Urban Permaculture Designs for Optimizing Carbon Sequestration and Local Soil Health

by
Cameron Couchman

supervised by
Roderick MacRae

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TABLE OF CONTENTS

FOREWORD

Though opinions differ on the efficacy of various climate mitigation strategies, I have narrowed my focus to the feasibility of carbon sequestration via healthy soils in the region, as I consider it most worth researching to counter status quo land use management. "Mechanized farm operations that depend on fossil fuel are a major contributor to emissions of CO_2. The energy-intensive farm operations are ploughing, subsoiling, combine harvesting, use of agrochemicals (especially nitrogenous fertilizers, pesticides) and lifting groundwater for irrigation. Judicious management of these operations is critical to reducing emissions from agriculture." (Lal 2014, 451-2) Understanding and devising agrarian methodologies capable of reducing, avoiding, or even reversing emissions on a local scale, while producing nutritious, abundant sources of food, is the driving objective presented herein.

The following portfolio is a collection of small projects demonstrating the potential for urban permaculture, in various iterations, to contribute alternative solutions. The Rexdale and Annex residential sites each explore urban permaculture design and theory, whereas the location at St. Gabriel's Parish is an exercise in site preparation and practice. At the core of each site is the steady promotion of the potential productivity and versatility of permaculture and food forestry on various scales, with an emphasis on city plots. It is my view that there is great room for improved local awareness on the subject of food. Ideally, such tangible examples of successful alternatives would provide an opportunity for behavioural changes—even an increased willingness to become involved in political capacities. With the right approach, urban permaculture designs that illustrate the practicality of alternative food culture might stem wider engagement on food issues such as security, sovereignty and ecological advocacy.

From the perspective of the individual, addressing the flaws of the current food system may seem a daunting and unlikely objective: "given the current dominance of the existing world food economy, people working toward foodshed objectives will need to carve out insulated spaces in which to maintain or create alternatives that will eventually bring substantive change." (Kloppenburg et al 1996) Secession, a fundamental principle of foodsheds as explained by Kloppenburg et al, is a "strategic preference for withdrawing from and/or creating alternatives to the dominant system rather than challenging it directly…[as] activities

and commitments involve various degrees of disengagement from the existing food system and especially from the narrow commodity and market relations on which it is based." Using 'secession' as a guiding force, we must create productive, concentrated, self-renewing food spaces, at various scales, to provide sustenance as we transition towards a post-fossil-fuel society. Using urban permaculture design as a catalyst, we can pursue gradual enlightenment throughout the process, potentially resulting in a more active community—socially and politically.

To best encourage action, the establishment of diverse, productive, carbon farming systems in an urban setting must first be tested and experimented with. Emphasizing practices such as minimizing soil disturbance; sowing and maintaining cover crops; providing habitat for active soil biology; diversifying yields; and promoting animal nutrient cycling will not only build soil organic matter, but also "increase soil carbon stocks and enhance resilience to drought and climate change." (Conant 2010)

A shift towards a more perennial-based diet would yield countless benefits—improved carbon capture chief among them: "[i]ncreasing soil organic matter by just 1 percent on the world's estimated 14 billion acres of agricultural land would sequester 256 billion tons of carbon – three quarters of the CO_2 we need to sequester to get back to 350 ppm [parts per million]." (Neiger 2016, 74) Due to its impact on global weather patterns, sequestering carbon has become an international focus, with carbon farming beginning to garner attention. Much of the excitement surrounding food forestry and permaculture practices stems from the potential to drawdown atmospheric carbon while simultaneously producing food and other valuable ecosystem services. In such integrated systems, "farming and land management can sequester more carbon than they emit. Growing deep-rooted perennial plants is one of the primary strategies. Perennial root systems produce nine times more roots than annuals, building carbon in the soil as the root systems become established and shed from the plant." (Neiger 2016, 74) Fortunately, there exists a vast array of useful perennial crops, many of which would make suitable replacements for the annual plants that constitute the majority of today's diet, for both human and livestock. Though a transition to a more perennial-based food system faces myriad obstacles, the payoff could be significant, as potential byproducts of increasing soil organic carbon (SOC) include increased yields, among

other socioeconomic benefits. (Toensmeier 2016, 57-59) "Increases in SOC pool in the root zone by 1 Mg/ha can enhance total food production in developing countries by 30–50 million Mg/year. The rate of SOC sequestration in most cropland soils ranges from 100 to 1,000 kgC/ha/year with a total global sequestration potential of 0.4–1.2 PgC over 50–100 years. The potential of C sequestration in the terrestrial biosphere is estimated to be equivalent to a drawdown of 50 ppm of atmospheric CO2 over a century." (Lal 2014, 444) As such research continues to mount, and if "all carbon farming practices increase soil organic matter" (Toensmeier 2016, 54), the potential for carbon farming to feed more people while intrinsically reversing climate change becomes more realistic, along with our objectives to reduce reliance on imported goods; improve resilience and security in increasingly uncertain growing conditions; and reduce general maintenance inputs and requirements.

HOW SMALL-SCALE PROJECTS CAN CONTRIBUTE

Reversing climate change via carbon sequestration

Carbon farming performs a number of functions, namely its potential as a biological tool for reversing impacts of the ongoing climate crisis. With potential carbon capture estimates ranging from 90x106 Mg C per year in the US (Nair et al 2010), to over 100 billion tons globally (Toensmeier 2016, 51), research is showing that carbon farming offers a hopeful approach to curbing emissions while producing food and other useful crops for various industries. "[T]he solution is to bring perennials back to agriculture in a broad and integrated manner. Their capacity to increase soil organic matter is three times greater than no-till [annuals]…[as] perennial pastures have year-round living root systems that allow carbon sequestration deep in the soil profile as well as close to the soil surface." (Carter 2016) While woody perennials such as fruit and nut trees or shrubs are the most powerful carbon sequestering crops (Toensmeier 2016, 33), a dietary shift towards perennial vegetables for both human and livestock would have a significant impact. Ben Caesar is one of a growing number of Ontario farmers celebrating the idea of perennial vegetables. For over five years, Caesar has been cultivating a wide variety of perennial vegetables, and has even narrowed down a list of the ten most successful crops for our climate—several of which have been included in the Annex design.

Producing more food than conventional agriculture

Polyculture systems significantly outperform their monoculture counterparts in many facets. (Algieri 1995, Shepard 2013) "Polycultures demonstrate increased stability in the face of pests, pathogens, climatic variations, and other stress by building a better food web, providing more species diversity to respond to climatic and other fluctuations, and offering more diverse species to replace dead community members. Stability may not be evident until a time of catastrophe, or you may never see its effect since it prevents a crisis." (Jacke 2005a, 165) Research examining the net primary productivity (the amount of solar energy a system can convert to biomass) of various ecosystems found that temperate forests are the fourth most productive ecosystems in the world—trailing only tropical forests, swamps and marshes, and attached algae and estuaries. Agricultural land was found to annually produce only half as many calories per square meter as temperate forests. (Whitaker 1970 and Kormundy 1976) Since tropical forests aren't exactly feasible in northern climates, and exploring the edibility of algae falls just beyond the scope of this project, temperate forests seem to hold the greatest potential as templates for new food system models. "[T]emperate forests are among the most productive ecosystems in the world. Agricultural land cannot share that distinction. This is especially true because the net energy production of agricultural land turns negative…when we include the energy cost of fossil fuels in the equation." (Jacke 2005a, 31) In other words, we've managed to invest more energy in growing our food than we yield in the final product. The promise of permaculture design can only be delivered by mimicking natural ecosystem dynamics. Nature not only functions but thrives without our intervention, and by building diverse food forests we can improve production while approaching self-maintenance and renewal. Moreover, conventional annual agriculture becomes more fragile as growing conditions become more volatile, and the soil more degraded as we continue to mismanage land. "[L]ong-term yield of the agroforestry systems may be better since annual cropping on sloping land, for example, may eventually cause enough erosion to reduce yields drastically." (Toensmeier 2016, 60) Even a certified organic approach to farming is often characterized by constant soil-degrading tillage, as well as steady importation of offsite resources. A form of agriculture that is not a closed loop, or "robs Peter to pay Paul" as Holmgren (1995) explains, would be difficult to classify as sustainable. Though agricultural systems produce large amounts of food, embedded and externalized energy costs are immense. While temperate forest systems may or may not

immediately produce as much food for human consumption, we can mimic this system by substituting species of more human value in order to maximize output while minimizing chemical inputs. Although pursuing closed-loop systems admittedly demands greater attention to on-site nutrient cycling and regeneration, there are a number of actors that help accomplish this, such as the development of healthy soil food webs, the presence of diverse wildlife, and livestock (i.e., cows, ducks, worms, etc.). Naturally, how effective these actors operate depends heavily on how we select and situate plants and other elements within our design.

Reducing reliance on imported goods and resources

If our local food systems are more productive, the necessity for food importation and its embedded costs are reduced. On-site nutrient production and cycling eliminates synthetic inputs and its associated costs. By transitioning to perennial agricultures—woody crops in particular—we drastically reduce the need for chemical intervention, as forests have historically proven to be productive without us. In comparing the main factors contributing to sustainability between industrial agriculture and native forest or prairie ecosystems, Soule and Piper (1992, 122) note that the overall fragility and nutrient leaching in conventional systems is high, whereas natural forests are very durable, with low levels of nutrient flux. Native systems were also found to exhibit much higher resilience, species diversity, and biotic interdependence, or 'functional interconnection'. As for nutrient and energy sources, conventional agriculture relies heavily on fertilizers from fossil energy, whereas forest systems utilize local resources recycled within the system. As Jacke (2005a, 29) observes, the principal advantage agricultural systems have over native ones is the amount of human food produced, albeit with its associated waste and pollution. If forest ecosystems outperform their conventional counterparts in virtually every other category, perhaps the key is to use native ecosystems as food system templates, tinkering and incorporating more useful food crops along the way, as we seek a superior food model. By advancing dietary awareness of the many advantages provided by the perennial crops already produced on mass scales (i.e. fruits and tree nuts), we move closer to realizing the marriage between biomimicry and food production, including perennial vegetables and fodder crops.

Improving food security, soil durability and resilience in uncertain conditions

As defined by the High Level Panel of Experts, food insecurity is "the inability to secure an adequate diet today and the risk of being unable to do so in the future." (HLPE 2012) 'Stationarity', a term used to describe the realm of relatively predictable weather fluctuations based on historical data, was, until recently, helpful in planning a wide range of industry—from agriculture to urban development. At some point in the first decade of the 21st century, weather scientists began to observe variations in water and climate systems well beyond previous norms. (Schapiro 2015, ix-x) Since then, we have found ourselves in a world of unpredictable climate conditions, and concerns over abrupt climate change (ACC) have become more pervasive, posing significant threats to many of the staple crops we've become dependent upon. Annual crops, accustomed to relatively stable, predictable growing conditions, are now especially vulnerable. In a post-stationarity climate, "ACC can exacerbate food insecurity by reducing crop production because of high temperatures and increasing frequency of extreme events; decreasing access by lowering income and raising prices; reducing utilization by aggravating water pollution and increasing the risks of infectious diseases; and accentuating instability by increasing risks of drought/floods and adverse trade, stocks and market conditions…ACC-induced changes in temperature and precipitation can affect edaphic conditions (e.g. onset, end and the duration of growing season; incidence of pests and pathogens) with a profound impact on use efficiency of inputs and net primary production." (Lal 2014, 452) At the farm level, such unpredictable growing conditions should give us pause before continuing 'business as usual', and delve deeper into how we can equip ourselves with more adaptive agricultural practices. Draught, deluge and other extreme events wreak havoc on pastures and soil health, and have become relatively common in recent memory. As land is continuously compacted, left bare or tilled in conventional farming, soil biology is severely compromised—along with its ability to manage and recover from stress events. This directly impacts global food security, as degraded soil inhibits the production of healthy crops. Once again we find merit in the farming methods inherently capable of building and fostering soil durability. "Resilience of soils and agroecosystems in the face of ACC can be enhanced by improving soil quality and its physical, chemical, biological and ecological components…through SOC [soil organic carbon] sequestration. SOC sequestration implies transfer of atmospheric CO_2 into humus by application of biomass (agricultural residues, cover crops, etc.) to soils in such a way that

the mean residence time (MRT) of C in soils is drastically prolonged and that the sequestered C is not re-emitted into the atmosphere. The biomass applied is converted into humus through biotic activity, especially microbial processes." (Lal 2014, 447) Developing the population and activity of soil microorganisms becomes an essential aspect of climate resilience, supported by the appropriate selection of plants to maximize site biomass. In this respect, it follows that in accumulating organic matter, we are building the ecological tools required to buffer against potentially volatile growing conditions. "Soil organic matter does much more than sequester carbon. It improves soil fertility, resulting in better crop yields, pH buffering, disease prevention, water-holding capacity, and more…Improving soil carbon is a critical adaptation strategy because it is useful against almost any climate challenge." (Toensmeier 2016, 24-26) Not only are woody perennial fruit and nut crops the most effective carbon sequesterers, deep-rooted trees—particularly those with taproot root systems—are likely more adaptable to climate volatilities. Research on the subject has shown that plants or trees capable of extending root growth into deeper soil horizons tend to experience faster growth, sustained health, and higher, more consistent yields. (Sweet 1933) Deep-rooted trees are also better equipped in responding to weather stress and insect or disease pressure due to advanced resource access and storage. (Jacke 2005a, 201) Seemingly, the further we divest from an agricultural system dominated by tender annual crops, the less fragile and vulnerable to weather vagaries we become. In such food strategies, developing and managing immediate mechanisms for instituting the many existing food crops exhibiting drought-tolerance, pollution-tolerance and pest-resistance becomes a priority.

