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SCENARIOS FOR VERTICAL AGRICULTURE DEVELOPMENT IN THE LOWER MAINLAND, BRITISH COLUMBIA

This report models the potential contribution of vertical agriculture to urban/regional food systems in the Lower Mainland, British Columbia. To see our other research, please visit http://www.tinyurl.com/FAI-vertag

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ACKNOWLEDGEMENTS

The Food and Agriculture Institute at the University of the Fraser Valley is situated on the sacred lands of the Stó:lō peoples. The Stó:lō have an intrinsic relationship with S'ólh Tém:éxw (Our Sacred Land), and we express our gratitude and respect for the honour of living and working in this territory.

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Background

The city-region has emerged as a key focus for food system planning, with substantial public interest in developing local (i.e., urban, peri-urban, and regional) networks of food production and distribution in ways that contribute to urban food security and ecosystem services. To date, very little research has modelled the potential impacts of vertical agriculture in these local food systems. As an emerging approach to urban food production, it is important to consider what role vertical agriculture can play in the urban and regional agricultural landscape. To this end, this research examines six scenarios for vertical agriculture development in the Lower Mainland, British Columbia. It models the potential food security and environmental implications of establishing up to 100 vertical farms across the region in different development patterns.

Key Findings

- Scenarios for vertical agriculture can vary depending on the scale of operation (medium vs. large), business model (direct-to-consumer vs. wholesale), and the land-use and building type (mixed-use vs. commercial industrial vs. community food development)

- Approximately 85% of the census tracts within the Lower Mainland British Columbia were deemed as potentially suitable for vertical agriculture deployment. A total of 53 census tracts were appropriate sites of vertical agriculture in all scenarios, and thus may be the best locations for multiple types of vertical farms and operations.

- Communities with many suitable locations for vertical agriculture development in the mixed-use context include Surrey, White Rock, and parts of Chilliwack. In the commercial and industrial land-use contexts, communities with many suitable locations include North Vancouver, Coquitlam, Langley, Abbotsford, and parts of Chilliwack. Vancouver has the greatest number of census tracts that are suitable for developing vertical agriculture to support social services and community food organizations.

- Most census tracts could be suitable for mixed-use development that includes vertical agriculture. In best case yield scenarios, vertical agriculture could meet the daily recommended greens intake for between 20-130% of residents located within walking distance of each farm, while in medium yield scenarios ~4-25% of local residents could be supplied their recommended greens intake.

- It is estimated that 100 high yielding vertical farms in the Lower Mainland could increase British Columbia's current reported yield of lettuce and spinach by 1.3 fold, with no additional agricultural land use.

Future work is required to work with community members, industry, and local government to ground-truth scenarios with respect to actual yields, land footprint, water consumption, and site suitability. Further efforts to refine the criteria and weightings of the metrics in the analysis of the scenarios will make for a more robust analysis. Future efforts to diversify product offerings from vertical farms could contribute significantly to sustainability objectives around food security and the environment.

1. Introduction

The scaling and strengthening of regional food supply chains has emerged over the past several decades as a key public and policy priority in North America. The local food movement has resulted in the rise of local food policy councils, urban farms, community shared agriculture systems, local buying campaigns, and food waste reduction schemes, and many other programs and projects that aim to safeguard urban food security in times of real and potential supply chain disruptions (Blay-Palmer, 2018; Glaros et al., 2021). The “city-region”, comprised of interconnected urban, peri-urban, and rural spaces and communities within a metropolitan area, is an important geographical scale for sustainable and resilient food system planning and development.

Urban agriculture is a strategy for strengthening local and regional food systems. Growing food within urban areas or along the peri-urban fringe can support an array of food system resilience and sustainability-related goals. For example, urban gardens have been used to support food supply in times of crisis and supply chain disruptions (Hamilton et al., 2014; Mok et al., 2014). Urban farms can also benefit local ecosystem services, such as maintenance of genetic diversity and biological control to suppress pests (Evans et al., 2022). Urban farms and gardens are further associated with a number of socio-economic benefits, such as local employment opportunities, building social capital, as well as educational opportunities and knowledge sharing (Colding et al., 2015).

Despite the promise, researchers caution that there is a need for more place-based and quantitative studies to fully assess urban agriculture’s potential benefits on food security and the environment (Goodman & Minner, 2019; Evans et al., 2022). Accordingly, some research has attempted to better understand how many people in a city can be fed through urban production, as well as the economic and environmental implications of this production. Desjardins et al. (2009) modelled how much land is needed to support the nutritive needs of residents in the Waterloo Region, Ontario, finding that a modest increase in acreage devoted to local food production could support 10-100% of recommended nutritional intake of grains and produce. In a study based in Edmonton, Alberta, Wang et al (2014) explored how increasing urban agriculture operations could help increase local food access in food desert areas in the city. In related work, Smith et al (2021) found that local government and stakeholders in the Phoenix metropolitan area prioritized social factors, such as low income and low food access, to guide the strategic placement of urban food gardens, and they identified how site selection for urban agriculture can be a contested process with potential tradeoffs.

Emerging approaches to urban agriculture such as vertical agriculture (i.e., producing food indoors using stacked shelves and hydroponic or aeroponic methods) have the potential to increase local, year-round availability of produce using minimal land and water resources (Newman et al., 2023). However, questions remain about the degree to which vertical agriculture can contribute to food security and environmental objectives, as well as the spatial configurations and site locations that optimize these contributions. Only recently have studies modelled these aspects of vertical agriculture, and such studies typically involve limited geographic contexts and using company self-reported environmental performance and yield data (Goodman & Minner, 2019). Goodman and Minner (2019) found that the potential contribution of vertical agriculture to sustainable and resilient local food systems is dependent on its scale, location, and governance as a commercial, institutional, or community operation, thusly indicating a need for mapping, modelling, and analysing different vertical agriculture scenarios in a community or region based on these types of considerations.

This research serves to support planning for the integration of vertical farming as a part of urban and regional food and agriculture systems. We develop a set of social and economic criteria to define potential land use scenarios for vertical agriculture. Then, using publicly available environmental and demographic data, we model the potential food security and environmental outcomes of different vertical agriculture development scenarios in the Lower Mainland, British Columbia.

2. Methods

2.1 Data

Data for this study were sourced from publicly available repositories, including Census Canada data tables (for census tracts, income, population counts, densities), open geodatabases from municipalities (n=13) in the study area, Open Street Map, and the Government of British Columbia's Open Data Catalogue. Population density data was sourced from Worldpop (2018), and average commercial property lease values for each municipality were calculated from the website Realtor.ca.

All analyses were done at the level of census tracts with the Lower Mainland region, which are geographic units with populations between 2,500 and 8,000 in each area. The analysis targeted 'population centres' in particular, defined by Statistics Canada as census tracts with a population of over 1,000 people and a density of greater than 400 people per square kilometer. Approximately 85% of the census tracts in the Lower Mainland followed this definition (n=532), and were included as relevant for our analysis.

2.2 Scenario Mapping and Site Suitability

The first step of the analysis involved defining different scenarios and mapping them based on criteria related to the features and objectives of the scenarios. In consultation with our industry partners at QuantoTech and i-Open Technologies, we identified six scenarios for vertical agriculture development in the Lower Mainland. These scenarios were developed based on three considerations: scale of operation, business model, and land/building use. As seen in Figure 1, these considerations were arranged on axes on which scenarios could be placed and characterized.

