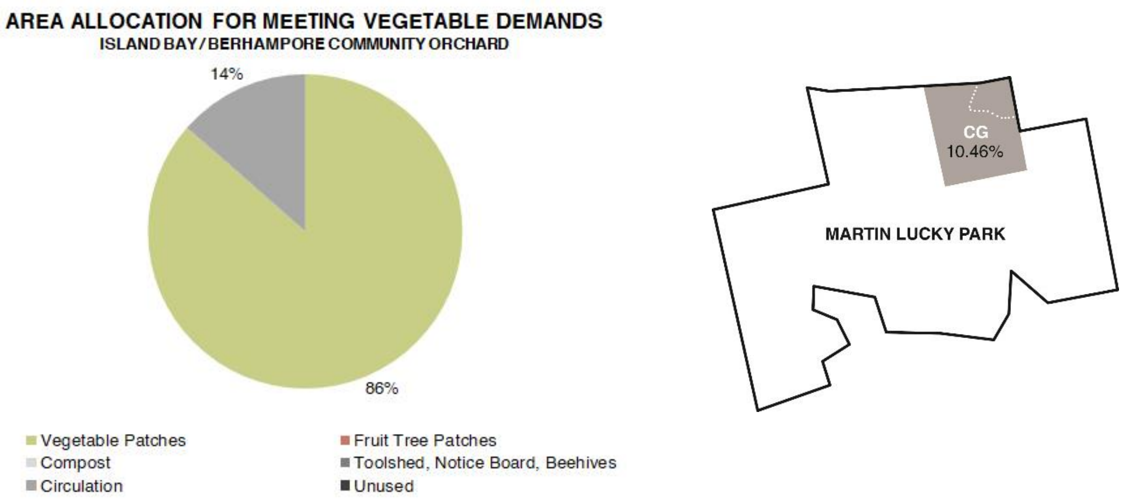


Figure 13

- Meeting Fruit Demands

In order to meet just the fruit demands of the surrounding population, this CG would need to increase from the current 1.75% of Martin Lucky Park to 16.13%, thus being 9.2 times larger than the existing CG.

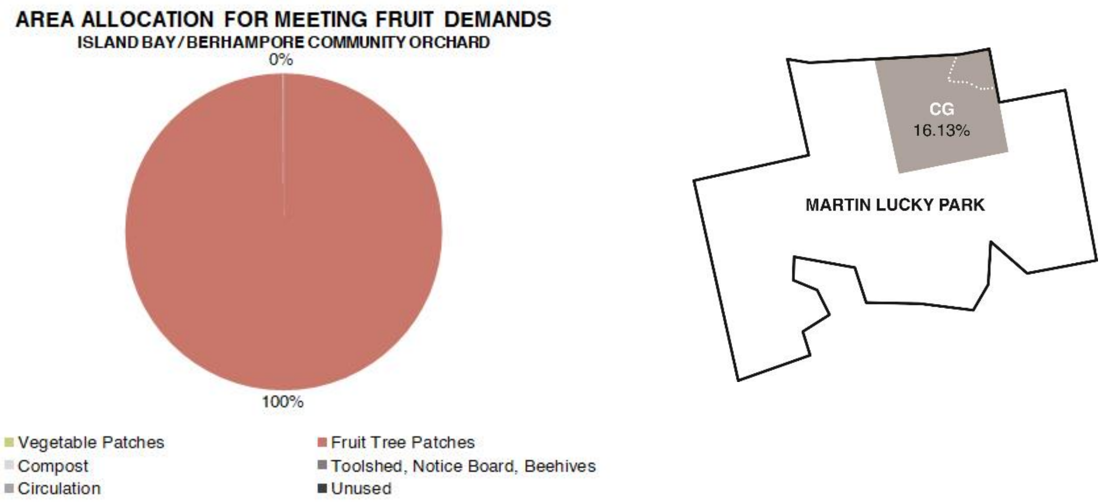


Figure 14

- Meeting Produce Demands

In order to meet the produce demands of the surrounding population, this CG would need to increase from the current 1.75% of Martin Lucky Park to 10.46%, thus being 15.2 times larger than the existing CG.