Reducing energy and capital input required to grow food

"Polycultures appear to offer many options for improving weed control with less labor, fewer chemicals and lower costs…in many cases farmers are interested primarily in the yield of a main crop into which other species are sown for insurance against crop failure, minor economic uses, erosion control, soil fertility improvement, weed control, or other purposes." (Altieri 1995) While the yield of a main crop in a polyculture is likely lower versus a monocrop, the net system gain is higher in numerous aspects, including output and buffering against crop failure. The more diverse a system is, the better equipped it is to respond to stress. By developing guilds of perennial plants, we align with "the natural tendency towards complexity; enhanced crop biodiversity both above and below ground mimics natural

succession and thus less external inputs are required to maintain the crop community." (Altieri 1995) A stronger understanding of complex natural systems and how we can apply them to each unique scenario is a critical aspect of permanent food systems, one that requires an early investment of time, observation and participation. As Jacke (2005a, 174) states, "[p]rotracted and thoughtful observation will help us avoid protracted and thoughtless labour." Once established, "inputs" are voluntary and largely self-regulating. If inputs are drastically reduced, we can redirect our human labour and financial capital to other areas of need, such as continued observation, design, harvesting, and so on. "[I]f we can get even half the percentage of useful energy—or yield—out of temperate forest ecosystems as we get out of farmland, we will get the same yield in calories per acre. Alternatively, we can keep our energy inputs low and get lower yields, but higher net production—more yield per amount of energy expended." (Jacke 2005a, 31) Due to modern industrial farm methods (i.e., tillage, excessive spraying, bare soil), nutrients are far more prone to leaching—negatively impacting fertility and overall system productivity. By mimicking healthy ecosystems, strong permaculture design can "conserve and accumulate nutrients by stripping them from the soil water and mineral particles and putting them into three kinds of organic matter—…living organisms, active organic matter, and stable humus. Plants…spawn all of this organic matter. So in healthy forest ecosystems, nutrients cycle and gather primarily in an on living and dead tissues. This means that managing nutrients in living systems fundamentally means nourishing and interacting with life, not applying chemicals or rock dust." (Jacke 2005a, 214) By taking a more holistic approach to land management via investment in plants and biology, nutrient cycling becomes more cost-effective in that it can occur primarily on site through its own devices. Though initial investment costs may be higher than imported chemical inputs, the aggregate gains are extensive: "the cost of sequestration of CO_2 in depleted soils and degraded/desertified ecosystems can be negative because of its many collateral benefits – which include increase in agronomic productivity, decrease in risk of soil erosion, increase in biodiversity, reduction in sedimentation and non-point-source pollution and improvement in water quality." (Lal 2014, 453) As we curtail our dependence on synthetic inputs and industrialized food schemes, we learn to enjoy the many associated benefits of the conscious development of productive, edible ecosystems.

With the underlying contextual framework and currents of thought outlined, elaborating on food forestry theory and permaculture principles can help guide us in our design and methodology.

INTRODUCTION TO THEORY

Soil health and carbon sequestration have been identified as key areas for exploring ways to improve our fundamentally disruptive food systems. In delving deeper into the issue, we find that of the food crops at our disposal, woody perennials have the greatest potential for carbon capture and storage (Toensmeier 2016, 33). Regionally, by embracing the multifunctionality of perennial plants, we can illustrate a food system model that builds microbial health and soil fertility; regenerates local ecological diversity; and increases the nutritional value of our food. While these advantages hold tremendous value, particularly as global resources become more scarce, there are certain challenges to overcome in instituting such "permanent" agricultural systems. Namely, the nature of such systems involves a great deal of careful observation and foresight. Permaculture design is a long-term operation, and ensuring system elements are properly selected and situated demands a certain intuition and finesse as we coevolve with a given space. Though it pays immensely in the end, patience is required, as many woody perennials take years to establish before they begin to produce: "[t]he most potent values in a system are yielded across the greatest length of time; for example, nut pines such as *Pinus koraiensis*…take twenty or more years to begin bearing but yield for four hundred or more years. Plums and peaches bear within five years and yield for thirty to forty years. Nut pines are made up of mostly rich fat and protein; plums and peaches are tasty but offer mostly only sugar and basic vitamins. The best soils in the world weren't build overnight but over thousands of years." (Falk 2013, 36) Though nut pines are an extreme example, if we want our food source to be productive over the long haul, there are certain initial procedures that must be enacted.

Establishing microbial diversity and building soil fertility

Microbial diversity and plants work synchronously in soil and ecosystem development. Understanding how to accomplish long-term soil fertility without sacrificing biodiversity—whether internal or external to a given ecosystem—is a crucial step towards self-renewing food systems. "Importation of nutrients must be an investment in biological capital rather

than a perpetual input." (Holmgren 1995) If we are to avoid the importation of fertility and health, we must direct our attention to on-site nutrient cycling, facilitated by effective management of plant-microbe relationships.

Regenerating ecological diversity and maintaining soil health

"The anatomy of self-renewing fertility consists of the continuous, transformative living-mineral-chemical cycles (biogeochemical cycles) of plant nutrients. These cycles occur through the interaction between the physical ecosystem architecture, the ecosystem social structure, and the geological constituents of landscapes. Nutrients weave in and out of these structural elements of the ecosystem and tie them together." (Jacke 2005a, 174) To maximize social interaction, we must make a conscious effort to attract as many different species of wildlife as possible to our spaces. By incorporating a wide variety of plants and architectural variance, we provide a diverse set of resources and habitat niches required by different species. As one of the main containers or 'nutrient plugs', plants also play a major role in preventing extreme nutrient loss from leaching or erosion by interacting with various community members. Perennial plants inherently have longer, stronger and more active relationships, generating organic matter that "increase[s] the soil's water-holding capacity and aggregation, thereby reducing the rates of erosion and leaching." (Jacke 2005a, 179) The more stable the social network, the longer a given site can be healthy and productive, attracting and retaining more community members as it continues to develop. By employing perennial-based design, regenerating and maintaining such diverse systems is more feasible due to ongoing resource contribution from various local species. "The stability of root-zone microbe populations engendered by perennial plants facilitates…nutrient pathway[s]…[I]t is not the plants alone that conserve nutrients. The interconnected system of plants, organic matter, and soil organisms, especially root-zone mutualists, creates this nutrient-conserving ecosystem." (Jacke 2005a, 180-1) By nurturing on-site relationships, our food system builds higher order over time, facilitating continued health and overall productivity. What's more, the intricate nutrient cycling regimes occurring within such diverse, thriving ecosystems may ultimately result in boosted nutritional content on our dinner plates.

Producing more nutritious food than conventional agriculture

Employing a diverse array of plant crops allows farming to "take advantage of the variability of nutrient uptake, both in terms of different nutrients and in capturing nutrients from different depths of soil…[and] the use of plants that readily form symbiotic associations, such as [nitrogen-fixing] legumes, and more widespread use of perennials in the production system, as a means of nutrient pumping from different depths of the soil and to increase the total ecosystem nutrient storage capacity." (Altieri 1995) The term 'nutritarianism', coined by Joel Fuhrman (2003) describes a dietary focus on "healthful, nutrient-rich foods" and considering health and food in terms of maximizing nutrient-density, or, "your nutrient intake divided by your intake of calories." Speaking from this perspective of diet and health, Falk (2013, 254) adds that "[m]any foods that should be nutrient dense are not if grown in poor soils, and conversely, many foods that are normally not considered nutrient rich can be if grown in rich soils or in ways that cause the plant to mine subsoil minerals." In prioritizing active soil biology and perennial polycultures we prioritize our own health, as the micronutrients scavenged and absorbed by plants are passed directly on to the consumer. A study comparing nutrition between conventional and biodynamic potatoes supported such claims, as the level of antioxidants was roughly 40 percent higher in biodynamic versus conventional, with an advantage of 90 percent in organic milk. (Smith 2009, 204) There is growing evidence indicating that the widespread application of synthetic sprays in conventional agricultural has resulted in nutritionally bankrupt food offerings: "during the period throughout which chemical fertilizers and pesticides made their greatest impact on the food market there was a 75% reduction in the mineral content of fruit and vegetables." (Smith 2009, 204) In such cases, any sweeping conveniences reaped from conventional methods become suspect as the nutritional content of the crop is diminished. Yield and food waste also may be exacerbated in industrial agriculture, most notably for storage crops, as "potatoes grown conventionally achieved 4 tonnes per hectare more [yield] than a paired biodynamic crop, yet after several months storage the situation was reversed through higher levels of wastage incurred by the conventional crop." (Smith 2009, 204-5) Additional discrepancies include a 5% advantage in true protein, a 2.6% advantage in vitamin C, and superior taste for the biodynamic crop. (Smith 2009, 204) By investing more time and resources in the natural development of soil, permaculture and biodynamic agricultural methods can improve our nutritional intake, further illustrating the potential

multifunctionality of a more integrated food system approach. It quickly becomes apparent that the hegemonic annual monoculture is unsatisfactory in nearly every way imaginable, and the necessity for a paradigm shift is clear. To make this transition, our first task is understanding and defining what permaculture and food forest systems essentially are.

Defining Permaculture and Food Forestry

In order to be considered a true forest garden—to borrow a term coined by permaculture pioneer Robert Hart in the 1980s—any given site must consist of three or more vegetative layers. The polar opposite of a thriving forest garden would be a monoculture of a given crop, whether for food or other uses such as ornamental. Whether we realize it or not, raising the perfect lawn demands so much effort largely because it is an endless battle against nature's inherent processes of succession. In such cases, early-succession plants such as dandelion and clover, also known as pioneer plants, are often among the first to arrive. These ruderals mine the soil depths, transporting valuable nutrients and nitrogen to the surface and making them available for the next stage of plants in the succession. Disturbances such as mowing, cutting, and spraying are methods we tend to use in our efforts to combat natural processes, much to the detriment of life and land itself. Without human intervention, succession continues and countless other plant species soon appear, dynamically building the soil and local biology in many ways, ultimately creating a healthy site for more elaborate, productive ecosystems to establish and eventually thrive—sequestering carbon along the way.

Guiding Succession Using Permaculture Principles

In many ways, the core concepts of permaculture design are explorations of ways to direct or guide succession, with nature and all of its members, to meet some of our most basic needs. Although the study of natural succession remains complex, there are several tools we can deploy in concert with the natural world in order to optimize productivity while restoring degraded areas and providing essential services to humanity: "guiding which plants join the community when is fundamental to any agricultural enterprise…Directing succession helps us achieve…high, diverse yields, maximal self-maintenance, and maximum ecological health in several ways. By limiting opportunities for unwanted plants to take over, we help ensure the yields we desire. Through intelligent design and management we hope to create a self-

directed succession, one that requires few interventions from us once we set it up and get it going. This reduces our maintenance work. Ecological health arises from the fact that intervening less frequently and less intensively allows the system to build ecological capital…Within the system, food webs develop and diversify, and increases occur in soil nutrients, soil organic matter, biomass, biodiversity, plant and animal health, and system stability and resilience." (Jacke 2005b, 39) Simply, humans working against nature squander resources on both sides of the equation. Conversely, participating and evolving alongside natural systems, at various stages of plant succession, epitomizes the power and beauty of applied permaculture and food forestry.