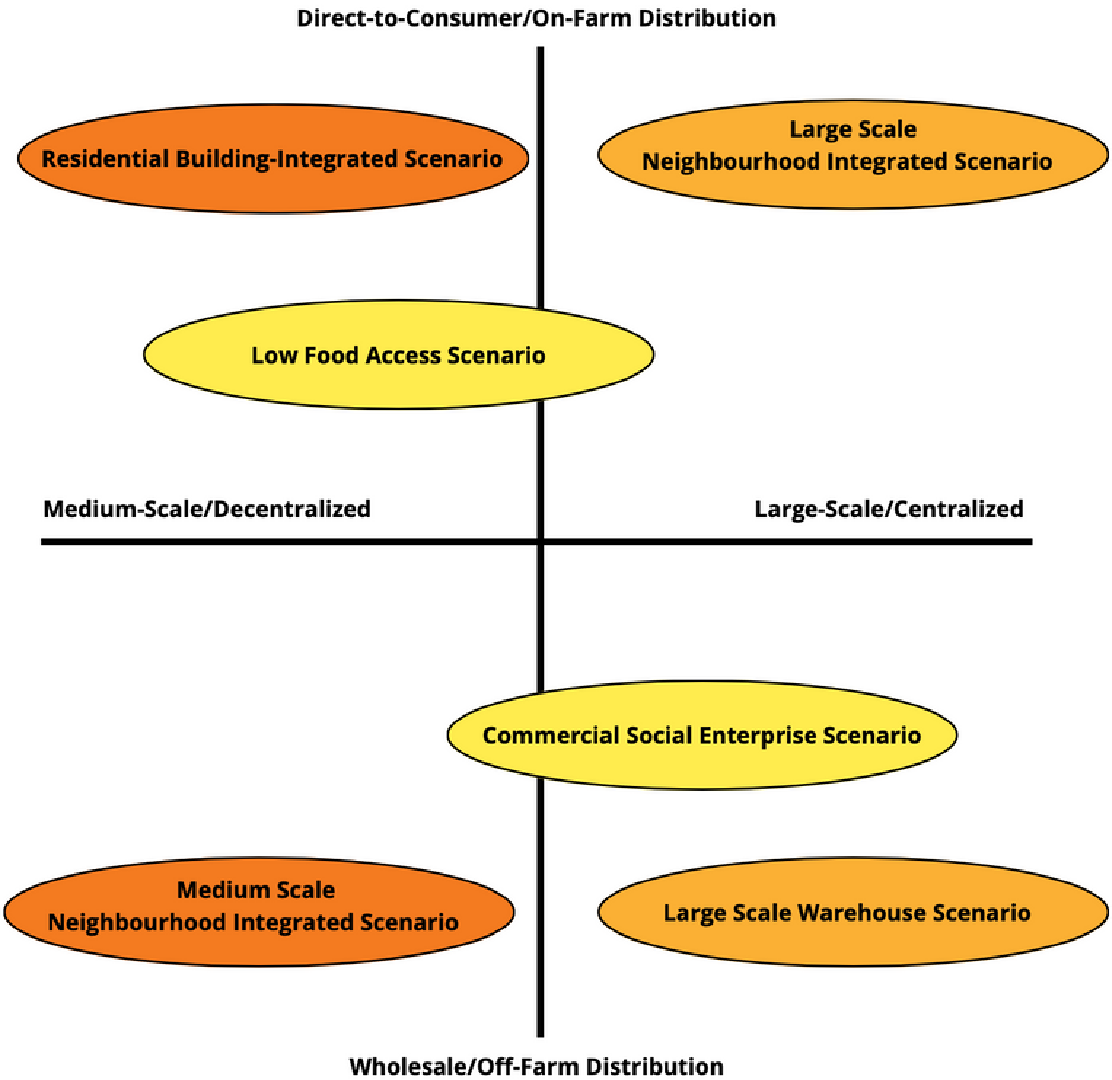

Figure 1. Scenarios for vertical agriculture deployment in the Lower Mainland, British Columbia.

The left side of the horizontal axis in Figure 1 refers to medium-scale operations (i.e., no larger than a small retail store or a small office space for production), while the right side refers to large-scale operations (i.e., large warehouse/office and light industrial spaces for production). The top of the vertical axis refers to direct-to-consumer operations (i.e., where consumers can pick or purchase products right from the farm or from a farmstand), while the bottom refers to wholesale business models (i.e., selling product from farms to retailers). The colour of each bubble refers to land use types, where the dark orange bubbles capture scenarios where vertical farms are in mixed-use developments, medium orange capture commercial and industrial land use scenarios, and yellow capture scenarios where vertical agriculture supports social service and food bank/community food organizations.

Drawing from similar approaches for urban agriculture used by Smith et al (2021) and Mosammam et al (2017), the presence of food deserts (e.g., low proximity to food assets and low income populations) were included as a potential way of selecting potential sites for vertical agriculture development. Then in consultation with our industry partners, additional considerations for vertical agriculture development were identified using a business perspective. The resulting 10 criteria for defining scenarios were assigned varying weights, based on the scenario features and objectives. Table 1 provides more detail on the criteria for defining the scenarios. In future research, we will undertake a Delphi approach to assign more accurate and representative weights based upon stakeholder opinion and considerations.

Table 1. Scenario criteria descriptions.

Criteria	Description
Proximity to grocery stores	Euclidean distance (in meters) from population weighted centroid to nearest grocery store.
Proximity to restaurants	Euclidean distance (in meters) from population weighted centroid to nearest restaurant.
Proximity to public transit	Euclidean distance (in meters) from population weighted centroid to nearest public transit stop.
Proximity to grocery store clusters	Euclidean distance (in meters) from population weighted centroid to nearest cluster of grocery stores. Grocery store clusters were found using DBSCAN clustering technique, defined as a minimum of 5 stores within 1000 meters of one another.
Proximity to restaurant clusters	Euclidean distance (in meters) from population weighted centroid to nearest cluster of restaurants. Restaurant clusters were found using DBSCAN clustering technique, defined as a minimum of 6 restaurants within 500 meters of one another.
After tax income	Average after tax income (2021) per census tract.
Population density	Number of people per square kilometer per census tract.

The land-use and building types for the scenarios were defined using Official Community Plan and Zoning data of the municipalities. Due to limitations around data availability and usage, the cities of Richmond and Delta were not included in this analysis.

2.3 Scenario Outcomes

After mapping the most suitable locations for vertical agriculture development under each scenario, potential scenario outcomes were modelled using Geographic Information Systems (GIS) software and environmental performance data from the life cycle literature. Metrics used for this analysis are provided in Table 2. Using the top ten, fifty, and one hundred most appropriate census tracts based on the scenario criteria, scenario modelling estimated the number of people within walking distance of potential vertical farm locations and reductions in water, land, and energy consumption due to decreased production through conventional agriculture.

All distances from potential retail sources (i.e., grocery or restaurant stores/clusters) were calculated to their respective census tract's centroid, weighted by population distribution in the census tract (calculated using 100m by 100m population rasters) (Worldpop, 2018). Walking distances were analysed by using 353m buffers around the potential retail locations. This number was used as it is the hypotenuse of a triangle with two 250m sides, and working under the assumption that residents will walk a grid-like road network to the retail location, a 353m buffer suggests the location is within half a kilometer (i.e., 250m + 250m) walkability distance of residents living within the buffer.

Scenario analysis drew from life cycle assessments and vertical agriculture models in the academic literature (Table 2). Estimates for conventional open field lettuce yield and water usage were comparable across multiple studies; thus, a common value was use for the analysis. However, yield estimates varied dramatically across many of the life cycle analysis studies; thus, three estimates are used for all calculations, ranging from worst to best case. The worst performing yield is highly conservative, derived from a horizontal hydroponic system without stacked growing shelves (Barbosa et al., 2015). The middle performing yield case was found in a study on a 7-layer, indoor lettuce producing system (Blom et al., 2022). The best case yield was obtained by multiplying Touliatos and McAinsh (2016) yield by a factor of 6 to account for year-long production, as their yield estimate (95 kg/m^2) was collected over a period of 5-6 weeks. They found that vertical production had a 13.8 times greater yield in their system as compared to a horizontal hydroponic production system. Multiplying Barbosa et al. (2015) horizontal hydroponic yield (40 kg/m^2/year) as well as Blom et al. (2022) horizontal hydroponic yield (53 kg/m^2/year) by a factor of 13.8 yields similarly high yield estimates (552 - 731.4 kg/m^2 /year), and so we include the 570 kg/m^2/year estimate as a plausible best case scenario.