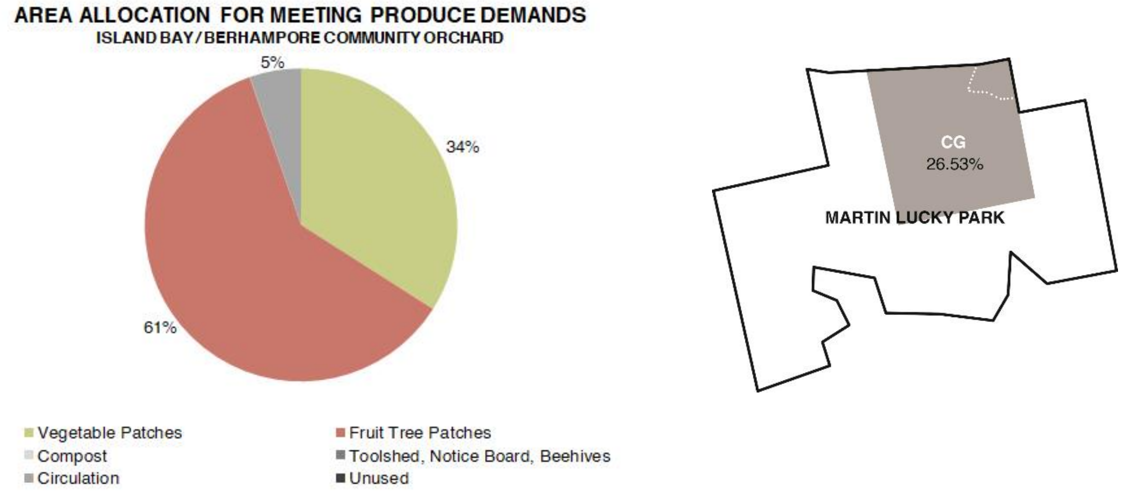


Figure 15

- Stan's Edible Garden: Meeting Vegetable Demands

In order to meet just the vegetable demands of the surrounding population, this CG would need to increase from the current 0.09% of Macalister Park to 14.50%, being 161 times larger than the existing CG.

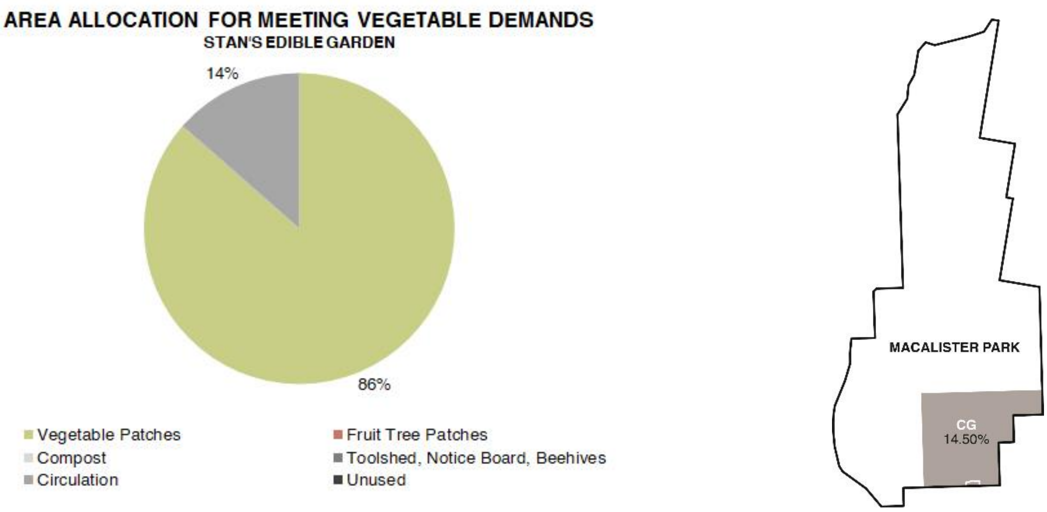


Figure 16

- Meeting Fruit Demands

In order to meet just the fruit demands of the surrounding population, this CG would need to increase from the current 0.09% of Macalister Park to 18.51%, being 205.7 times larger than the existing CG.