INTRODUCTION TO DESIGN AND METHODOLOGY

Cultivating Diversity

"A forest with complex architecture is like a house with many rooms. It provides greater opportunity to find a space providing protection from enemies, and it allows the evolution of unique niches that effectively reduce conflicts over resources." (Perry 1994, 172) In other words, structural diversity begets biological diversity (Falk 2013, 34). In designing diverse habitats, we are inviting a diversity of life to take up residence in our food systems. If we consciously promote a variety of habitats (i.e., microclimates, tree and branch size, moisture, aspect, etc.), the result should be a thriving and resilient edible ecosystem: "[a]ny healthy ecosystem needs a diverse array of community roles filled to function well…More community niches filled means more diversity of function, which in turn helps stabilize the community." (Jacke 2005a, 143) Maximizing diversity is a primary concern, as it creates niches, limits competition between species, improves productivity and yield, provides functional links between elements, significantly improves stability and resilience, and suppresses disease and pest issues. (Jacke 2005a, 107-8) As Shepard (2013, 276) observes, "the greater the species diversity of a site, the greater the total site yield. As farmers, isn't this really what we're looking for—how to get the greatest total yield from my acres of land?" Following this logic, we should grow the most appropriate amount of plant species and do everything we can to attract and retain wildlife. As the fitness of one aspect of the food web supports the health of another, the importance of maximizing system diversity at every level in order to maintain self-renewing fertility becomes apparent.

Observation and Site Context

Another critical aspect of permaculture design is observation. To create a forest garden, it is often suggested that before undertaking the design process for a particular site, at least one full year of deliberate observation is required to maximize system health in both the short- and long-term. As we strive for permanence in such systems, it is in the best interest of the designer to make mistakes on paper, rather than having to transplant trees, for instance. In a full calendar year, there are countless seasonal observations that help shape a design—including, but not limited to: recording sun/shade patterns; average rainfall; soil conditions; wind influence; microclimates; outside influences or 'vectors'; available resources (i.e., water, existing vegetation, organic matter, etc.); and wildlife presence and behaviour. Keen awareness of soil biology and texture, water flow regimes, weather patterns, and niche availabilities will improve our chances of success and reduce the likelihood of system failures that would require resource-intensive corrections. Essentially, the more we can observe and understand the conditions of a site, the more appropriate our plant selection and spacing, and ultimately, the more productive the system can become. Only after we have exhausted our observational palette should we feel fully comfortable in advancing to the design phase. In the meantime, we can also take simple measures to build soil as we observe, which pays dividends down the line.

The three main aspects of soil improvement are physical, biological and chemical. Physical soil improvements can be as simple as forking compacted soils and planting root crops such as tillage radish, capable of breaking up hardpan before decomposing and becoming organic matter. More organic matter, along with plentiful soil cover, can go a long way in encouraging microbial activity and improving soil biology and tilth. Chemical improvements are more nuanced, as they require addressing nutrient composition and availability. Performing soil tests is a great way to learn about the nutrient composition of a given site, providing useful information pertaining to micronutrient levels and heavy metal contaminants. However, this process can encounter time and cost restraints, so alternative methods for understanding and building the chemical character of a given soil are worth exploring. If possible, researching the history of the area is advised as contamination may rise above levels safe for eating, particularly in urban soils. Once we feel comfortable that the soil is a safe medium in which to grow food, we can turn our attention to plant health and

limiting factors. "Understand resource conditions and other legacies present, and consider how they will influence your site-preparation needs, the species you'll plant, their performance, the rate of succession, and your maintenance workload." (Jacke 2005b, 41) To ensure our plants will thrive, we require an acute sense of the macro and micronutrients onsite, and whether they are in abundance or in short supply: "lack of nitrogen is the most frequent limit on ecosystem productivity, followed by lack of phosphorus…Potassium and calcium are the next most frequently limiting nutrients…Most deciduous trees and many evergreens require significant levels of calcium." (Jacke 2005a, 176) Many of these nutrients are already present in most soils, though they may not be available to all plants: "phosphorus limitation…is most frequently a question of lack of availability rather than a lack of phosphorus in the soil." (Jacke 2005a, 176) Fortunately, there are countless plants known for their ability to access specific nutrients, and with the help of soil organisms, bring them to the soil surface, rendering them available for the plants that succeed it. Simply sowing buckwheat and clover can broadly address the most frequent limiting factors of plant health, as "[b]uckwheat is second to none at scavenging hard to reach phosphorus and potassium, making it available for the following crops…Red clover [is a] quick growing biennial green manure that fixes nitrogen." (William Dam 2017) These two plants exemplify the many tools we have at our disposal to rapidly add organic matter while chemically developing soil onsite, without having to import resource-intensive inputs. Furthermore, many of these essential micronutrients are highly leachable in conventional agricultural systems, reiterating the importance of a healthy soil food web: "once these nutrients become embedded in the secondary minerals [deeper soil substrates] they are not directly available to plants except through the action of soil organisms such as mycorrhizal fungi." (Jacke 2005a, 176-7) As an added bonus, soils with healthy biology, especially those with an active mycorrhizal community, have the ability to render heavily contaminated soils safe for gardening, alleviating concerns for the presence of lead, cadmium and mercury in urban soils. (Jacke 2005a, 177)

Once as much information as possible is gathered, it can be used to begin shaping the design in order to ameliorate such concerns: "[w]indbreaks, irrigation or drainage systems, rhizome barriers, and even roads and paths can alter climate, microclimate, water, and soil conditions, as well as the patterns of animal- and wind-borne seed dispersing into your site." (Jacke

2005b, 41) It is helpful to be aware of the site history, whether it be soil treatment and composition, severe storm events, wind patterns, seed brought in from surrounding flora, and so on. Armed with a stronger comprehension of general site function, the plant consideration process is simplified, narrowing and refining many design decisions.

Plant Interpretation and Selection

Upon carefully determining the general infrastructure design, we can begin to consider species selection. This juncture of the design process lays the foundation for the site's prevailing outlook: "Once plants have occupied an available site or niche, plant performance reigns as the core ecological process determining the path of succession. Therefore, plant species selection largely determines the course of designed successions, because our species choices determine the characteristics of the plants in a succession, and consequently how they will perform in the conditions they encounter and create. Species selection also affects social interactions in the community, and the resulting propagule pool." (Jacke 2005b, 42) Context gained during the observation stage should provide a stronger understanding of which plants would thrive, and which would experience stress on a particular site. This, along with our driving objectives, shapes our consideration for plant selection. Without clearly defined goals or a more refined scope of appropriate plants, choosing the right elements for our designs can become overwhelming.

Knowing the great diversity of plant functions required to sustain a healthy space is an important step in selecting species and ultimately shaping the succession pathway. A greater awareness of the general resource conditions and outside vectors is also necessary before consideration and selection of plant species and placement. Observation continues to play a role here, as there are ways to obtain a general understanding of resource limitations or abundances without having to rely on a soil test. For instance, "reading" the preexisting vegetation—or making note of which plants are already present on the site, their health, and being familiar with their resource requirements—can provide us with a better idea of which plants would or wouldn't thrive as we consider our design. Observing onsite plants can yield a wealth of information, helping us "determine successional stage and estimate future successional trajectory; gauge soil moisture or, by examining root systems, the water table depth; estimate the recentness of soil disturbance (e.g., cultivation); indicate soil tilth or

texture; estimate the abundance of soil nutrients, specifically or generally; and estimate pH." (Jacke 2005a, 131) The more information we have on specific system elements the better, emphasizing the practicality of using plants as indicators for various conditions.

As we learn more about individual plants' attributes, we should have a better understanding of how they might perform in a polyculture. In avoiding monocultures (identical species with similar root patterns maximize competition for limited resources), plant guilds and polyculture design become important tools for building healthy, diverse food systems: "[t]he fact that species evolve to avoid competition is a good hint for us…Groups of species can act as guilds in two ways: by partitioning resources among species with similar community niches to avoid competition, and by forming networks of mutual support among species with different niches." (Jacke 2005a, 134-142) For instance, if two species occupy the same area in a garden (community niche), resources may be shared via different root types or resource requirements. Mutual support can occur in many ways, a classic example being the 'three sisters' polyculture in annual gardening. Research and experimentation of perennial examples of such polycultures is ongoing, and due to the complex nature of interspecies relationships, "[w]e must come at it from the perspective of the whole community and how it is put together, as well as from the pieces and how they relate to each other." (Jacke 2005a, 141) Mimicking native ecosystems, or 'biomimicry', is another effective method for understanding and implementing natural plant guilds and function. On the subject of bioregionalism, Shepard (2013, 72) advocates we "[l]earn the biome. Get to know the soil types, the rainfall patterns and what kinds of trees live (or have lived pre-European settlement) in your location so that you can learn how to fit into the site in the most effective way possible. Wherever you live, and whatever biome it is, you will have greater success if you imitate what was there." The naturally occurring systems already in place exemplify and epitomize self-renewing, self-maintaining, thriving ecosystems, so it follows that observing and recreating such systems are worthy pursuits with respect to how we source our food. A greater familiarity with the community roles each plant might play in natural systems can refine our search during species selection: "[t[he common denominator is the role in the community, a role generic enough that a number of species could fill it, and specific enough to be useful as an analysis and design tool." (Jacke 2005a, 143) By investing our time in

understanding such species now, we can ultimately mitigate needless labour expenditures, reduce system stressors, and improve productivity.

Another way to refine our species selection is in terms of plant families and genera. In a seminar on resilient urban plants, Ormston-Holloway (2018) proposed no more than a ten, twenty, and thirty percent representation of any particular species, genus, and family, respectively, to optimize ecological function. For *Permaculture News*, Toensmeier (2012) outlines a few noteworthy considerations for such parameters: "[I]t is desirable to maximize compositional diversity…[though] certain important uses and functions are limited to certain families. Nitrogen fixation is mostly limited to the legumes (Fabales) and certain orders within the rose (Rosales) and beech (Fagales) orders. Specialist nectary plants are generally limited to the Apiaceae, Araliaceae, Saxifragaceae, and portions of the Asteraceae. The great majority of fruit and nut species that can grow in cold climates are in the rose order (Rosales)…Thus there is little avoiding the fact that your garden is likely to have heavy representation from these groups of plants. Beyond this limitation, however, you can make an effort to include as wide a sampling of diversity as possible. Groundcovers, dynamic accumulators, and shelter and nectary plants come from a great diversity of families, and you will find a remarkable range of edibles to choose from as well." (Toensmeier 2012) Viewing a given landscape through this genetic lense can be an important tool for defending the onslaught of pests. For instance, Japanese beetles, a major pest to roses, are also liable to feast on the foliage of other members of the Rosaceae family, such as cherries, almonds or plums. Such pests, diseases and other unexpected failures are persistent concerns, alleviated by considering our designs in terms of healthy plant communities, rather than isolated members. Thus, the value of a diverse set of fruit and nut trees, perennial vegetables, and self-seeding multifunctional flowers becomes apparent. Bearing this in mind, operating within the parameters of Ormston-Holloway's 10/20/30 rule may preempt certain pest or disease concerns, while attenuating our species selection palette.

With a better understanding of plant selection, a referral guide could be useful in training our design processes and behaviour for developing healthy food ecosystems.

Design Checklist

A design checklist can be a helpful tool for establishing a few of the core plants most suited to our plant community or guild. Attempting to replicate natural systems plant-by-plant would be challenging, and would prevent us from realizing our desired yields. At the same time, we cannot simply select the species we want the most, as discussed. The study of evolution and its various subcategories illuminate a happy medium: coevolution, evolutionary adjustment and convergence are each areas of study showing how communities can adapt to similar yet different environments, provided the niches and functions of the analog are similar to the origin. This influences our design, allowing us "flexibility to substitute species within certain limits while maintaining functional community social structure and interactions. They should also give us pause, though, because we probably cannot know all of the interactions going on in an ecosystem. We may miss critical functional elements if we mess around too much or leave out strands in the web…Consider using exotic species [only] when a native species does not fit the site conditions, your functional needs, or your planting goals." (Jacke 2005a, 155-9) Though random composition of polycultures may produce some beneficial combinations not otherwise considered, the opportunity for plant illness or failure is significant. As we experiment with perennial polycultures of "unique structure and composition…more possibilities for creativity exist, but a lack of coevolution between species may result in more interactions that are negative." (Jacke 2005a, 166) For instance, ignorance to the likelihood that an overstory of allelopathic black walnuts would suppress the bulk of understory growth might prove costly. Clearly, we ought to equip ourselves with the tools to avoid or at least minimize the effects of such design blunders. As outlined by Jacke (2005a, 168-71), there are two helpful approaches at our disposal to improve the success of our polycultures: building guilds and ecological analogs.