We use the same floor area as Blom et al (2022) to estimate production yields, given that their growing system is relatively conservative in size (90m^2) and is part of an office development with both a growing facility and processing space on-site. This size is appropriate given our desire to model small- to medium-scale vertical agriculture in the mixed land use scenarios. We assumed that vertical agriculture development in commercial industrial scenarios would occur at a substantially larger-scale, and so we doubled the floor area (180m^2). Cost estimates were based on an assumption that the local lettuce would displace imported lettuce, predominantly from the Salinas region of California. Thus, we use water costs specific to non-residential metered sites in the Salinas Valley, as well as state-wise estimates for farm real estate costs.

The carbon emissions calculations drew from Crawford (2023), comparing avoided transportation of lettuce from California the United States and emissions due to operational energy use for vertical farms. Such a comparison captures a 'promise' and a concern commonly attributed to vertical agriculture, respectively that vertical farming may reduce emissions related to food miles but also may increase emissions related to energy consumption (Newman et al., 2023). Our calculation does not capture emissions of conventional agriculture practices nor the transportation of vertically-grown produce.

Table 2. Food security, economic and environmental impact metrics and assumptions.

Metrics	Value/Range	Source
Yield of Greens	40 kg/m^2/year 101 kg/m^2/year 570 kg/m^2/year	Barbosa et al (2015) Blom et al (2022) Touliatos & McAinsh (2016)
Water Saved in Comparison to Conventional	3.7 l/kg freshweight lettuce	Blom et al (2022)
Conventional open field lettuce yield	2.95 kg/m^2/year	Blom et al (2022)
Cost of water (Salinas California)	5.55 $CAD/100 cubic feet	California Water Service Company (2021)
Cost of farm real estate (California)	16,312 $CAD/Acre	USDA (2022)
Building size	$90m^2$	Blom et al (2022)
Carbon emissions from long-distance refrigerated transport of lettuce to Vancouver	1168.7 $kgCO_2e$/tonne lettuce	Crawford (2023)
Energy use values of vertical farm	14.7 kWh/kg fresh weight lettuce	Blom et al (2022) Crawford (2023)
Vancouver energy grid emissions	0.0130 $kgCO_2e$/kWh	Government of Canada (2022)

3. Vertical Agriculture Scenarios

This section provides the results of the scenario mapping and modelling work, and it is organized into three subsections. The first subsection provides 'scenario narratives' that describe how the scenarios may appear in Lower Mainland communities if implemented in the real-world, and then identifies the features and site selection criteria for the scenarios. The following subsection discusses where the most suitable locations for vertical agriculture development are based on the different scenarios criteria, features, and objectives, and this discussion is complemented with a series of figures displaying suitability maps. The final subsection describes the results of the outcomes analysis, examining the potential food security and environmental outcomes for the diverse scenarios for vertical agriculture development.

3.1 Scenario Narratives and Criteria

Table 3. Suitability weightings by scenario.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Income	20	10	20	10	36	30
Population Density	30	5	30	5	11	25
Percentage without Employment	0	0	0	0	18	0
Distance to Grocery Stores	0	0	0	0	22	25
Distance to Restaurants	0	0	0	0	0	20
Distance to Public Transit	0	0	10	0	13	0
Distance to Grocery Clusters	0	25	0	25	0	0
Distance to Restaurant Clusters	0	15	0	15	0	0
Land and Zoning Incentives	30	30	0	0	0	0
Property Values	20	15	40	45	0	0

3.1.1 Mixed-Use

Scenario 1: Mixed-use Building Scale

Exiting their apartment door, an Abbotsford resident grabs a plastic bag and takes the elevator down to the basement of their 8-story apartment building. The metal doors slide open. They turn right, walking another 10 meters past the carpark doors to the farm entrance. They greet the grower, who is crouched down reading the pH level of one of the nutrient water reservoirs. The grower is another building resident, receiving a rent discount to manage the grow facility between 5-8pm three nights a week. The resident selects a bundle of butterhead lettuce and taps their credit card on the way out, heading upstairs to prepare dinner.

In this scenario, we assume vertical agriculture develops within mixed-use development zones, with a focus on incorporating farms into residential and mixed-use spaces (e.g., apartment or condominium buildings). Medium-scale production of vegetables takes place for a mix of educational, for-profit, and on-site retail and consumption purposes.

The site selection criteria for this scenario is most highly weighted toward population density (30%) and presence of land use and zoning incentives (30%). This is based on the assumption that vertical agriculture under this scenario would here be targeted toward dense, local population centres, and would be attractive to developers seeking density bonuses. The second highest weighted criteria are high income (20%) and low property values (20%). High local income values indicate a larger potential local consumer base for purchasing farm products, while lower property values may attract new developers.

Scenario 2: Medium-use Neighbourhood Scale

On a walk with their dog, a resident passes the new farm in their neighbourhood. The farm had recently replaced a retail store that had seen better days, and it certainly did not look like their community garden at the local church. A truck in the back parking lot loads pallets of packaged microgreens and butterhead lettuce. The resident ties their dog to a small bench outside, and enters the door. A small selection of greens is packaged and displayed on the right. The person at the counter explains that most of their produce is available from local superstores and restaurants. The resident takes a package of greens home to try.

In this scenario, we assume vertical agriculture develops within mixed-use neighbourhoods, focusing on establishing farms into dense commercial spaces and near residential parcels. The scenario differs from Scenario 1 in that it establishes farms in commercial buildings or as stand-alone units (i.e., containers/sheds in a lot) rather than mixed-use residential-commercial. Medium-scale production of vegetables takes place for distribution to local retailers, including grocery stores and restaurants.

Site selection criteria in this scenario are most weighted toward land use and zoning incentives (30%), as well as close proximity to nearby potential retailers including grocery store clusters (25%) and restaurant clusters (15%). Other criteria weightings include high income (10%), high population density (5%) and low local property value for facility placement (15%).

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3.1.2 Commercial and Industrial

Scenario 3: Large-Scale Neighbourhood-Integrated

A North Vancouver resident rides their bike a short fifteen minutes to their local farm. After locking their bike, they walk through a doorway into a cool hallway, past a window framing a scene of an active warehouse lit by purple grow lights, with spinning conveyor belts and a team of 10 people harvesting and placing produce delicately in clam-shell packages. The local resident proceeds into a retail shop next to the growing warehouse, selects a head of romaine lettuce, a package of microgreens, and two pints of strawberries from the produce aisle.

In this scenario, we assume that vertical agriculture develops within commercial-industrial zones located nearby areas of high population densities. The scenario also includes development of vertical farms on ALR land in urban areas that currently have buildings which can be repurposed for such use. The scenario targets large-scale production and economies of scale, leading to greater resource use efficiencies. Sales are carried out mostly on-site via a large retail site attached to the grow facility.

Site selection criteria are weighted toward low local property values (40%) for site placement. Weightings also include high local income (20%), high population density (30%), and high access to transit (10%) for potential customers and local distribution.

Scenario 4: Large-Scale Warehouse

It is a Sunday in January, and a Burnaby resident hops in the car to do their weekly shopping trip for their family. They enter a Save-on-Foods and proceed to the produce section. Picking up some bananas and berries, they walk over to take some romaine lettuce. The resident's eyes widen at how small the handful of romaine packages from California are while being priced at $15 for the second week in a row. They look to their right and see a selection of local, hydroponically grown lettuce, roots still attached, for $6. The lettuce is from a vertical farm located thirty kilometers away in a building that was previously a carpet factory. Lettuce is grown year-round in this large warehouse, with on average, one ton of lettuce being grown daily.

In this scenario, we assume that vertical agriculture develops in industrial, peri-urban commercial-industrial zones, and repurposed buildings on ALR land in urban areas. As with Scenario 3, this scenario targets large-scale production and economies of scale, leading to greater resource use efficiencies. Distribution primarily involves wholesale supply to large grocery chains, local food retailers, and restaurants, with limited direct-to-consumer sales.