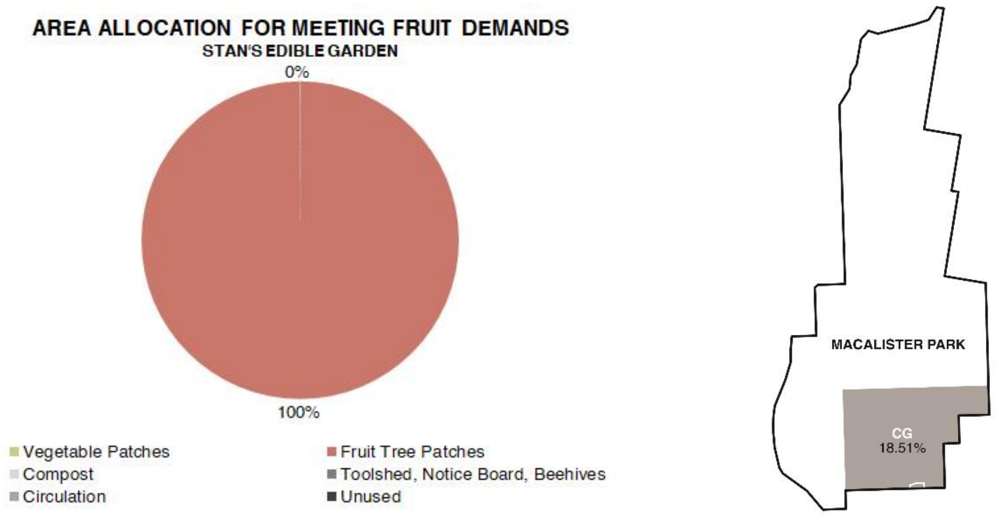


Figure 17

- Meeting Produce Demands

In order to meet the produce demands of the surrounding population, this CG would need to increase from the current 0.09% of Macalister Park to 32.99%, being 366.6 times larger than the existing CG.

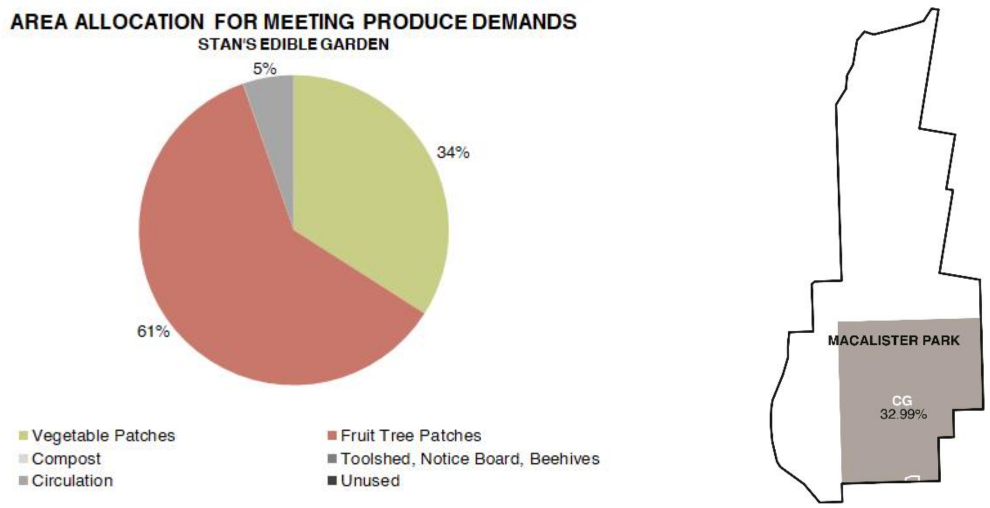


Figure 18

These calculations do not take into account conditions on site (such as steepness, soil quality, growing conditions etc.) and assume good management. These results are therefore are only speculative as to the percentage of the park needed to satisfy conditions such as; "meeting vegetable demands", "meeting fruit demands" and "meeting produce demands" for the population within a 400m/5min walk zone around each case study garden. These factors will be examined further in the limitations and further research chapter of this report.