Guild Building

Building guilds entails establishing a community of plants essentially from scratch. Guild building is typified more by research and information than the ecological analog approach, and less by observation. "Effective use of the guild-build process requires…clear objectives, knowledge of the site's limiting factors, and an understanding of the species niches of the species you are working with." (Jacke 2005a, 167) Seemingly, an advantage to guild building

is its adaptability, as the unique conditions of a particular site can be tailored to as necessary: "limiting factors act as one of the most important initial filters to help you eliminate candidate species." (Jacke 2005a, 167) Thorough site analysis, working in conjunction with detailed understanding of plant requirements and behaviour, are a major component of the guild build approach. This includes outlining the most limiting factors and growing conditions before basing species selections on such information.

Ecological Analogs

Ecological analogs examine the preexisting ecological systems of a particular region and mimicking or substituting desired elements, attributes, structures, and so on: "[w]e know that the species in local native ecosystems survived in our locale, so we should mimic that ecosystem as directly as possible, right down to the species…Even if we don't know how the species in the native ecosystem function, using them or their analogs should provide our gardens with many of the benefits we seek." (Jacke 2005a, 168) On the surface, knowing that these systems are already capable of functioning at a high order relieves the necessity for rigorous experimentation or research. However, the process of observing these systems in nature likely requires more polish, and they are liable to be less suitable for urban scenarios. With the myriad stressors intrinsic to city environments, the ecological analog approach should be used only under a strong conviction that such a template can be adapted to a particular site and thrive. "Determine the characteristics of your soils and site, find out what kind of precolonial ecosystem grew there, and then look for actual examples or written references to the species that lived in such habitats." (Jacke 2005a, 168-9) A sophisticated understanding of the regional biome would likely reveal that certain elements have sensitivities to urban conditions. Conversely, complete exclusion of this approach from urban scenarios could result in missed opportunities for easy productivity and rewilding. The presence of natural guild members in urban locations may indicate a certain degree of compatible conditions or microclimates within city limits.

Furthermore, these two approaches need not be mutually exclusive, as it is not uncommon for natural plant communities to have some niche gaps. Employing a comprehensive understanding of a specific site, influenced by proven natural systems in the region, blends useful attributes of both methods as we strive for optimal design.

Defining the Checklist

Bearing this in mind, the following list has been compiled to improve productivity and overall system health for our designs:

a) Familiarize with limiting factors on site and nutrient requirements

b) Ensure each guild has at least one nitrogen-fixing plant

c) Ensure each guild has at least one dynamic nutrient-accumulating plant

d) Ensure each guild has at least one soil-building plant or 'mulch maker'

e) Ensure each guild will always have at least one plant species in bloom, throughout the season, for hosting beneficial insects and pollinators (a 'bloom calendar')

f) Ensure each guild has cover crops protecting soil surface throughout

g) Ensure root types are compatible between guild members

h) Ensure nutrient requirements are compatible between guild members

i) Ensure adequate spacing for fully established plants

j) Ensure pollination requirements are satisfied (male/female, self-pollinating, timing, etc.)

k) Explore temporal niches (i.e., asparagus intercrop)

l) Consider harvest calendar (timing and type of harvest, masts or 'bumper crops', etc.)

m) Consider carbon sequestration potential for the site and diet

n) Ensure soil depth is observed or measured as thoroughly as possible

o) Consider complete utilization of layers

p) Consider Ormston-Holloway's rule of 10/20/30

r) Consider replacing non-natives with suitable natives

s) Consider replacing opportunists with non-opportunists

a) Familiarize with limiting factors on site and nutrient requirements

A soil test is the most effective method for understanding soil conditions and nutrient availability on site—though not always possible due to timing or financial restrictions. Reading the preexisting vegetation on a given site can help indicate an abundance or dearth of a specific nutrient, as well as soil pH. An area dominated by pines, for instance, is likely to contain more acidic soil. Soil pH can also be determined from a soil test, though many plants tolerate a range of pH conditions, as discussed below.

b) Ensure each guild has at least one nitrogen-fixing plant

As the main macronutrient required for leafy growth, nitrogen is often the most limiting factor of plant health. Although pollution in cities makes atmospheric nitrogen more plentiful in urban scenarios, the need for nitrogen remains an important element of healthy plant communities. (Jacke 2005a, 175)

c) Ensure each guild has at least one dynamic nutrient-accumulating plant

While different nutrients are required by different plants and in different quantities, these nutrients can be organized into groups, prioritized by how limiting they can be to general plant health. Conveniently, such nutrients need not be imported, as they usually can be made available through the strategic utilization of specialized plants: "[i]ncreasing resources conventionally means importing them from elsewhere at high cost. Increasing nutrient supplies ecologically means using deep-rooted and otherwise nutrient-accumulating plants, mulches, and good soil biology to improve nutrient cycling, storage, and supply—though these take time." (Jacke 2005a, 133) Especially in the early stages of establishment, and for degraded soils in particular, dynamic accumulators play a critical role in scavenging the soil depths for nutrients and making them available to other plants in various space and time niches. The life strategies of these early-succession plants involve rapidly gathering nutrients, ultimately aiding the communal processes of a graduated succession throughout. While research on the subject remains somewhat limited, a plant is generally classified as a dynamic accumulator if it can mine the subsoil for at least one of the four most limiting plant nutrients (nitrogen, potassium, phosphorous and calcium), making them available to the plant community. (Jacke 2005b, 535) Stinging nettle, for instance, accumulates many nutrients such as potassium and calcium, and is known to increase the oil content and nutritional value of surrounding herbs and plants. (Foster 1984, 154) Other excellent dynamic accumulators, such as German chamomile, comfrey, sorrel, and dandelion, are effective ways to increase the availability of Ca, P, and K on site without importing outside resources. These plants also provide plenty of supplemental value as edibles, teas, medicinals, and so forth. The multifunctional attributes of such plants would be difficult to find in synthetic fertilizers, reiterating the advantages of permaculture design.

d) Ensure each guild has at least one soil-building plant or 'mulch maker'

Particularly important in urban scenarios where degraded soils abound and the opportunity for nutrient cycling from livestock is limited, soil-building plants are an excellent way to build local soils without imported resources. Comfrey is a shining example of a soil building plant, capable of rapidly generating biomass that is converted to dead organic matter relatively quickly—improving nutrient availability for surrounding plants.

e) Ensure each guild will always have at least one plant species in bloom, throughout the season, for hosting beneficial insects and pollinators (a 'bloom calendar')

"As we design our forest gardens, we must remain conscious that we are designing a food web and use that knowledge to help create a high-yield, self-maintaining system…Predation, parasitism and herbivory constitute a major portion of the links that create the food web and play a major role in regulating populations, managing competition, cycling nutrients, and dispersing energy both above- and belowground." (Jacke 2005a, 144) In order to attract pollinators and encourage their continued presence, scheduling and implementing a calendar of when plants on site are in bloom—ensuring sources of nectar are consistently available—is required. If we want to alleviate our concerns about pests, seasonal habitat for a wide range of pest predators should be included in our designs. An exemplary insectary plant is sweet fennel, capable of attracting nearly fifty different species of ichneumon wasps—many of which prey on the many pests of the Rosaceae family. (Bugg et al 1998) A strong grasp of the food web—namely knowing who eats whom—will help us achieve a steady, balanced control of pest populations without chemical intervention. Furthermore, there exists a distinct correlation between increases in botanical diversity and the presence of beneficial insects. (Hani et al 1998, 185-6) Fostering diversity—including pest diversity—is key, as diverse pest populations represent a diversity of food for predators, and providing a diversity of habitat keeps them around. When we apply pesticides—even certified organic pesticides—we reduce biodiversity across the board, potentially creating conditions where pests are more likely to thrive than their predators. (Jacke 2005a, 148) Deliberate selection and establishment of certain plants can naturally regulate pest population booms, while honouring their diversity. (Hani et al 1998, 185-6)

f) Ensure each guild has cover crops protecting soil surface throughout

Cover crops can take many shapes and forms, and perform many different functions. Ideally, they are edible, native, mat forming, nitrogen fixing, nutrient accumulating, low-maintenance, traffic-tolerant, shade-tolerant, or some combination thereof. The main functions of ground covers are to protect the soil and its biology from compaction, erosion, moisture and nutrient loss, and to provide buffering from temperature extremes. These factors play a critical role in maintaining soil fertility and overall system health, so using cover crops to eliminate bare soil is another important aspect of permaculture design.

g) Ensure root types are compatible between guild members

Diversifying root types in a guild also diversifies plants nutrient needs, partitions soil resources and access, and minimizes competition. A basic example in annual gardening scenarios would be planting tomatoes (taproot or fibrous root system) alongside onions (bulbous) in order to maximize space and plant health.

h) Ensure nutrient requirements are compatible between guild members

"Polycultures have the highest chance of additive yielding when their component species occupy divergent niches, especially with respect to the most limiting resources." (Jacke 2005a, 166) Returning to the annual garden scenario: if a tomato's most limiting resource was nitrogen, then planting it next to an onion, that may feed heavily on phosphorous or perhaps nitrogen later in the season, exemplifies nutrient compatibility in a guild.

i) Ensure adequate spacing for fully established plants

Working backwards in time is a good way to determine the location and quantity of plants in a design, using the estimated dimensions of plants at maturity. Overplanting can result in a host of problems such as limited pathway access, transmission of disease, intense competition and reduced nutrient availability. There are varying schools of thought on this, however. While many agree that spacing should be adequate initially—with any gaps filed in with desired species later—Shepard (2013) posits that we should plant as densely as possible, using as many varieties as possible. In his view, the many seedlings that do not survive indicate varieties incompatible to the location, and should provide ample space as they are

removed and replaced by more appropriate cultivars. However, budgetary constraints associated to rising nursery costs may be a barrier to this approach.

j) Ensure pollination requirements are satisfied (male/female, self-pollinating, timing, etc.)

Many different fruit and nut trees have varying requirements for bearing fruit. Some are self-fertile, while others require counterparts within various ranges of the vicinity. A familiarity with such requirements is an important factor to ensure a yield is realized (i.e., healthy male-to-female ratio, overlapping flowering periods, etc.).

k) Explore temporal niches (i.e., asparagus intercrop)

Resources can be partitioned in numerous ways—such as plants of various root types and resource demands accessing soil nutrients found in different soil layers. Another way to partition resources is through deliberate temporal niche design. For instance, spring ephemerals (i.e., asparagus, ramps) access the first flush of nutrients from snow melt before going dormant, making way for succeeding crops to occupy the same space and nutrient bank. Many ephemerals make excellent understory layers, as they "grow in virtually full sun, since their leaves emerge before those of the canopy trees." (Jacke 2005a, 77) Paying close attention to available temporal vacancies can maximize productivity that would otherwise go unrealized in late successional forests.

l) Consider harvest calendar (timing and type of harvest, masts or 'bumper crops', etc.)

This aspect of design might be more prone to being overlooked. Hypothetically speaking, if everything else in our design were perfect, but each system element produced fruit on the same day, we would either have to import significant resources (i.e., labour) to manage such an immense harvest, or lose a great deal of system yield to waste as a result of our inability to collect, process, and store such abundance before spoilage occurs. In this respect, by selecting species and cultivars with variant fruiting patterns, we allow ourselves to spread our harvest as evenly as possible throughout the season. Type of harvest is also a factor and should be planned in detail to optimize yields. For instance, designing polycultures involving a root crop such as Jerusalem artichoke requires some foresight, as soil disturbance might damage other plants in the guild before they can be harvested. With this in mind, it may be preferable to install compatible root crops to avoid such encumbrances. Another example

would be ensuring that the crops growing beneath a fruit tree would not be damaged by increased foot traffic during harvest.

m) Consider carbon sequestration potential for the site and diet

Carbon sequestration and storage potential for home gardens consisting of woody polycultures is estimated to fall between 8-16 tons of C per hectare per year, based on "scientific reviews or estimations by experts in the field." (Toensmeier 2016, 31-33) Substituting herbaceous annuals with perennials is a step in the right direction, effectively reducing soil disturbance and food web degeneration. All else equal, we should look to expand our usage of strong carbon sequesters whenever possible.