Site selection criteria is weighted toward low local property values (45%) for site placement. Additional weightings include distance to nearby grocery store clusters (25%) and restaurant clusters (15%). Although the scenario primarily consists of wholesale businesses, some weighting was given to income (10%) and population density (5%), working under the assumption that the farms may be interested in adding a direct-to-consumer sales component to their business model.

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3.1.3 Community Food Development

Scenario 5: Low Food Access, Social Enterprise

A volunteer for a community food organization walks downstairs from the food pantry to the basement. On the left are boxes and odd trinkets from community programs run over the years, and they hear the slow gurgle of water draining into plastic totes straight ahead of them. The sound is the ebb-and-flow hydroponic grow system the organization purchased three months ago. The volunteer pulls back the translucent plastic sheets that dim the glow of the grow lights, and then they enter the harvest room. Using a clean pair of scissors, they harvest spinach and microgreens for the next hour, and then wash it before bringing the produce upstairs to the pantry for donation.

In this scenario, we assume that vertical agriculture facilities are established in census tracts where social service agencies and community food organizations (e.g., food banks, assisted living services, community service agencies) are currently located. Small/medium-scale vertical production facilities are located on-site and produce food primarily for the community members and clients served by the organization.

Weightings for the site selection criteria in this scenario are based on literature on food deserts and communities/areas of low food access. The highest weighted criteria here are low income (36%), low proximity to grocery stores (22%), high percentage without employment (18%). Additional weightings include high population density (10%), and low public transit access (14%).

Scenario 6: Commercial Social Enterprise

A community food organization just received a sizable grant to support local food security programming and capacity building. They hold a town hall meeting in which they decide to purchase a pre-built vertical agriculture facility to grow herbs, microgreens, and lettuce, which they will sell to a local grocery retailer and through their community supported agriculture box system. The farm is a large-sized shipping container that they place in the corner of their parking lot. Local residents are excited about having a creative and nutritious way to support the organization. Produce sales support the ongoing maintenance of the farm and the management of a separate food skills program.

As in Scenario 5, this scenario establishes vertical agriculture facilities in census tracts where social service agencies and community food organizations (e.g., food banks, assisted living services, community service agencies) are located. Medium to large-scale vertical production facilities are located nearby or on-site, and produce food primarily for distribution and retail at local food retailers.

Site selection criteria are weighted toward high population density (25%) and high income (30%), with objectives of (respectively) serving the highest number of local community members and targeting a customer base for higher-priced, social enterprise products. Other weightings include high proximity to local food retailers (as potential customers), specifically grocery stores (25%) and restaurants (20%).

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3.2 Development Patterns and Site Suitability

A total of 3,897 land parcels were labeled as "Mixed-Use" and 991 land parcels were labeled as "Commercial-Industrial", based upon official community plan land designation descriptions. Approximately 74% of the study area's census tracts (n = 392) intersected with mixed-use land parcels, and were included in Scenarios 1 and 2. Approximately 44% of the study area's census tracts (n = 239) intersected with commercial-industrial land parcels, and were included in Scenarios 3 and 4. Finally, approximately one quarter (23%) of the study area's census tracts (n = 122) contained social service, food bank, or community organizations, and were included in Scenarios 5 and 6. Ten percent (n = 53) of all census tracts in the study intersected with land parcels that were defined as mixed-use, commercial industrial, as well as containing potential community food development sites, and were included in all analyses.

3.2.1 Mixed-use

The most suitable locations for vertical agriculture in the mixed-use scenarios (Scenarios 1 and 2) are in census tracts in Surrey, White Rock, and in Chilliwack (south of the major Highway 1) (Figure 2a,b). Vancouver also has a number of potentially suitable census tracts for the mixed-use scenarios for vertical agriculture development; however, high property values make this potentially less suitable than the other areas.

Many of the census tracts in the top two suitability quintiles are located in downtown core and dense urban areas of the municipalities, while the least suitable census tracts were more peripherally located.

3.2.2 Commercial and Industrial

The most suitable census tracts for commercial and industrial scenarios (Scenario 3 and 4) are located in North Vancouver, Coquitlam, Langley, Abbotsford, and north of Highway 1 in Chilliwack (Figure 3a, b). The least suitable vertical farm locations for this scenario are in Vancouver. Many of the census tracts in top suitability quintiles are located outside the downtown cores and major population centres of the municipalities.

3.2.3 Community Food Development

When mapping the community food and social service scenarios (Scenario 5 and 6), we found that most major population centres, with the exception of a few (e.g., North and West Vancouver), have at least 1 moderately suitable census tract (Quintile 3 or above) for community food development scenarios for vertical agriculture development. The highest number of possibly suitable census tracts is in Vancouver (Figure 4a, b).