City Wide GHG Emissions Reduction Strategies

The strategies “maximum lawn”, “maximum fruit and vegetables” and “maximum native New Zealand forest”, “maximum macrocarpa forest” and “maximum radiata forest” were mapped next to determine the net carbon values for each strategy when using the total area designated to CGs in Wellington City. Total area designated to CGs in Wellington City is the total area of land within WCC owned greenspace that is being used by the current 19 registered CGs. To get net carbon values for each strategy, the emissions associated with the management of the strategy are subtracted from the total amount of carbon stored from sequestration.

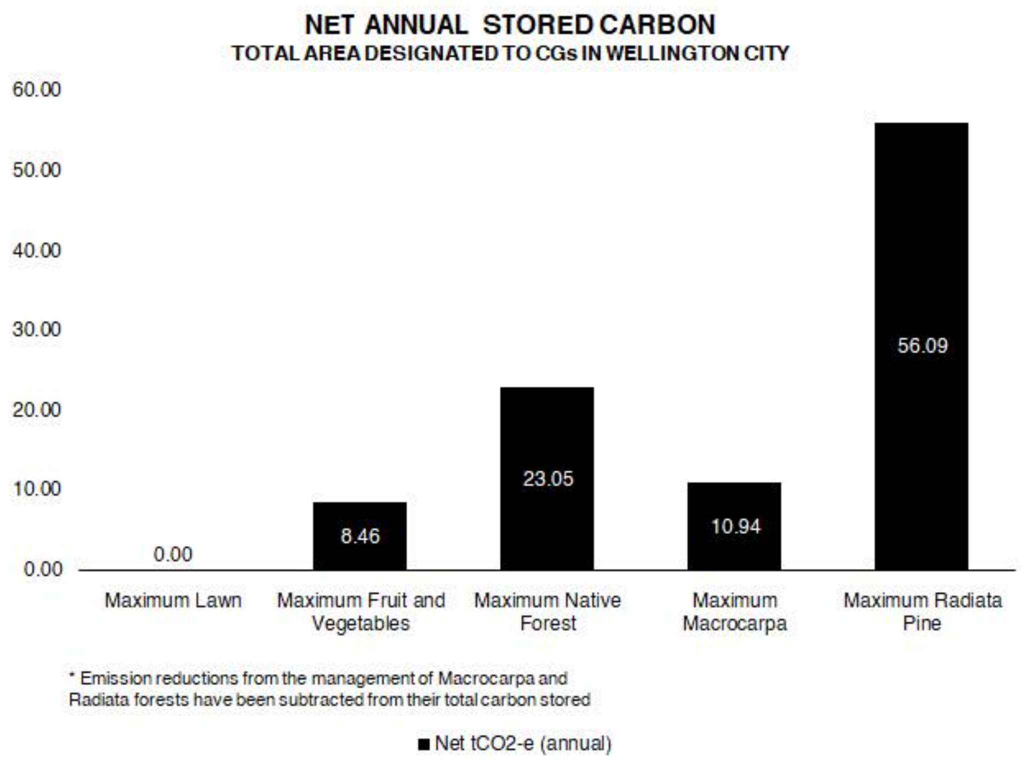


Figure 19

Figure 25 shows the annual tonnes of carbon equivalent stored by each strategy if it were applied to the whole of Wellington’s CGs. The calculations of food miles for each strategy have been based off a few assumptions due to the limited availability of information for this investigation. Because of this, the GHG emissions associated with food miles for each strategy have been stated but not included within the results of figure 25. The details of each strategy are given below.

- Maximum lawn

The carbon that is able to be sequestered by lawn has been disregarded due to the factors previously discussed, therefore this strategy will have 0tCO_2 stored per year. This strategy supplied 0% of Wellington City’s produce demands locally, and the emissions associated with supplying 100% of the produce demands through conventional supply was 304.88tCO_2.