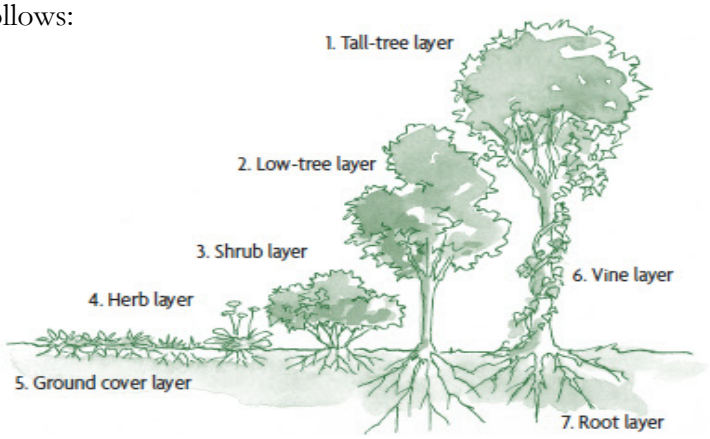
n) Ensure soil depth is observed or measured as thoroughly as possible

This is more of a concern for designs consisting of trees with deep taproots, as potential impermeable horizontal layers will have adverse effects on plant health and survival. The presence of power lines, gas lines, subway tunnels and the like is also a major factor and should give us pause in any scenario where digging is required.

o) Consider complete utilization of layers

By creating food systems of varied structure, we diversify our yields while promoting the involvement of an assortment of community members from the local biology. For instance, the majority of beneficial insects prefer undisturbed soil and varying layers of vegetation in which to perch and overwinter; while "bird[s] with feet adapted to perching on small twigs can live only where there are small twigs." (Jacke 2005a, 130) In view of a forest garden, the seven layers can be characterized as follows:

1. Large tree
2. Small tree
3. Shrub
4. Herbaceous
5. Ground Cover
6. Vine
7. Rhizome or root



(Image source: Hemenway 2009, 216)

Filling each vertical niche with a wide range of plants not only supports biodiversity but also maximizes a site's energy capture from the sun, whereas the solar gain of a relatively flat monocrop is limited.

p) Consider Ormston-Holloway's rule of 10/20/30

As mentioned, considering Ormston-Holloway's suggestion of balancing ten, twenty, and thirty percent samplings of any particular species, genus, and family, respectively, should enhance the performance of our designed ecosystems.

r) Consider replacing non-natives with suitable natives

If there is a non-native plant exhibiting certain characteristics that we enjoy, we may be surprised to discover a native plant with similar traits that would likely perform in greater harmony with the local ecology.

s) Consider replacing opportunists with non-opportunists

Moreover, if a plant that we desire also happens to be an aggressive spreader, it would behoove us to search for a less vigorous replacement before including them in our design.

While there are many other factors to consider, many of which may be specific to each individual location, a checklist can be effective for both preparatory and retrospective design purposes.

PROJECT ONE: ANNEX RESIDENTIAL

Ecological Analog Approach

A small backyard in a residential area, this space receives full sun for much of the Northern portion, with some challenging shade patterns from neighbouring buildings and coniferous tree lines to the South. Such elements provide considerable wind protection, though further observation would likely provide insight for a more refined windbreak design. Soil is degraded by moderate compaction from outside foot traffic (i.e., cable installations, fence renovations, neighbours' pets, etc.), and the possibility of chemical treatment throughout the history of the area. Preexisting vegetation is relatively minimal (goldenrod, clover, grass), lending further support to the necessity for physical and biological remediation.

In taking the ecological analog approach for this design, research on the Lake Erie Lowland bioregion shed light on ancient forest plant species common to the Greater Toronto Area. (Environment Canada 1995) Extending along the "Quebec City-Windsor corridor, including the densely-populated region of Southern Ontario", the Mixedwood Plains biome is home to thousands of plant species—with several of which holding greater potential than others for human food purposes—including sugar maple, red oak, black walnut, butternut, basswood, red mulberry, American ginseng, wild raspberry, staghorn sumac, highbush cranberry, serviceberry, and cattails. (Bernhardt) Though too large at maturity for this plot, the black walnut is an exciting core plant to demonstrate the ecological analog approach, as shown by its high degree of multifunctionality.

Design Levels

Mission of Project

Showcase the feasibility of permaculture gardening—emphasizing perennial vegetables and woody fruit and nut crops to restore degraded urban soils, produce a yield, and capture carbon.

Project Goals

Convert degraded and potentially lead-contaminated soils to an edible ecosystem—improving local biology and providing healthy, nutrient-dense food with an emphasis on perennial vegetables.

Strategies

Ecological Analog: Research plant guilds common to the regional biome, substituting similar plants where necessary.

Techniques

Observe and interact; basic soil development; follow design checklist

Design Methods

Applied Checklist

a) Familiarize with limiting factors on site and nutrient requirements

The relatively limited presence of preexisting vegetation suggested a lack of nutrients across the board, thus requiring basic soil development practices to improve general nutrient availability.

b) Ensure each guild has at least one nitrogen-fixing plant

There is a limited pool of native nitrogen fixers from which to draw. Wild indigo is one of few options, though it is not without its drawbacks, as parts of the plants are toxic to humans. If not for this trait, it would have been easier to include it in the final design. Instead, white clover was selected as a pathway cover crop. Although the small tree and shrub layer have a relatively low nitrogen demand in the guild—and atmospheric nitrogen is more plentiful in urban scenarios—as the most frequent factor limiting plant growth, it couldn't hurt to include one here. In designing the pathways, white clover was ultimately selected for its high traffic tolerance and nitrogen-fixing capability.

c) Ensure each guild has at least one dynamic nutrient-accumulating plant

Black walnut, dandelion, chickweed, and white clover all exhibit various nutrient scavenging capabilities.

d) Ensure each guild has at least one soil-building plant or 'mulch maker'

Clover and dandelion have soil-building properties, which can be supplemented by consistent soil development practices (i.e., compost, leaf mulch, etc.). Mulberry can be used as a coppice species for steady input of additional organic matter. Jerusalem artichoke, nasturtium, and rhubarb (leaves are toxic to ingest) can also make effective mulch-makers for the raised bed area.

e) Ensure each guild will always have at least one plant species in bloom, throughout the season, for hosting beneficial insects and pollinators (a 'bloom calendar')

- American red currant (flowers in April)
- Dandelion (Apr)

- White trillium (Apr, May)
- Chickweed (Apr, May, June, July)
- Sea kale (June)
- Sweet cicely (June, July, Aug)
- Udo (July, Aug; non-native)
- Goldenrod (Aug, Sep, Oct; already on site)
- White clover (Apr, May, June, July, Aug, Sep, Oct)

f) Ensure each guild has cover crops protecting soil surface throughout

Chickweed, clover, and white trillium provide adequate ground cover for varying sun requirements.

g) Ensure root types are compatible between guild members

An advantage to the ecological analog approach is the understanding that these plants are endemic to the area and should theoretically have fewer conflicts. However, double-checking the root types as situated in the design is advisable.

h) Ensure nutrient requirements are compatible between guild members

Moreover, nutrient requirements should be relatively compatible, but more information always helps.

i) Ensure adequate spacing for fully established plants

The conceptual designs are of plants at mature size, potentially allowing for interim harvest as trees and shrubs establish (i.e., annual crops, short-lived perennials, etc.), depending on future resource availability and inputs (i.e., labour, seedlings, etc.).

j) Ensure pollination requirements are satisfied (male/female, self-pollinating, timing, etc.)

Red mulberry, black raspberry, American red currant and fox grape are all self-fertile.

k) Explore temporal niches (i.e., asparagus intercrop)

Early spring ephemerals such as ramps intercropped with various annual and perennial vegetables in the raised part-shade bed exemplify obtaining yields in a temporal niche.

l) Consider harvest calendar (timing and type of harvest, masts or 'bumper crops', etc.)

- Red mulberry (July-Aug)
- American red currant (harvest early July; late July; early-mid Aug)
- Black raspberry (mid July; late July; late Aug-Sep)
- Fox grape (late Aug-early Oct)
- Black walnut (Sep-Oct; bumper crops every few years)

m) Consider carbon sequestration potential for the site and diet

The dominance of perennial woody crops and vegetables along with the steady accumulation of biomass and organic matter should improve the site's carbon sequestration performance. Drawdown potential of such practices for a lot size of just under 1500 square feet (33' x 44') was roughly calculated to fall between 1/10 and 1/5 of a ton of carbon per year, based on scientific and expert estimations. (Toensmeier 2016, 31) In systems such as this, we can sequester carbon while also producing dietary yields. For instance, we annually realize roughly 1-2 quarts, 10-15 pounds, and 5 pounds yield per plant of raspberry, currant, and grape, respectively (Shepard 2013, 108).

n) Ensure soil depth is observed or measured as thoroughly as possible

Though deep taprooted trees were not included in the design, a complete physical loosening of the top 2-3' of soil was considered advantageous.

o) Consider complete utilization of layers

Each of the seven layers is represented in the final design, though further exploration of additional yields from the root layer might prove beneficial.

p) Consider Ormston-Holloway's rule of 10/20/30

Though Holloway's suggestion pertains chiefly to canopy diversity, the point remains valid and was considered here for the small tree, shrub, herbaceous and vine layers—an estimated total of 100 plants:

1 - Red mulberry *morus rubra* (Moraceae)

3 - Black raspberry *rubus occidentalis* (Rosaceae)

12 - American red currant *ribes triste* (Grossulariaceae)

14 - Bee balm and wild bergamot *monarda* spp. (Lamiaceae)

25 - Purple coneflower *echinaceae purpurea* (Asteraceae)

15 - Solomon's seal *polygonatum biflorum* (Convallariaceae)

15 - Sweet cicely *myrrhis odorata* (Apiaceae)

11 - Fox grape *vitis labrusca* (Vitaceae)

4 - American basswood *tilia americana* (Tiliaceae)

As the plants from the root and cover layers were excluded to simplify calculations, it is interesting to note the diverse selection of families represented here. Though rough estimations, only Asters approached the 30 percent suggested threshold. A scenario in which every other guild plant comes from a unique family should bode well for defending against unexpected pest population explosions. Purple coneflower was the only plant to exceed the recommended thresholds for both genus (10%) and species (20%), though quantities could be adjusted as necessary.

r) Consider replacing non-natives with suitable natives

In emphasizing native plants with the ecological analog approach, exotic plants were of little account in the final design.

s) Consider replacing opportunists with non-opportunists

The presence of opportunistic plants was negligible, though many mints and balms can be expansive via rhizomatous spreading. If a concern, such pollinator-friendly plants can be limited by containers or other means of blocking root expansion. In this case, plants from the *monarda* genus were included for their tolerance to juglone.

Function-element links

In more integrated food system designs, "each element performs multiple functions, and each function is served by multiple elements." (Hemenway 2009, 35) As each element provides a number of functions that have multiple connections to other system elements, a higher level or order is established and overall system performance increases, especially with respect to encountering or avoiding stress. The specific multiple functions performed by each element are outlined in the 'Master planning' section.

Resource analysis and needs

Goldenrod and clover preexisting on-site suggest the possible compatibility of the ecological analog suite with the location. Without executing a soil test, efforts should be made to establish and maintain the needs required by the plants in this community, as outlined below.

Contemplating vectors or 'outside influences'

Most notable outside influences for the Annex design comes in the form of unexpected foot traffic from neighbours, contractors, and pets, resulting in dissatisfying soil compaction. Clearly designated, legible pathways should at least alleviate such compaction concerns.

Design Process

Observation and site context

With more frequent access to the Annex site, observation was logistically more frequent, though only dating back to October and therefore incomplete. In the interest of time, some extrapolations or assumptions were necessary, such as forecasting shade patterns based on equinox—though including crops with shade tolerances can simplify such design challenges.

Research (potential guilds, etc.)

The city of Toronto is situated in the Lake Erie Lowland, categorized under the Mixedwood Plains bioregion. Using the ecological analog approach, the majority of plants selected for this design are native to the Mixedwood Plains bioregion. Species substituted for various reasons—such as incompatibility with specific site conditions or other social interactions—are noted accordingly.