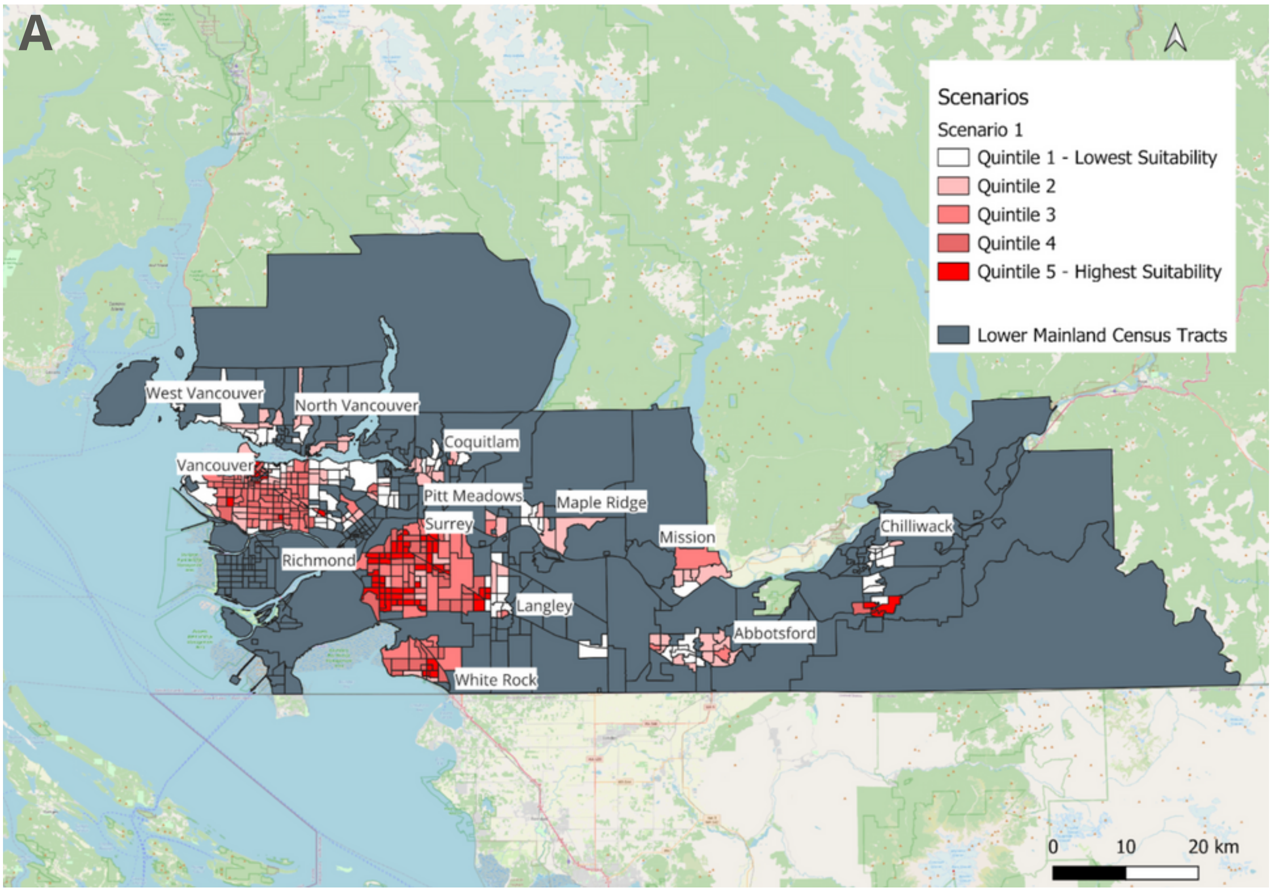

Figure 2a. Site suitability for mixed-use scenarios

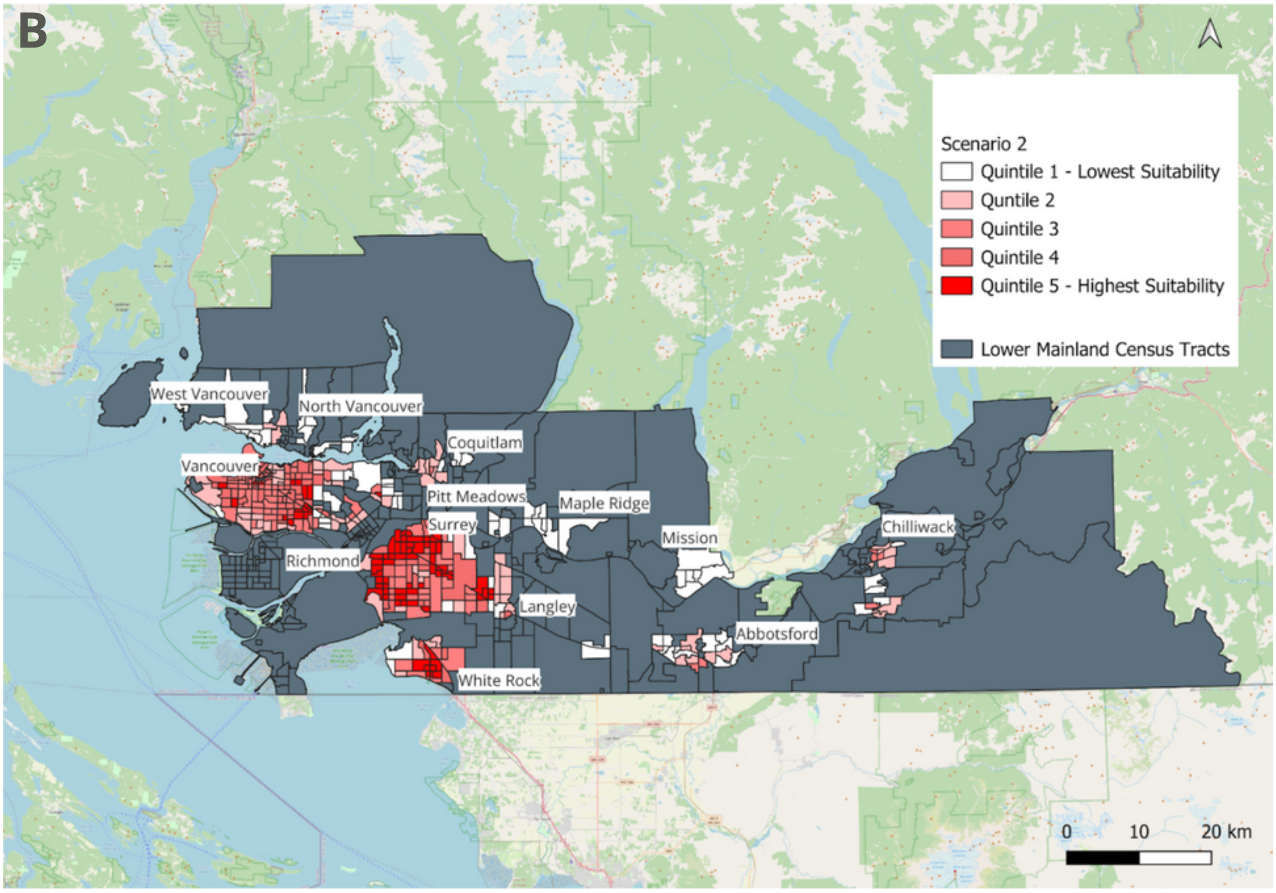

Figure 2b. Site suitability for mixed-use scenarios

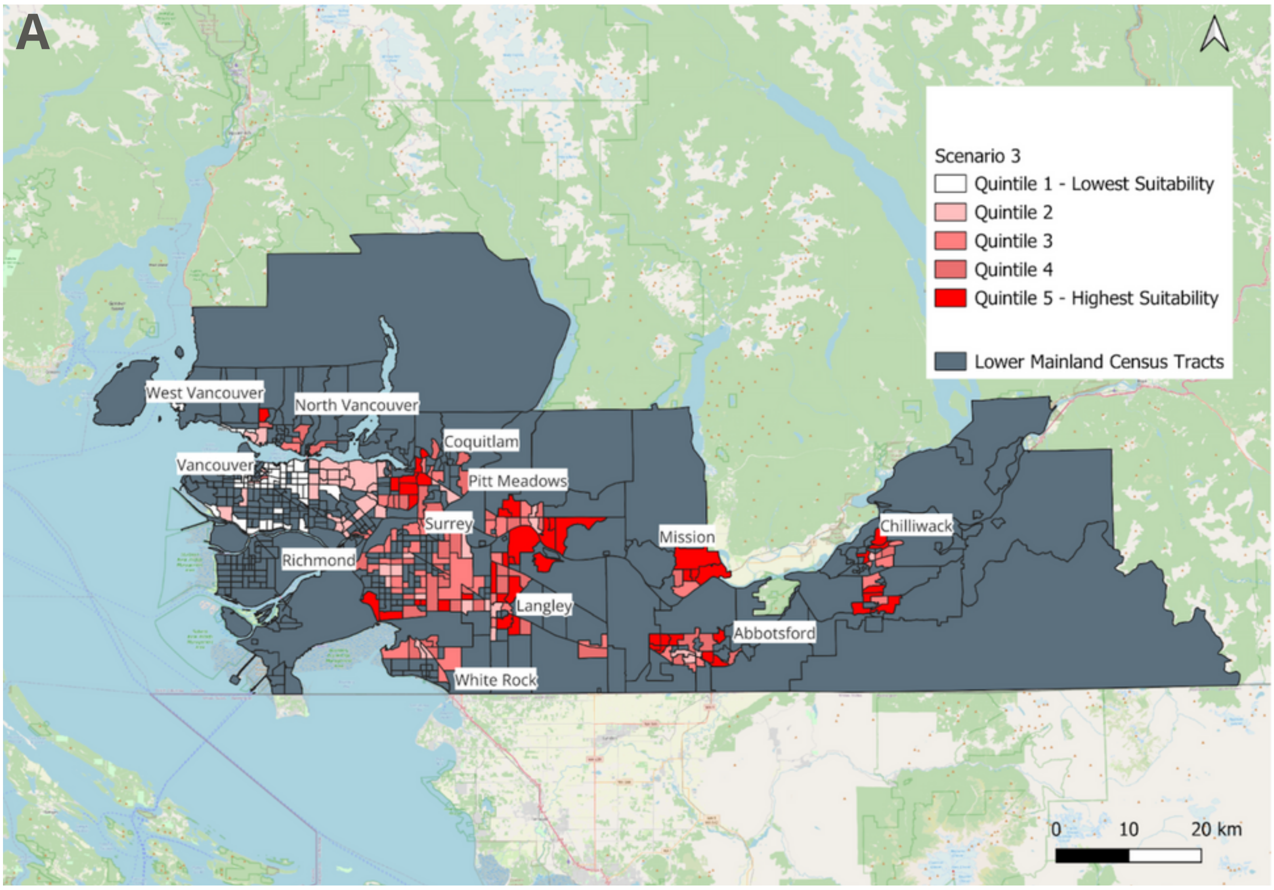

Figure 3a. Site suitability for commercial and industrial scenarios

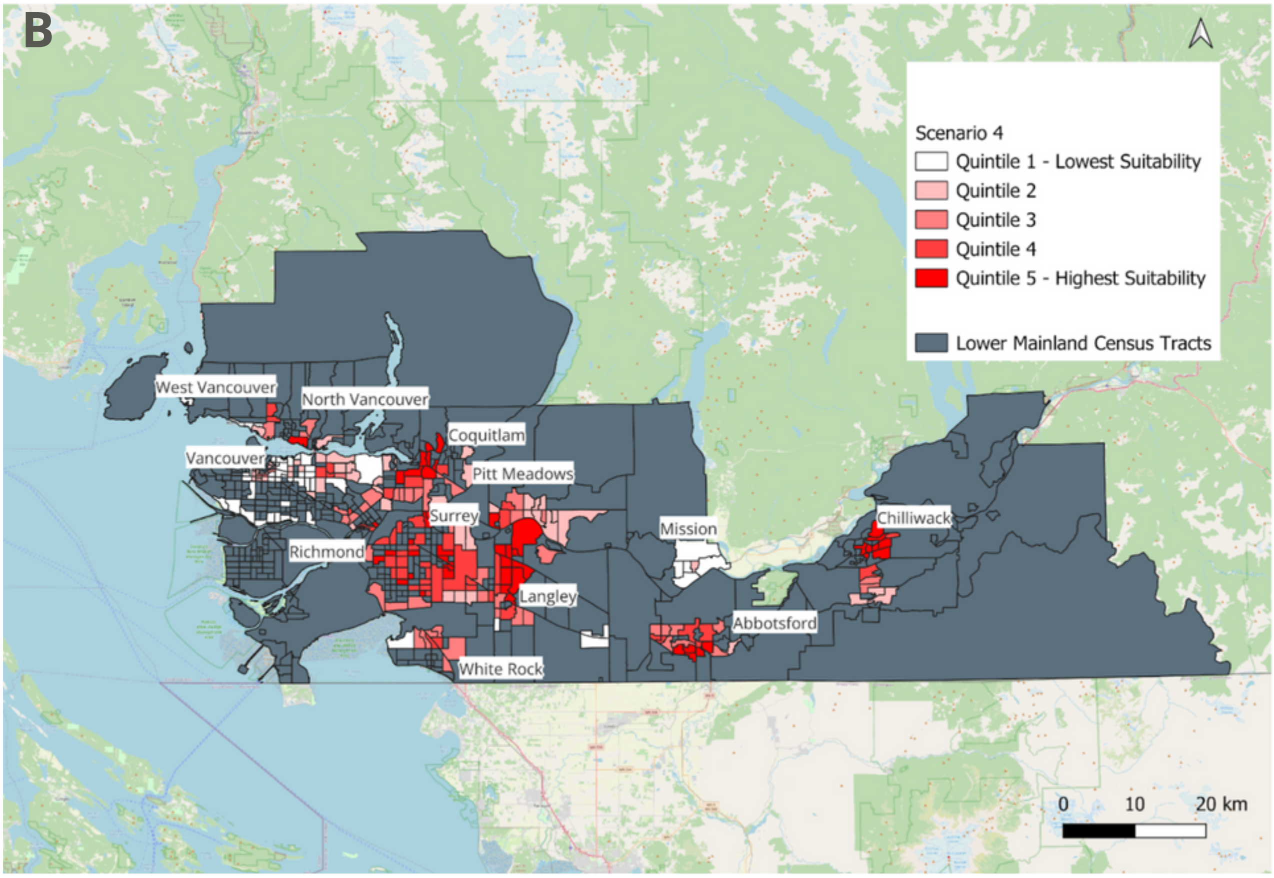

Figure 3b. Site suitability for commercial and industrial scenarios

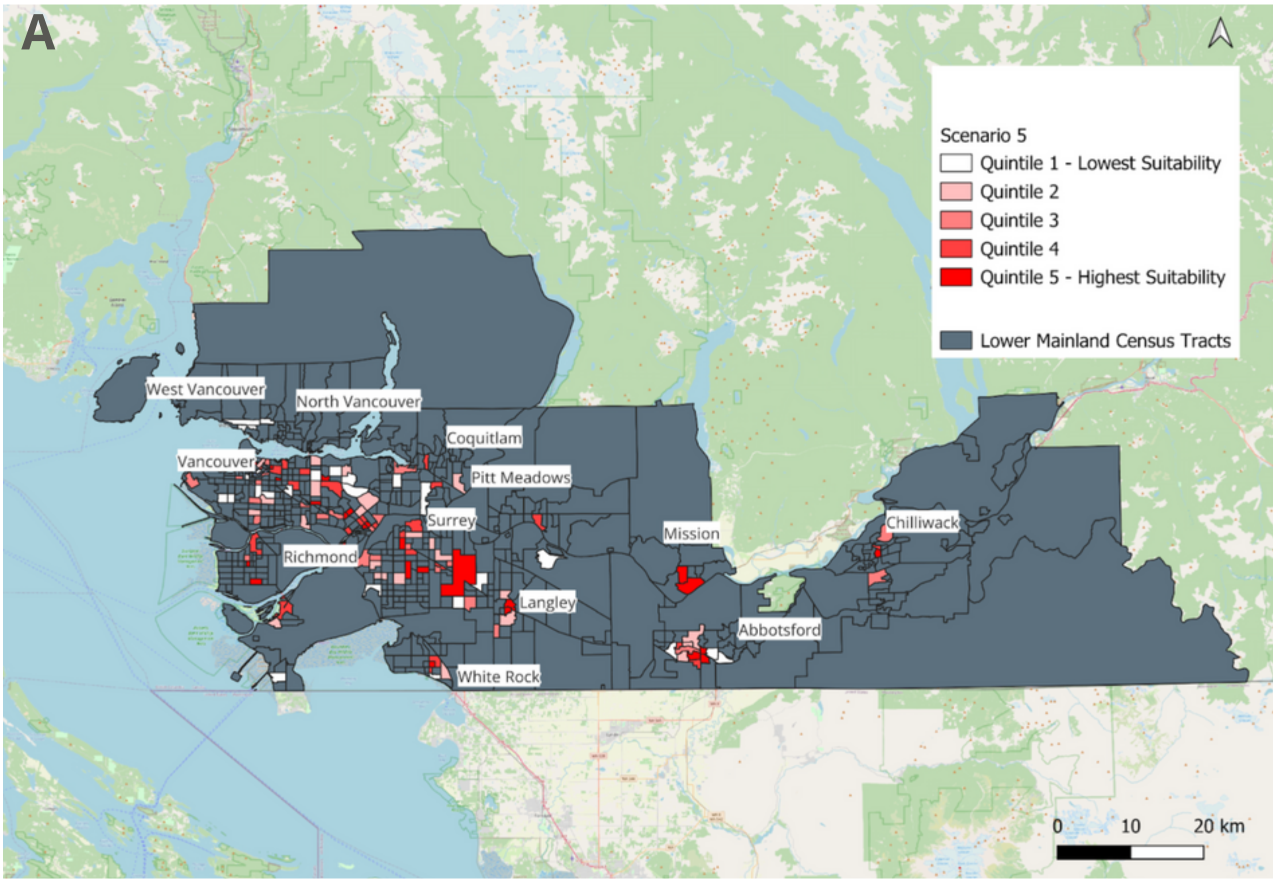

Figure 4a. Site suitability for community food and social service

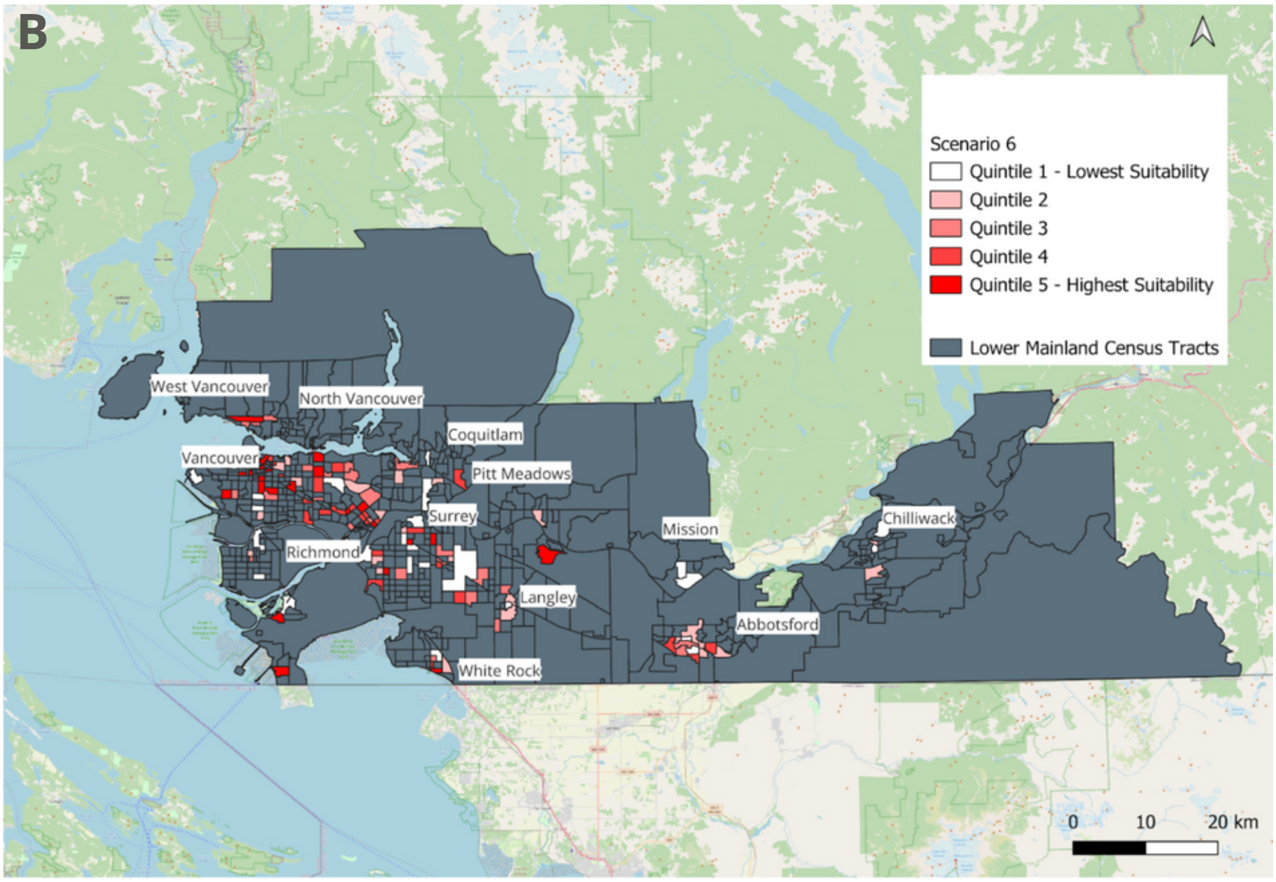

Figure 4b. Site suitability for community food and social service

3.3 Scenario Outcomes

We found that there was a higher number of residents within walking distance to each potential farm location within Mixed-Use and Community Food Development scenarios as compared to Commercial-Industrial (1.2-2.7 times the number of residents). There were also many more suitable locations for mixed-use vertical agriculture development than for the commercial-industrial scenario development pattern. However, despite servicing fewer people, the commercial-industrial scenario farms held the ability to supply the complete local (i.e., walking distance) population with their full daily green intake, whereas this was not the case with the mixed-use and community-oriented scenarios.

Table 4. Potential food security impact modelling results

	Yield of Greens (kg/y)	People Supplied Daily Greens Intake (0.15 kg/person/d)	Scenario	Population within Walking Distance	Percent Population within Walking Distance Supplied Daily Greens Intake
Mixed Use Scenarios					
Top 10 (n = 10) census tracts	WC: 36,000 MC: 90,900 BC: 513,000	WC: 658 MC: 1,660 BC: 9,376	Scenario 1	47,711	1.4 – 19.7%