- Maximum Fruit and Vegetables

This strategy was able to store 8.46tCO_2 annually by the fruit trees used in this strategy. This strategy was thus able to store the equivalent of 13 person's annual carbon emissions. This strategy supplied 0.23% of Wellington Cities produce demands locally, therefore the emissions associated with supplying the other 99.77% of Wellington Cities produce demands through conventional supply was 304.17tCO_2

- Maximum Native New Zealand Forest

This strategy was able to store 23.05tCO_2 annually. This strategy was able to store the equivalent of 3.5 Wellingtonian's carbon emissions annually. This strategy supplied 0% of Wellington City's produce demands locally, therefore the emissions associated with supplying 100% of Wellington City's produce demands through conventional supply was 304.88tCO_2.

- Maximum Macrocarpa Forest

The carbon sequestered by a macrocarpa forest was calculated to be 11.09tCO_2. The emissions associated with the management of a macrocarpa forest was calculated to be 0.15tCO_2. This value was then subtracted from the 11.09tCO_2 stored to get a net carbon value of 10.94tCO_2 per year. This strategy was able to store the equivalent of 17 Wellingtonian's carbon emissions annually. This strategy supplied 0% of Wellington Cities produce demands locally, therefore the emissions associated with supplying 100% of Wellington Cities produce demands through conventional supply was 304.88tCO_2.

- Maximum Radiata Forest

The carbon sequestered by a radiata forest was calculated to be 68.02tCO_2. The emissions associated with the management of a radiata forest were calculated to be 11.93tCO_2. This value was then subtracted from the 68.02tCO_2 stored to get a net carbon value of 56.09tCO_2 per year. This strategy was able to store the equivalent of 85 Wellingtonian's carbon emissions annually. This strategy supplied 0% of Wellington City's produce demands locally, therefore the emissions associated with supplying 100% of Wellington City's produce demands through conventional supply was 304.88tCO_2.

These results show that all urban forest strategies are more effective at reducing carbon emissions than dedicating the same space to growing produce. Radiata forest was able to store the most carbon, followed by native New Zealand forest and then macrocarpa forest. Even though radiata forest was found to be the most effective strategy at storing carbon, it comes with a range of disadvantages. These include the lost social, economic and environmental benefits from having no space designated to CGs as well as short term carbon storage and bio-diversity decrease. These disadvantages will be examined further in the "discussion chapter" of this research.

Mapping Impact Reduction Strategies for WCC Owned Open Space

The land uses of WCC owned greenspace are currently dedicated to bush, reserve, town belt, the harbour, sportsgrounds, walkways, play areas, bedding, gardens, shrub areas and general purpose parks (WCC, n.d.). While not all of WCC owned greenspace could logically be cultivated for produce