Master planning

1. Black walnut
2. Mulberry
3. Black raspberry; American red currant
4. Bee balm or wild bergamot; dandelion; purple coneflower; solomon's seal; sweet cicely
5. Chickweed; white clover; white trillium
6. Fox grapes; beans
7. Perennial onions, ramps and garlic; wild ginger

Layer number) Common Name *Latin name* (Plant family)

Hardiness zone; solar preference; soil moisture tolerance range (xeric=drought tolerant; mesic=moist-somewhat dry; hydric=damp-wet); soil pH range; root pattern; various functions; size at maturity (height x width)

Sources: Caesar (2018); Hemenway (2009, 2015); Jacke (2005); Kourik (1986); Toensmeier (2007); Whiffletree (2017); William Dam (2017)

LARGE TREE LAYER

1) Black walnut *juglans nigra* (Juglandaceae)

Zone 4b-7; full sun; xeric/mesic; garden to alkaline soil pH; taproot; dynamic accumulator of potassium, phosphorous and calcium; generalist nectary; 75-100' x 75-100'

Taprooted root pattern thrives in deep, well-drained fertile soil, which may be a challenge in some urban scenarios, though certainly feasible ~ Excellent value as superfood and for medicinal purposes ~ Useful coppice species ~ Requires another nearby for pollination ~ High nitrogen demand ~ Though black walnuts have open crowns "providing more than 50 percent openings in their canopies, with sparse branching, light foliage, and light shade", as the crown fills in, more shade tolerant species such as wild ginger, white trillium, and pawpaw should be incorporated

SMALL TREE LAYER

2) Red mulberry *morus rubra* (Moraceae)

Zone 5b-9; full sun to part shade; xeric/mesic; garden to alkaline soil ph; taproot or heartroot; wildlife shelter and food source; 35-50' x 35-50'

Excellent medicinal value ~ Dense crown ~ Self-fertile but will be more productive with cross-pollination ~ Useful coppice species ~ Moderate nitrogen demand ~ Juglone tolerant

SHRUB LAYER

3a) Black raspberry *rubus occidentalis* (Rosaceae)

Zone 4; full sun; xeric/mesic; acidic to garden soil ph; fibrous, suckering root pattern; wildlife shelter and food source; generalist nectary; 3-6' x 6'+

Superfood ~ Leaves valuable for tea and medicinal use ~ Self-pollinating ~ Edible young shoots ~ Low nitrogen demand ~ Juglone tolerant

3b) American red currant *ribes triste* (Grossulariaceae)

Zone 3; full sun to part shade; mesic/hydric; acidic to garden soil ph; suckering roots; wildlife shelter and food source; generalist nectary; 3-5' x 3-5'

Self-pollinating ~ Very low nitrogen demand ~ Juglone tolerant

HERBACEOUS LAYER

4a) Bee balm and wild bergamot *monarda* spp. (Lamiaceae)

Zone 3-9; full sun to part shade; xeric/mesic; acidic to garden soil ph; rhizomatmous root pattern; hummingbird food source; generalist nectary; aromatic pest confuser; 2-4' x 2-6'

Valuable uses include culinary, tea and medicinal ~ Sweet and minty edible flowers ~ Oviposition (egg-laying) sites for beneficial lacewings ~ Juglone tolerant

4b) Dandelion *taraxacum officinale* (Asteraceae)

Zone 3; full sun to part shade; mesic; garden to alkaline soil ph; taproot; dynamic accumulator of potassium, phosphorus, calcium, copper, and iron; invertebrate shelter; generalist nectary; 6-24" x 6-24"

Leaves, flower and root are all edible and highly nutritious ~ Excellent for teas, coffee, wine and medicinal use ~ Parasitoid wasps find shelter in foliage ~ Juglone tolerant ~ Non-native

4c) Purple coneflower *echinaceae purpurea* (Asteraceae)

Zone 3-8; full sun to part shade; mesic; garden soil ph; taproot; invertebrate shelter; generalist nectary; 3-4' x 1-2'

Excellent medicinal use ~ Parasitoid wasps find shelter in foliage ~ Juglone tolerant

4d) Solomon's seal *polygonatum biflorum* (Convallariaceae)

Zone 3-7; full sun to full shade; xeric/mesic; strongly acidic to garden soil ph; rhizomatous root pattern; 1-5' x 4'+

Excellent medicinal use ~ Edible young shoots ~ Starchy rootstocks are edible when cooked ~ Juglone tolerant

4e) Sweet cicely *myrrhis odorata* (Apiaceae)

Zone 4; full sun to part shade; mesic; acidic to alkaline soil ph; flat taproot; invertebrate shelter; specialist and generalist nectary; aromatic pest confuser; 3' x 3'

Cooked roots and leaves are edible and have a sweet anise flavour ~ Also used as culinary spice or tea ~ Excellent medicinal value ~ Oviposition sites for beneficial lacewings ~ Parasitoid wasps find shelter in foliage ~ Juglone tolerant

GROUND COVER LAYER

5a) Chickweed *stellaria* spp. (Caryophylaceae)

Zone 4; full sun to part shade; mesic; garden soil ph; fibrous root pattern; dynamic accumulator of potassium and phosphorus; invertebrate shelter; generalist nectary; 6-12" x 1-2'; self-seeding annual

Edible leafy greens excellent raw ~ Superfood ~ Excellent medicinal use ~ Indicator species for high fertility sites ~ Juglone tolerant ~ Giant chickweed is a shade-tolerant native perennial to zone 5, though flavour is less appetizing and does not share dynamic accumulating capability of chickweed

5b) White clover *trifolium repens* (Fabaceae)

Zone 4; full sun to part shade; mesic; acidic to garden soil ph; stoloniferous root pattern; nitrogen fixer; dynamic accumulator of phosphorus; invertebrate shelter; generalist nectary; 4-10" x 6-36"

Flowers are edible and used for tea ~ Oviposition sites for beneficial lacewings ~ Parasitoid wasps, spiders and ground beetles find shelter in foliage ~ Indicator species for dry, low-nitrogen sites ~ Juglone tolerant ~ Non-native ~ Makes excellent ground cover due to its high tolerance for foot traffic ~ Preferred food source for rabbits, drawing them away from other crops

5c) White trillium *trillium grandiflorum* (Trilliaceae)

Zone 3-7; part shade to full shade; mesic; acidic to alkaline soil ph; rhizomatous root pattern; generalist nectary; 12-18" x 12"+

Young unfolding leaves are edible with a sunflower flavour ~ Good medicinal value ~ Juglone tolerant

VINE LAYER

6) Fox grape *vitis labrusca* (Vitaceae)

Zone 3-9; full sun; xeric to hydric; acidic to alkaline soil ph; wildlife food source; generalist nectary; 35'+ x 20-35'

Edible leaves for pickling, wraps, etc. ~ Seeds and fruit have excellent value as medicinal and superfood ~ Self-pollinating ~ Juglone tolerant (beans are also known to be tolerant of juglone, noted here as a potential annual option for the vine layer)

ROOT LAYER

7a) Perennial onions, ramps and garlic *allium* spp. (Alliaceae)

Zone 3-10; full sun to full shade; xeric to mesic; acidic to garden soil ph; bulbous root pattern; generalist nectary; aromatic pest confuser; 6-24" x 1'+

Edible greens, roots, flowers ~ Also used medicinally and for spices ~ Juglone tolerant

7b) Wild ginger *asarum canadense* (Aristolochiaceae)

Zone 3-8; part shade to full shade; mesic; acidic to alkaline soil ph; rhizomatous root pattern; 4-8" x 8"+

Edible roots, used medicinally and for spices ~ Leaves are toxic ~ Juglone tolerant

RAISED BEDS FOR PERENNIAL AND ANNUAL VEGETABLES

3c) American basswood *tilia americana* (Tiliaceae)

Zone 3; full sun to full shade; mesic; garden to alkaline soil ph; flat taproot pattern; dynamic accumulator of phosphorous and calcium; generalist nectary; 75-100' x 40'

Large at maturity but can be coppiced regularly for easier harvest and keeping leaves "low and tender" ~ Dense crown ~ Tea and medicinal use ~ Highly dispersive by seed ~ Negatively affected by juglone ~ Very low nitrogen demand

French Sorrel *rumex acetosa* (Polygonaceae)

Zone 3-9; full sun to part shade; mesic; acidic to alkaline soil ph; fibrous pattern; dynamic accumulator of potassium, phosphorous, calcium, iron, and sodium; 1-3' x 1'

Edible leaves with lemony flavour ~ Few disease or pest problems

Good king Henry *chenopodium bonus-henricus* (Chenopodiaceae)

Zone 3-9; full sun to part shade; mesic; acidic to alkaline soil ph; fibrous taproot pattern; 1-3' x 12-18"

Edible shoots, flowerbuds, seeds and greens, similar to spinach in taste when cooked ~ Minimal disease or pest problems

Sea kale *crambe maritima* (Brassicaceae)

Zone 4; full sun to part shade; xeric to mesic; garden to alkaline soil ph; taproot pattern; generalist nectary; 2-3' x 3'

Edible broccolis, shoots and leaves with a collard taste ~ Good medicinal value

Udo *aralia cordata* (Araliaceae)

Zone 5; light shade to full shade; mesic; garden soil ph; specialist and generalist nectary; 4' x 4'

Edible shoots ~ Highly productive ~ Excellent medicinal value

Site Design Map [see Appendix A]

PROJECT TWO: REXDALE COMMUNITY CENTRE

Guild Build Approach

A relatively flat, open area near the community centre characterizes the Rexdale site, with basketball courts to the South and a neighbouring daycare North of the fence. A preexisting white pine in the southwest corner of the designated area provides some shade in an otherwise sunny location. The soil in this area is presumed acidic, after years of needle mulch from the pine having accumulated and decomposed. A mild slope begins its decline at around the pine's location, before a fence divides the section between the shrubberies of a highway ditch. To the East, high-rise residential towers exacerbate an easterly wind tunnel effect. A natural windbreak adjacent to the sidewalk provides moderate relief from the prevailing winds, though this could be reinforced with appropriate species such as Siberian pea shrub. Soil is degraded by moderate compaction from recreational and general foot traffic**.** Concerns over soil salinity due to its proximity to the highway are relaxed due to the aforementioned shrubbery—though a soil test might prove beneficial in determining whether including halophytes (plants tolerant of salty soil such as seaberry, sugar beet, or yucca) should be included in the design. Otherwise, the flat and lifeless stretch of lawn works

in favour of the guild build approach, providing something of a blank slate from which to build guilds from scratch. However, without executing a soil test, information on the site's limiting factors is scarce to say the least. As such, methods for rebuilding soil structure as broadly and wholly as possible are advisable (see Project Three). Clear objectives from the client help otherwise narrow our plant palette.

Design Levels

Mission of Project

To engage disadvantaged communities on the subject of local food nutrition, low-maintenance forest gardening, and the climate crisis

Project Goals

Restore and convert compacted and degraded soils to a fruit garden, improving local biology and providing healthy, nutrient-dense food with an emphasis on small fruit and berries

Strategies

Guild building: entails establishing a community of plants more or less from scratch. Strategy is shaped by client request and availability from local nursery catalogues

Techniques

Observe and interact; basic soil development; sheet mulching to kill grass monoculture; follow design checklist

Design Methods

Applied Checklist

a) Familiarize with limiting factors on site and nutrient requirements

In view of the minimal diversity of vegetation, and without conducting a soil test, limiting factors were considered broadly, as discussed.

b) Ensure each guild has at least one nitrogen-fixing plant

Goumi substituted goji for its nitrogen fixing abilities. However, if a soil test were to indicate low nutrient levels, autumn olive may be an alternative for its ability to tolerate poor soils.

Though larger in size, the autumn olive could be pruned as chop-and-drop mulch to scatter throughout the site as well. In healthier soils, autumn olive is more opportunistic and would require containment or more intensive management. Understory herbaceous plants such as lupine and white clover can also make nitrogen available to surrounding plants.

c) Ensure each guild has at least one dynamic nutrient-accumulating plant

Comfrey planted at the base of large fruit trees "draws minerals and nutrients from the subsoil into its leaves." (Whiffletree 2017) As a plant in high-demand, comfrey was not included in the final design due to its unavailability. Consequently, other nutrient-scavenging plants such as lupine (nitrogen and phosphorus) and yarrow (potassium, phosphorous and copper) were situated beneath the cherry trees as substitutes.

d) Ensure each guild has at least one soil-building plant or 'mulch maker'

Comfrey could be employed here as well, to "[c]hop and drop the leaves three or four times in a growing season for an effective living mulch." (Whiffletree 2017) Clover species, especially red clover, can also be an effective biomass plant when slashed regularly.

e) Ensure each guild will always have at least one plant species in bloom, throughout the season, for hosting beneficial insects and pollinators (a 'bloom calendar')

- Wintergreen (flowers Apr)
- Columbine (Apr, May, June, July)
- Cherry (May, June)
- Lupine (May, June, July)
- Anise Hyssop (June, July, Aug, Sep)
- Yarrow (June, July, Aug, Sep)
- White clover (Apr, May, June, July, Aug, Sep, Oct)

f) Ensure each guild has cover crops protecting soil surface throughout

Clover, cranberry, lingonberry, and wintergreen provide adequate ground cover for varying sun and soil pH requirements. Wild strawberries are considered an excellent ground cover, and make good companions to comfrey, Siberian purslane, sorrel and perennial onions: "Wild strawberries are good in mixtures, as they move to fill any gaps." (Jacke 2005a, 296)

Though yield is not typically comparable to cultivated species, there do exist ground covers that yield small berries, which would better suit the goals of this site. Lingonberry and wintergreen for pine understory "require very well drained, acidic soil, even more so than most blueberries…Interplant with low-bush blueberries for a truly impressive ground cover." (Whiffletree 2017)

g) Ensure root types are compatible between guild members

Polycultures of currants (heartshaped suckers), goumi (fibrous stolons) and haskaps (unknown root pattern) should have limited conflicts—though the client's penchant for cherries could increase competition for resources, and promote disease and pest issues. However, some research suggests that several species from the *prunus* genus do not perform well in polycultures, due to shallow roots, compact crowns, or other potential factors. (Crawford 1997)

h) Ensure nutrient requirements are compatible between guild members

In considering nitrogen, as a major plant nutrient, we find that our overstory of cherry has a low nitrogen demand. This bodes well for the remainder of the guild, with members exhibiting varying degrees of nitrogen demand. Other resource requirements such as sun, soil pH and moisture are fairly compatible across the board, as all guild members show a preference or at least tolerance of full sun, garden soil pH and mesic conditions. Plants in the acidic guild seem to prefer more moist soils, simplifying irrigation whenever necessary. Ideally, additional plant nutrient requirements are moderated by the presence of nutrient-scavenging plants installed throughout.

i) Ensure adequate spacing for fully established plants

The plan view is a projection of plants at maturity, allowing for filling in as necessary. Leaning towards wider spacing was considered to be most logical for the site. With labour input expected to be low, any regular of pruning trees to avoid root and foliar mingling is unlikely to occur.

j) Ensure pollination requirements are satisfied (male/female, self-pollinating, timing, etc.)