			Scenario 2	24,841	2.6 – 37.7%
Top 50 (n = 50) census tracts	WC: 180,000 MC: 454,500 BC: 2,565,000	WC: 3,290 MC: 8,300 BC: 46,880	Scenario 1	150,916	2.2 – 31.2%
			Scenario 2	104,840	2.3 – 33.3%
Top 100 (n = 100) census tracts	WC: 360,000 MC: 909,000 BC: 5,130,000	WC: 6,580 MC: 16,600 BC: 93,760	Scenario 1	267,674	2.5 – 35.0%
			Scenario 2	245,023	2.7 – 38.3%
Commercial Industrial Scenarios					
Top 10 (n = 10) census tracts	WC: 72,000 MC: 181,800 BC: 1,026,000	WC: 1,315 MC: 3,321 BC: 18,739	Scenario 3	17,340	7.6 – 108.1%
			Scenario 4	19,984	6.6 – 93.8%
Top 50 (n = 50) census tracts	WC: 360,000 MC: 909,900 BC: 5,130,000	WC: 6,575 MC: 16,605 BC: 93,695	Scenario 3	68,030	9.7 – 137.7%
			Scenario 4	92,048	7.1 – 101.8%
Top 100 (N=100) census tracts	WC: 720,000 MC: 1,818,000 BC: 10,260,000	WC: 13,150 MC: 33,210 BC: 187,390	Scenario 3	144,197	9.1 – 130.0%
			Scenario 4	180,997	7.3 – 103.5%
Community Food Development Scenarios					
Top 10 (n = 10) census tracts	WC: 36,000 MC: 90,900 BC: 513,000	WC: 658 MC: 1,660 BC: 9,376	Scenario 5	33,618	2.0 – 27.9%
			Scenario 6	42,266	1.6 – 22.2%
Top 50 (n = 50) census tracts	WC: 180,000 MC: 454,500 BC: 2,565,000	WC: 3,290 MC: 8,300 BC: 46,880	Scenario 5	146,248	2.2 – 32.1%
			Scenario 6	156,818	2.1 – 29.9%

Top 100 (n = 100) census tracts	WC: 360,000 MC: 909,000 BC: 5,130,000	WC: 6,580 MC: 16,600 BC: 93,760	Scenario 5	256,896	2.6 – 36.5%
			Scenario 6	261,602	2.5 – 35.8%
Combined (census tracts intersecting with mixed use land, commercial industrial land, and containing community food organizations)					
All census tracts (n = 53)	WC: 190,800 MC: 481,770 BC: 2,718,900	WC: 3,487 MC: 8,798 BC: 49,693	N/A	122,612	2.8 – 40.5%