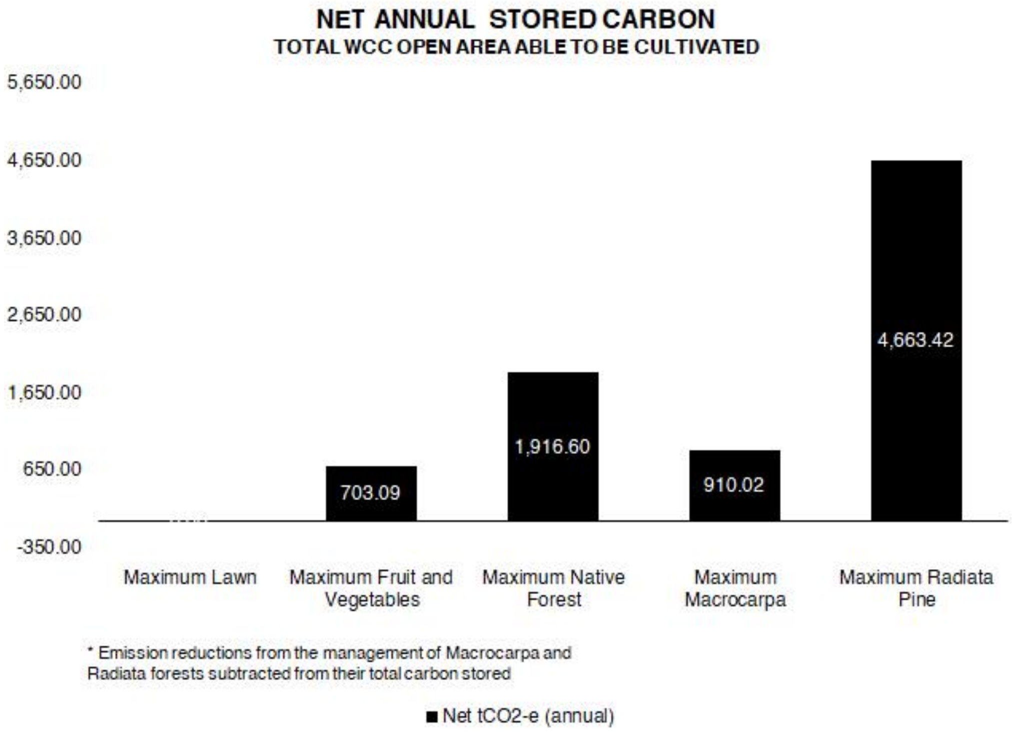


Figure 20

or planted in urban forest (due to land use and site conditions), this investigation assumes that it would be possible to turn the spaces dedicated to sportsgrounds, bedding, gardens, shrub areas and general purpose parks into either land cultivated for produce or urban forest. Using estimations provided by WCC on their website the area that could logically be cultivated was calculated to be 3,073,600m^2. The same city wide impact reduction strategies used for the previous calculations have been mapped within this area and the results are presented in figure 26.

Strategy	Net Annual Stored Carbon	Equivalent Emissions (per person)
Maximum Lawn	0tCO_2	0
Maximum Fruit and Vegetables	703.09tCO_2	1065
Maximum Native Forest	1,916.60tCO_2	2904
Maximum Macrocarpa	910.02tCO_2	1379
Maximum Radiata	4,663.42tCO_2	7066

Predicted Density Increase

This research has primarily focused on data from 2013, due to limited availability of data from the 2018 New Zealand census, and data from Food and Agriculture Organization Corporate Statistical Database (FAOSTAT). As previously discussed, urban populations are predicted to increase by 66% by 2050 (UN, 2012b). Wellington City has been predicted to grow to a population of 250,000 by 2043 (Wellington (N. Z.). City Council, 2014). As this predicted population increase will have an effect on