Four different varieties of cherry were selected to constitute the overstory, all of which are self-fertile. A variety of shrub cherries were selected, all semi-fertile, indicating that they "will bear fruit if planted alone…[though] more (and possibly larger) fruit if you plant a second (different) variety for cross-pollination." (Whiffletree 2017) In the shrub layer, red currant, goumi and gooseberry are all self-fertile. Haskaps have specific cross-pollination requirements, so special attention to selecting the proper cultivars is necessary. For the vines, fox grape is self-fertile; the magnolia has both male and female flowers on each plant; and the group of female kiwis requires one non-fruiting male in the guild.

k) Explore temporal niches (i.e., asparagus intercrop)

With an emphasis on fruit, spring ephemerals such as asparagus or ramps were not included in design. Therefore, time and resource requirements were considered to be relatively stable throughout the growing season.

l) Consider harvest calendar (timing and type of harvest, masts or 'bumper crops', etc.)

- Haskap (June to July)
- Various cherry cultivars
    - White Gold (early mid July)
    - Benton (mid July)
    - Black Gold (mid late July)
    - 4-in-1 (rolling harvest throughout July and Aug)
- Various currants cultivars
    - Jonkheer Van Tets (early July)
    - Red Lake (late July)
    - Rovada (early-mid Aug)
- Various gooseberry cultivars
    - Poorman (mid July)
    - Captivator (late July)
    - Jeanne (early Aug)
- Goumi (late Aug)
- Mongolian bush cherry (late July to mid Aug)

- Fox grape (early Sep to early Oct)
- Hardy kiwi (early Sep to early Oct)
- Magnolia vine (late Sep)

m) Consider carbon sequestration potential for the site and diet

Strong C drawdown potential is a byproduct of the emphasis on woody perennials such as fruit trees and shrubs. Drawdown potential of such practices for a lot size of 2700 square feet (30' x 90') was estimated between 1/5 to 2/5 of a carbon ton annually, based on scientific and expert estimations. (Toensmeier 2016, 31) In this system, we can sequester carbon while also realizing dietary yields of roughly 50-100 pounds, 10-15 pounds, and 10-20 pounds per plant of hardy kiwi, currant, and magnolia vine, respectively. (Whiffletree 2017)

n) Ensure soil depth is observed or measured as thoroughly as possible

A thorough physical loosening of the top 2-3' of soil was advisable to remediate compaction of upper soil layers, though deep taprooted trees were not a part of the final design.

o) Consider complete utilization of layers

With a focus on fruit crops, utilization of the rhizome layer was not included, but would augment system productivity (i.e., potatoes for acidic soil guild). Grapes, hardy kiwis and magnolia vines are included in the design along the back fence, though it is advised to allow time for large trees to establish first to provide an adequate living trellis in maximizing the vine layer.

p) Consider Ormston-Holloway's rule of 10/20/30

Again, focusing on overstory plants and to simplify totals, plants under three feet in size were omitted from the weighted total (80):

4 - Sweet cherry *prunus avium* (Rosaceae)

13 - American red currant *ribes triste* (Grossulariaceae)

13 - Gooseberry *ribes uva-crispa* (Grossulariaceae)

11 - Goumi *eleagnus multiflora* (Eleagnaceae)

11 - Haskap *lonicera caerulea* var. *edulis* (Caprifoliaceae)

8 - Mongolian bush cherry *prunus fruiticosa* (Rosaceae)

6 - Highbush blueberry *vaccinium corymbosum* (Ericaceae)

3 - Fox grape *vitis labrusca* (Vitaceae)

5 - Hardy kiwi *actinidia arguta* (Actinidiaceae)

6 - Magnolia vine *schisandra chinensis* (Schisandraceae)

After a closer look, *ribes* species are perhaps too heavily weighted, as the number of currants and gooseberries exceed the limitations recommended for both genus and species here. In such cases, finding a substitute or selecting gooseberry cultivars with stronger resistance to disease and pest attacks may improve site health. Otherwise, the created guild is relatively diverse—concerns of overrepresentation of Ericaceae in the acidic soil guild notwithstanding, as it appears that plants with acidic soil preferences largely hail from the Ericaceae family.

r) Consider replacing non-natives with suitable natives

The native chokeberry *(aronia melanocarpa)* might be worth replacing non-native gooseberry or haskap plants in the guild, as demand is increasing for its high antioxidant levels. Due to its tolerance for acidic soils, the native Eastern dwarf cherry (*prunus pumila*) would be preferable to other cherry shrubs if possible, particularly for areas closer to the pine. Potential replacements for cherry trees and shrubs include the native red mulberry *(morus alba)*, American persimmon *(diospyros virginiana)*, and elderberry *(sambucus canadensis)*.

s) Consider replacing opportunists with non-opportunists

Though less of a concern in poor soils, certain opportunistic plants can become a nuisance when spreading vigorously. Certain plants can be dispersive by seed (i.e. goumi, hardy kiwi) and can be replaced as necessary by similar plants without such drawbacks (i.e. buffaloberry, Caucasian spinach).

Function-element links

See 'Master planning' section for details specific to the plants for this site.

Resource analysis and needs

With the exception of the white pine, preexisting vegetation is non-existent, indicating a generally lifeless environment for plant growth. Again, without a soil test, efforts should be

made to broadly establish and maintain the needs required by the plants in this community, as outlined in Project Three.

Contemplating vectors (outside influences)

Notable outside influences include regular traffic from neighbours and pets; strong Easterly winds; and salt residue from the highway to the West. Installed wood chip pathways are expected to alleviate compaction concerns, while the moderate windbreak hedge already on site should help with wind buffering. The aforementioned pine, slope, and thick shrub patch populating the ditch between the site and the highway provide the area with ample protection from excessive road runoff.

Design Process

Observation and site context

For the portfolio, this aspect was the most challenging. Access to the Rexdale site was limited, resulting in a dependence on secondhand observations from community members. In this case, information was gathered as diligently as possible, with the understanding that a more adapt-on-the-fly approach might be necessary. The general openness and full sun characteristics of the site helped simplify certain aspects of site context.

Research (potential guilds, etc.)

Basic research on plant attributes (i.e., physical structure, resource requirements, tolerances, etc.) can provide much of the information we need with regards to how plants might perform in polycultures or certain environments. Exploring elements from the design checklist (i.e. root types, bloom times, etc.) helped illuminate certain factors for healthy guild construction.

Master planning

1. No large tree layer
2. Sweet cherry [note possible subs: mulberry, persimmon, elderberry etc]
3. Currants; gooseberry; goumi; haskap; Mongolian bush cherry
4. Anise hyssop; columbine; lupine; yarrow
5. White clover

6. Fox grape; hardy kiwi; magnolia vine

7. No root layer

SMALL TREE LAYER

2a) Sweet cherry *prunus avium* (Rosaceae)

Zone 5-9; full sun; mesic; garden soil ph; wildlife food source; generalist nectary; 10-15' x 14-20'

Medicinal value ~ Open crown ~ Self-fertile but will be more productive with cross-pollination ~ Useful coppice species ~ Low nitrogen demand ~ Poisonous pits and leaves

SHRUB LAYER

3a) American red currant *ribes triste* (Grossulariaceae)

Zone 3; full sun to part shade; mesic to hydric; acidic to garden soil ph; suckering roots; wildlife shelter and food source; generalist nectary; 3-5' x 3-5'

Self-pollinating ~ Very low nitrogen demand

3b) Gooseberry *ribes uva-crispa* (Grossulariaceae)

Zone 3; full sun to part shade; mesic; acidic to garden soil ph; suckering roots; wildlife shelter and food source; generalist nectary; 3-5' x 3-5'

Self-pollinating ~ Moderate nitrogen demand

3c) Goumi *eleagnus multiflora* (Eleagnaceae)

Zone 5-8; full sun to part shade; xeric to mesic; acidic to alkaline soil ph; multi-stemmed; nitrogen fixer; wildlife food source; generalist nectary; 6-8' x 6-8'

Self-fertile but will be more productive with cross-pollination ~ Pollution tolerant ~ Highly dispersive

3d) Haskap *lonicera caerulea* var. *edulis* (Caprifoliaceae)

Zone 3; full sun; mesic; acidic to garden soil ph; generalist nectary; 5' x 5'

Very high vitamin C content ~ Requires cross-pollination

3e) Mongolian bush cherry *prunus fruiticosa* (Rosaceae)

Zone 2; full sun; mesic; garden soil ph; wildlife food source; generalist nectary; 3' x 3'

Self-fertile but will be more productive with cross-pollination ~ Low nitrogen demand

HERBACEOUS LAYER

4a) Anise hyssop *agastache foeniculum* (Lamiaceae)

Zone 3-8; full sun to part shade; mesic; garden soil ph; flat root pattern; invertebrate shelter; generalist nectary; aromatic pest confuser; 2-4' x 1-2'

Edible leaves ~ Flowers excellent for tea and medicinal use ~ Oviposition sites for beneficial lacewings ~ Wide range of invertebrates find shelter in foliage

4b) Columbine *aquilegia canadensis* (Ranunculaceae)

Zone 3-8; full sun to full shade; mesic; acidic to alkaline soil ph; taproot; hummingbird food source; generalist nectary; 1-2' x 1-2'

4c) Lupine *lupinus perennis* (Fabaceae)

Zone 3-9; full sun; xeric to mesic; strongly acidic to garden soil ph; flat root pattern; nitrogen fixer; dynamic accumulator of phosphorous; invertebrate shelter; 1-2' x 1-2'

Oviposition sites for beneficial lacewings ~ Parasitoid wasps find shelter in foliage

4d) Yarrow *achillea millefolium* (Asteraceae)

Zone 3-10; full sun; xeric to mesic; acidic to alkaline soil ph; fibrous or rhizomatous root pattern; dynamic accumulator of potassium, phosphorous and copper; invertebrate shelter; generalist and specialist nectary; aromatic pest confuser; 2-3' x 2-3'+

Excellent medicinal use ~ Indicator species for low potassium ~ Oviposition sites for beneficial lacewings ~ Overwintering sites for parasitoid wasps, ground beetles, and spiders ~ Parasitoid wasps find shelter in foliage

GROUND COVER LAYER

5a) White clover *trifolium repens* (Fabaceae)

Zone 4; full sun to part shade; mesic; acidic to garden soil ph; stoloniferous root pattern; nitrogen fixer; dynamic accumulator of phosphorus; invertebrate shelter; generalist nectary; 4-10" x 6-36"

Flowers are edible and used for tea ~ Oviposition sites for beneficial lacewings ~ Parasitoid wasps, spiders and ground beetles find shelter in foliage ~ Indicator species for dry, low-

nitrogen sites ~ Makes excellent ground cover due to its high tolerance for foot traffic ~ Juglone tolerant ~ Non-native

VINE LAYER

6a) Fox grape *vitis labrusca* (Vitaceae)

Zone 3-9; full sun; xeric to hydric; acidic to alkaline soil ph; wildlife food source; generalist nectary; 35'+ x 20-35'

Edible leaves for pickling, wraps, etc. ~ Seeds and fruit have excellent value as medicinal and superfood ~ Self-pollinating

6b) Hardy kiwi *actinidia arguta* (Actinidiaceae)