With respect to environmental outcomes, even modest vertical agriculture development (only 10 farms across the entire Lower Mainland) demonstrated potential to spare land when compared to conventional agriculture in all scenarios. The amount of potential land spared varies significantly depending on the scenario ranging from 0.5% (i.e. 10 farms, worst case yield) to 134% (i.e. 100 farms, best case yield) equivalence of the Province of British Columbia's current reported lettuce and spinach acreage of 638 acres (Statistics Canada, 2021).

Water savings (and associated cost) from reduced water consumption initially appear modest in magnitude; however, these savings are still notable in light of increasing predicted frequency and severity of droughts in the major lettuce-producing regions of California and Arizona (Martinez, 2023). In the worst performing scenario, water savings are equivalent to 5% of an Olympic size swimming pool, while the water saved as a best case scenario is equivalent to 15 Olympic sized swimming pools per year.

In our calculations, we assume that emissions from long-distance transport of lettuce were roughly six times more than from local lettuce production through vertical farming, using emissions values from Crawford (2023) and Blom et al (2022). Assuming passenger vehicles emit 4,600 kgCO_2e per year (United States Environmental Protection Agency, 2023), in the lowest performing scenario, emissions reductions through local vertical farming would equate to removing 7.6 passenger vehicles from roads per year. In the highest performing scenario, emissions reductions through local vertical farming would equate to removing 5,451.2 passenger vehicles from roads per year.