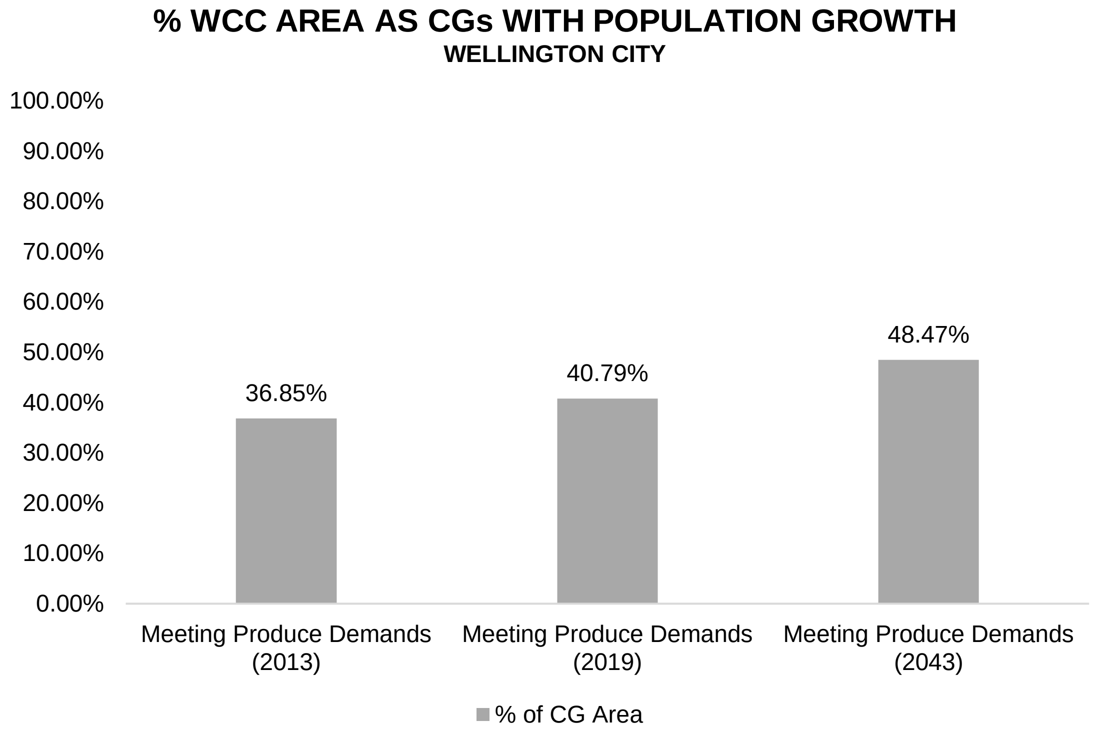


Figure 21

this investigation, a calculation has been carried out to determine the percentage of WCC owned greenspace needed to meet the produce demands for the 2013 population, the population from most recent 2019 estimate, and the predicted population of 2043, the results are shown in figure 27. These calculations have been carried out using the same methodology for “meeting produce demands”, as discussed previously, but has used total WCC owned appropriate green space and total Wellington populations of each year. In 2013, to meet the produce demands for a population of 190,062 people, 36.85% of WCC owned appropriate green space would need to be dedicated to growing fruit and vegetables. In 2019 to meet the produce demands for a population of 210,400 people, 40.79% of WCC owned appropriate green space would need to be dedicated to growing fruit and vegetables, and in 2043 to meet the produce demands for a population of 250,000 people this would need to be 48.47% of WCC owned appropriate green space.

Discussion

Density Implications

An interesting finding from this investigation was that the density difference between the case studies influenced the potential of each site to meet produce demands. While Island Bay / Berhampore Community Orchard has a larger overall area than Stan’s Edible Garden, it was surrounded by a smaller population, with 796 people within the 400m/5min walk zone of the Island Bay / Berhampore Community Orchard compared to 1088 people within the 400m/5min walk zone of Stan's Edible Garden. This means that when the area designated to Island Bay / Berhampore Community Orchard was mapped to be "maximum vegetable patches" or "maximum fruit trees", it was able to meet more of the produce demands for the surrounding area. The implication of this is that both the size of the CG and the surrounding population density will have an effect on the ability of the CG to meet produce demands.

Predicted Growth

The results of this investigation show that if all produce consumed by Wellington's population in 2043 was to be grown within the city the amount of CG space would need to grow by 1.3 times from the amount needed in 2013. While a feasibility study would be necessary to determine whether this increase in CG space is practical or not, the predicted population increase has implications for the UEI reduction strategies outlined in this investigation. As the population of Wellington City increases, the measures for UEI reduction would need to also increase if UEI is to be managed.

Should We Be Growing Produce or Trees?

This investigation determined that planting urban forests was a more effective strategy for reducing UEI through carbon emission reductions compared with using the same area to grow produce. However, this has been determined purely on the carbon emission benefits of these strategies, and does not take into account any of the other potential benefits or downsides of each strategy. Having CGs in a community provides a host of economic, social and environmental benefits that can potentially provide an overall greater reduction in UEI than planting urban forest to purely sequester carbon. The CG can encourage walking and cycling rather than driving to the supermarket, and the exercise from garden could offset driving to the gym. The reason this investigation primarily focuses on the carbon emission reductions of each strategy is that the reality of implementing each strategy is far more complex than this investigation could take into account. Using carbon emission reductions gave a metric that enabled comparison of the strategies. While this investigation does not suggest that planting urban forests is the best way to reduce UEI, the findings suggest that it is currently the most effective strategy out of those evaluated if nothing else changes. What is clear from the evaluation is that anything is better than having green space as grass.

Disadvantages of Radiata Pine

Out of the potential urban forests analysed, the results of this investigation suggest that a radiata pine forest would be the most effective strategy to reduce carbon emissions. This does not take into account the many disadvantages of planting such a forest. Radiata forests are primary grown in New Zealand as a harvested wood product (HWP). This means that when the forest plantation reaches its maximum carbon storage potential after 20 years it will be harvested and turned into timber products rather than acting as a long term carbon sink. Johnston & Radeloff (2019) found that HWPs are offsetting less than 1% of global carbon emissions due to the associated lifecycles of these forests. While a radiata forest may be able to sequester a larger amount of carbon than a native New Zealand forest could within the same time period, the latter is possibly a more effective solution to providing long term carbon storage. Another disadvantage that is often associated with a radiata forest is the loss of biodiversity. Braun et al. (2017) found that the maintenance and management of a plantation forest may be a factor that influences the loss of biodiversity within these types of forests. The less intensive maintenance and management of a native New Zealand forest may provide an increase in bio-diversity compared to the intensive maintenance and management of a radiata forest. While the results in this investigation suggest that radiata pine is the most effective urban forest for reducing carbon emissions annually, a native New Zealand forest may be more effective for reducing UEI overall due to its ability to provide long term carbon storage and its potential to provide more bio-diversity.

Limitations and Further Research

Due to the limited time and resources of this research some assumptions have been made when carrying out the investigations in this report.

Food Miles Assumptions

The food miles emissions associated with each UEI reduction strategy are based on the assumption that all the vegetables consumed by the population of Wellington City would come from the Otaki region, Kapiti and that all the fruit consumed would come from the Cromwell region, Central Otago. These assumptions were made in order to be able to calculate the food miles emissions but are not representative of how Wellington City's produce in supplied. Because of this, food mile emissions have been omitted from the "net annual stored carbon" calculations, but have still been reported to give an indication of the potential food mile emissions implications for each strategy. Further research would be required to verify the full impact of food mile emissions for Wellington City. There are other emissions associated with food from supermarkets such as the emissions from the retail store and those of driving to it and back to home that should also be included in a fuller study

Good Management

All of the UEI reduction strategies have assumed good management. This means that there would be enough resources and labour provided to produce the maximum yields from the fruit and vegetable patches planted and would allow the maximum sequestered carbon from the urban forest strategies. Good management would be largely influenced by the amount of funding these UEI reduction strategies would receive. This investigation has not taken into such factors into account, which could have an impact on the effectiveness of each strategy.

Site Conditions

For the calculations of "the percentage of WCC owned greenspace needed to meet produce demands" it has been assumed that the area of WCC owned greenspace needed would be suitable for growing the produce required. A feasibility study for sites within WCC owned greenspace would be required in order to verify that these strategies are in fact possible.

Conclusion

This research investigated how community gardens can reduce the environmental impact of urban areas within Wellington City, New Zealand. This investigation was conducted by mapping and analysing two established community gardens within Wellington City using metrics established from literature. Next, various UEI reduction strategies were mapped into both the case study garden and the total area designated to CGs within Wellington City. These strategies were analysed using the metrics established from the literature in order to determine the effectiveness of each UEI reduction strategy. The findings suggest that planting urban forests would be a more effective strategy for reducing UEI by storing more net carbon annually compared to cultivating fruit and vegetables to supply produce locally. These findings also suggest that a radiata pine forest was the most effective urban forest for reducing urban environmental impact through its ability to store the most net carbon annually. These findings do not take into account the disadvantages associated with converting this area into a radiata pine forest. As discussed, a native New Zealand forest may be a more effective urban environmental impact reduction strategy overall, compared to a radiata pine forest because of its ability to provide long term carbon storage and potential bio-diversity increase. Further research would be required to verify that these strategies are possible and practical.

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