Table 5. Potential land and water impact and cost modelling results

Number of Farms	Water Saved as Compared to Conventional (L)	Cost of Saved Water ($ CAD)	Agricultural Land Spared (Acres)	Cost of Land Saved ($ CAD)	Carbon Equivalent Emissions Saved (kgCO2e)
Per 10 Farms (Mixed-Use and Community Food Development Scenarios)	WC: 133,200 MC: 336,330 BC: 1,898,100	258.72 – 3,720.21	WC: 3.0 MC: 7.6 BC: 42.8	48,936 – 698,153.60	WC: 35,193.4 MC: 88,863.84 BC: 501,508.8
Per 10 Farms (Commercial-Industrial Scenarios)	WC: 266,400 MC: 672,660 BC: 3,796,200	517.44 – 7,440.42	WC: 6.0 MC: 15.2 BC: 85.5	97,872 – 1,394,676	WC: 70,386.8 MC: 177,727.68 BC: 1,003,017.6
Per 50 Farms (Mixed-Use and Community Food Scenarios)	WC: 666,000 MC: 1,681,650 BC: 9,490,500	1293.60 – 18,601.05	WC: 15.0 MC: 38.0 BC: 214	244,680 – 3,490,768	WC: 175,967 MC: 444,319.2 BC: 2,507,544
Per 50 Farms (Commercial-Industrial Scenarios)	WC: 1,332,000 MC: 3,363,300 BC: 18,981,000	2587.20 – 37,202.10	WC: 30 MC: 76 BC: 428	489,360 – 6,981,536.00	WC: 351,934 MC: 888,638.4 BC: 5,015,088
Per 100 Farms (Mixed-Use and Community Food Development Scenarios)	WC: 1,332,000 MC: 3,363,300 BC: 18,981,000	2587.20 – 37,202.10	WC: 30 MC: 76 BC: 428	489,360 – 6,981,536.00	WC: 351,934 MC: 888,638.4 BC: 5,015,088
Per 100 Farms (Commercial-Industrial Scenarios)	WC: 2,664,000 MC: 6,726,600 BC: 37,962,000	5,174,40 – 74,404.20	WC: 60 MC: 152 BC: 855	978,720 – 13,946,760	WC: 703,868 MC: 4,443,192 BC: 25,075,440

4. Discussion and Conclusions

Overall, this study suggests that vertical agriculture is a potentially viable strategy to increase local and regional production of leafy greens in the Province of British Columbia. Under the most optimistic yield projections, there is potential for vertical agriculture to provide enough daily greens to support between ~20% to over 100% of the local population within walking distance of each farm. Under medium yield projections, a modest percentage of the population within walking distance (~4-24%) could still be supplied with their recommended daily intake of leafy greens. Our analysis centres on population within walking distance to illustrate the potential for hyper-local consumption of greens; however, we note that in practice potential consumer markets are highly varied in terms of geography (i.e. people living within walking distance may not be interested in purchasing this produce), as well as demographics (i.e. if produce is not affordable or not culturally relevant or appropriate).

The modelling done in this study identified beneficial outcomes from the scenarios even in cases of modest vertical agriculture development, that is, only 10 farms developed across the Lower Mainland, British Columbia. The modelling also examined more ambitious development, assuming up to 100 farms will be established across this region. For context, Goodman and Minner (2019) found there to be one hundred and forty eight (n = 148) existing locations of controlled environment agriculture production in the city of New York (an ideal location for vertical agriculture development), spread across commercial, institutional, and community food contexts. Despite the relatively conservative estimate of vertical agriculture development in the region used in this study, the potential land and water savings are relatively high. This is crucial at a time when supply chain concerns and price volatility of lettuce among other greens imported from California is increasing.

In terms of suitable locations for vertical farms, a total of fifty three (n = 53) census tracts demonstrated suitability for vertical agriculture in all scenarios. These census tracts may hold the most possibility for vertical agriculture development, given their potential to accommodate multiple scales, business models, and forms of vertical agriculture business. However, most of the study area census tracts were found to be suitable for mixed-use vertical agriculture scenarios, indicating that this form of development holds the highest potential for widely distributing vertical farms throughout the Lower Mainland.

Commercial-industrial vertical agriculture development scenarios demonstrated the greatest potential for feeding the majority of the local population (i.e., within walking distance) their daily greens intake. These findings relate to how the growing area of large-scale commercial-industrial farms are double that of the mixed-use farms, as well as being located in areas of lower local population density. In contrast, the mixed-use and community food development scenarios provide walking-distance access to vertical farms for greater numbers of people. Such findings reveal that trade-offs occur between consumer access to farms and agricultural yields depending on business model for and development type of the farm. There are several caveats and considerations for the implementation of vertical agriculture in the Lower Mainland, British Columbia, as well as limitations to this modelling work. In particular, technologies and techniques need to be developed and implemented to diversify vertical agriculture product offerings to increase its potential contributions to food security (Pizzirani et al., 2023). Work is already being done in this area, as many companies are experimenting with diverse crops with varying degrees of success, including berry crops as well as roots and tubers (see e.g., Freight Farms, 2023). Some researchers suggest that vertical agriculture can even be an effective wheat production adaptation strategy for the most radical climate change scenarios, though currently vertical staple crop production is economically disadvantageous (Asseng et al., 2020). Future work that explores the potential for diverse crops (outside of just leafy greens) is required to provide a more holistic appraisal of vertical agriculture's potential food security implications.

It is also important to recognize that vertical agriculture is one component of many approaches to bolster local food systems, including soil-based community gardens, urban farms, rooftop gardens, as well as various efforts to reduce food waste and create producer-distributor networks and hubs (see Newman et al., 2023; Glaros et al., 2021). From a planning perspective, this requires thinking about how vertical farming fits within the broader urban agriculture landscape and local/regional food systems, with different food assets having their respective benefits, co-benefits, and trade-offs. When thinking of trade-offs, care should be taken to ensure that vertical agriculture facilities are appropriate within diverse geographic contexts. For example, there is potential for gentrification where vertical agriculture facilities are developed and implemented (Carolan, 2020). This is of particular concern for areas that may be classified as low food access and/or where property values are lower (i.e. Scenario 5, described in this report).

Our suitability analysis assesses the feasibility of potential site locations for vertical agriculture, while our modelling estimates outcomes of diverse scenarios for vertical agriculture development. This type of analysis can support planning by revealing advantages, tradeoffs and considerations for encouraging vertical agriculture development in urban areas, and it also provides useful insights for vertical agriculture technology developers and farmers seeking to open facilities. Missing from this analysis, however, are the financial costs associated with setting up as well as maintaining farms. The initial costs to set up small and medium-scale farms on mixed-use land or within community food organizations are lower than large-scale, capital intensive facilities located on commercial industrial land. Thus, vertical agriculture development may be more feasible, and effective in terms of rapid scaling, if done through private-public collaborations that focus on the mixed-use development approach. Echoing similar literature (see Goodman and Minner, 2019), local and regional governments should weigh the costs and possible benefits on a case-by-case basis to consider where vertical agriculture, among other forms of urban agriculture, could be deployed.

This study is the first to model potential land suitability for vertical agriculture in the Lower Mainland, British Columbia. The study uses publicly available data and defines a method for suitability analysis and vertical agriculture impact modelling that can be applied across other major urban and peri-urban regions of Canada. The research advances understanding of urban agriculture, by considering the role of an emerging approach to food production in urban areas. Vertical agriculture is not a panacea to food systems issues, and it should be considered part of a broad approach to bolster local food systems. Yet, vertical agriculture holds potential to contribute to food security and land/water savings in the Lower Mainland and beyond. Future work should focus on modelling diverse crop production scenarios beyond just leafy greens and also include an analysis of multiple urban agriculture production forms beyond just vertical agriculture to better assess total local food system potential in the region.

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