Zone 4-8; full sun; mesic; acidic to alkaline soil ph; heartroot pattern; 20-100' x 20-100'

Superfood (very high in vitamin C and K) ~ Medicinal use ~ Minimal pest or disease issues ~ Female plants require male companion

6c) Magnolia vine *schisandra chinensis* (Schisandraceae)

Zone 4b; full sun to part shade; mesic; acidic to garden soil ph; 20' x 20'

Berries eaten fresh or dried for tea ~ Excellent medicinal use ~ Many cultivars have both male and female flowers (self-fertile)

ACIDIC SOIL GUILD

2b) Preexisting pine

3f) Highbush blueberry *vaccinium corymbosum* (Ericaceae)

Zone 4b-8; full sun; mesic to hydric; strongly acidic to acidic soil ph; flat stoloniferous root pattern; wildlife food source; 4-12' x 4-12'

Medicinal value as superfood ~ Native ~ Varied shrub sizes to fill niche layers ~ Staggered summer harvest ~ Self-fertile but will be more productive with cross-pollination

5b) American Low Bush Cranberry *vaccinium macrocarpon* (Ericaceae)

Zone 3; full sun; hydric; strongly acidic to acidic soil ph; flat stoloniferous root pattern; wildlife food source; 6" x 6"+

Medicinal value as superfood ~ Native ~ Self-fertile evergreen

5c) Lingonberry *vaccinium vitus-idaea* (Ericaceae)

Zone 4-7; full sun; mesic; strongly acidic to acidic soil ph; suckering mat-forming habit; wildlife food source; 6-12" x 2'

Medicinal value as superfood ~ Native ~ Self-fertile evergreen

5d) Wintergreen *gaultheria procumbens* (Ericaceae)

Zone 3; part shade to full shade; xeric to mesic; strongly acidic to garden soil ph; flat stoloniferous root pattern; accumulator of magnesium; wildlife food source; 6-12" x 2'

Excellent edible berries ~ Leaves used for medicinal tea ~ Native ~ Evergreen allows for year-round ground cover during mild winter spells ~ Self-fertile ~ Traffic tolerant

Site Design Map [see Appendix B]

PROJECT THREE: ST. GABRIEL'S PARISH

Site Preparation and Practice

The third and final component of the portfolio is an exercise in permaculture practice, specifically the early stages of removing and rebuilding a site in preparation for eventual design. In this case, a floundering ornamental landscape was in need of transformation. Those at the parish were reimagining the site as low-maintenance as possible, though capable of providing some interest for members of the church and surrounding community—whether berries to eat or wildlife to observe. In its current state, the ornamental garden offered little else than some visual greenery and irrigation headaches. In order to establish a more productive space, tearing down and rebuilding the soil was deemed necessary.

From a permaculture approach, the task became how to reset succession in order to best guide the space toward natural health and productivity. Previously, landscape fabric was applied throughout, covered with wood chip mulch to suppress the growth of unwanted plants. Though soil compaction was not a major problem, the general lack of plants rendered the space largely devoid of organic matter. Failing two or three years after installment, an elaborate irrigation system buried beneath the surface had to be unearthed. Though large

trees and shrubs were left in place, the remaining space had to be redeveloped from the ground up.

Initial Observations

Queen Anne's lace, also known as wild carrot, had populated various segments of the site—a potential indicator for low fertility (Jacke 2005b, 207). A central butterfly garden and wildflower patches along the perimeter of the site support a healthy population of beneficial insects and pollinators. Useful nectary plants such as goldenrod, purple coneflower, black-eyed Susan, and butterfly weed were already in place, resulting in frequent sightings of bees, butterflies and wasps. Other forms of wildlife such as cardinals, blue jays, and rabbits also appeared on occasion, showing promise with respect to fostering continued biodiversity and the potential for steady participation from local community members—both human and animal. After removing the mulch and unwanted surface vegetation, observing soil behaviour was more practical, particularly during and after rainstorms. Witnessing how water flows and where it accumulates provided valuable lessons in the early stages. For instance, areas appearing to be relatively flat may have revealed deceptive slope, or certain water-holding characteristics, and so on. One section that was sheltered by a roof overhang, thereby obstructing it from appropriate moisture levels after the irrigation system failed, was especially degraded. Another area contained a significant deposit of rich soil and organic matter, unlike the vast majority of the site. Initially thought to be an area where mulch or other plant matter decomposed over the years, further observation of the site's hydrology revealed that this rich deposit was a congregation of eroded topsoil from upper tracts, contained by landscape fabric and plants from the butterfly garden. Even for this small, relatively sheltered site, water behaviour became a significant factor for shaping the soil development regime. It became apparent that further observing, measuring and flagging the contour of the land was necessary.

Basic Soil Development

"Careful attention to all aspects of soil development—physical, chemical, and biological—is critical to successful guidance of successional changes, particularly for soils that are barren." (Jacke 2005a, 242) After years of minimal watering, and little in the way of functional vegetation, soil at the parish was relatively lifeless. The originally applied mulch and

landscape fabric combination helped reduce compaction and evaporation to a certain extent, though the lack of vegetation may have contributed to the retardation of soil biology development, as well as a lack of nutrient accumulation. Physical, chemical and biological soil improvements were required in an effort to marshal it towards its productive capacity and restore overall site health.

Physical

A key aspect of site preparation, proper physical manipulation of the soil can optimize conditions for root growth. As mentioned, compaction was generally not an issue, though certain measures were considered necessary for a more complete restoration of soil health. Soil building plants (i.e. dandelion and horsetail) along with several nectary plants (i.e. Queen Anne's lace and goldenrod) had been removed at the request of the property owner. Though some vegetation was deemed appropriate to remain—such as the butterfly weed patch—soil health and structure had to be developed from scratch, consisting of the following tasks:

Removing pre-existing ornamentals, tree weeds, irrigation system, landscape fabric, and mulch

- Removing all obstacles allowed for maximized germination rates for new seeds to optimize soil development
- Tools used include shovels, rakes, hoes, and a wheelbarrow

Broadforking

- Loosening and breaking up soil allowed for broadcast seed to permeate soil and establish roots
- Broadforking in rows alongside contour flags created cultivated vegetation strips perpendicular to direction of water travel, increasing water absorption and reducing erosion
- Seeds remain largely in place upon broadcast—rather than being washed down sloping areas after heavy precipitation events—resulting in higher germination rates
- Tools used include broadforks of various sizes

Double Digging

- In the degraded area beneath the roof (or in areas designated for plants with deeper root systems), double digging is a method to loosen deeper horizons of the soil to allow for healthier root establishment:
  - Working systematically, soil is removed from the first cubic foot of a given soil plot before being place into a bucket
  - The now exposed area beneath the soil just removed is forked and aerated
  - Moving on to the next cubic foot in the row, the soil removed is then placed in the spot vacated by the initial cubic foot now in the bucket
  - This is repeated until the end of the strip, with the soil from the bucket emptied into the last remaining cubic foot
  - Process is then repeated for each row in a designated plot
- Tools used include broadforks, shovels, and wheelbarrow
- Though double digging has many advantages for enabling healthier root growth and establishment, it is a labour-intensive process and often not necessary, as "most tree and shrub roots grow horizontally through the soil near the surface, not vertically or in a mirror image of the tree branches…The top 1 to 2 feet (30 to 60 cm) of soil typically contains 60 to 80 percent of tree roots by weight, and the top 3 feet (1 m) up to 99 percent of root mass" (Jacke 2005a, 190) If taprooted trees were part of long- term design, a deeper dig would be advised. In this case, a loosening of soil in the top 1 to 2 feet was executed, supplemented by natural soil-building processes, such as the ongoing accumulation of organic matter.

Chemical

Without access to soil testing, brainstorming ways to incorporate or generate organic matter became the next logical step in organic nutrient cycling and biochemical soil development. "The organic matter container represents a supply of stored energy and nutrients…on which the soil organisms will feed. The organic matter also possesses additional cation exchange sites…[helping] the soil grab and hold onto more nutrients." (Jacke 2005a, 179) As the foundation of healthy soil and plant communities, organic matter became a priority in

practicing site restoration. Unless it is being imported from off-site (i.e., compost, manure, triple mix, etc.), establishing helpful amounts of organic matter can be a challenging process for barren soils. Fortunately, when applied in concert with the proper physical soil building techniques, there are several plants at our disposal capable of accumulating the three nutrients most essential to plant growth (N, P, K):

Buckwheat

- Fast-growing annual cover crop for June/July sowing
- Dynamic accumulator of phosphorous (P) and potassium (K)
- Can provide pollinators with a food source in lean periods (late summer)

Red clover

- Fast-growing biennial cover crop for summer sowing
- Nitrogen-fixing (N) capabilities

Biological

As plant and soil life require water to function, irrigation was mandated on days without rain after broadcasting the buckwheat and clover seeds. Once adequately established, scything of buckwheat and clover scattered plant material throughout the soil surface, acting as protective mulch as it decomposed—providing shelter for microorganisms and some buffering against weather extremes. The next step became preparing another installment of late season cover crops. Again, after physically manipulating the soil pre-broadcast, strategically sowing the following plants can rapidly generate biomass, decomposing into organic matter:

Winter rye

- Fast-growing annual crop for late summer/fall sowing
- Builds soil, reduces compaction, and its "extensive root system efficiently scavenges excess nitrogen that would be otherwise lost over the winter months" (William Dam 2017)

Daikon radish

- Fast-growing annual crop for late summer/fall sowing
- If large taproot systems are not harvested but left in place to decompose, daikon radish is very effective in breaking up hardpan soil, converting to organic matter for subsequent crops

In addition to using plants to develop soil, mature compost generated onsite can be an effective amendment for tackling many problems in the garden. In this instance, all unwanted plant and organic material removed at the beginning site preparation phase was added to a shaded pile. The landscape fabric that was also removed came in handy to protect the pile during winter months and preventing unwanted germination. Inoculating the compost heap with red wigglers and effective microbes is another method for jumpstarting biological soil processes.

To summarize, soil development is a crucial element of overall system health, described as "a process of mineral nutrients becoming increasingly bound up in organic matter as ecosystems mature, and being increasingly cycled within and between living organisms." (Jacke 2005a, 181) By encouraging—rather than attempting to eradicate—the living systems within our site, nutrient cycling programs are more likely to become self-regulating, and the necessity for our intervention dissipates. In employing plants that scavenge and make available the main nutrients most limiting to plant growth, and emphasizing building and accumulating organic matter for micronutrient availability, the foundation of our guided succession takes shape. We can also make time for higher-level observation as such soil-building plants work their magic for us.

REFLECTIONS AND REGRETS

Throughout the portfolio process, certain challenges presented themselves with respect to ensuring the success of each project. Upon revisiting a few key permaculture principles, it became more apparent that many of the advantages of such systems stem from routine site visits. Once designs are implemented, creatively responding to many of the daily changes that occur onsite can yield some of the most illuminating and rewarding food experiences. Steady participation motivates a healthier dialogue with a site, inspiring improved modes of

self-regulation and an enhanced ability to accept and interpret system feedback. Though much could be gleaned from sporadic visits, true feedback occurs constantly—with the responsibility of receiving and responding to such information falling on the hands of the principle members a given location. Ideally, as our knowledge and involvement progresses on the subject of urban agriculture, we can become better equipped to connect and engage with dynamic food systems on a wider level. Further, a more sophisticated understanding of best practices for maintaining soil health and sequestering carbon in our backyards and beyond—and exactly how much of it—would advance the progress of such ventures. Other notable challenges encountered throughout the portfolio process include the following:

Volatility of location

Tenants moving, limited site access, ownership challenges—all are problems that have much less of an impact on annual gardening. Appropriate periods for observation are more difficult, and investing in more permanent crops that may or may not yield for the first couple years become less enticing in light of these uncertainties. Permanent agriculture becomes much less viable in such transient contexts.

Inability to conduct thorough site analysis

With thorough observation wanting, soil tests and further exploration of soil horizons would go a long way in bettering our understanding of site conditions. Though costly, such thorough site analysis would likely pay off in the long run, as various complications could very well result from missing pieces of information.

Observation is not universal

Observing a goldenrod-strawberry polyculture occurring in a relatively undisturbed environment does not guarantee its success in every locale. For instance, there may exist a function-element link in an overstory of poplars under which the goldenrod and strawberry grow, or that particular regional ecosystem that promotes this guild. Though observing these natural plant communities may inspire design ideas or offer some insight into general

ecosystem functions, attempting to replicate such relationships more broadly may be counterproductive without a more comprehensive understanding of such links.

Concerns over dysfunctional designed polycultures

"[S]pecies in natural communities coevolve to some degree, [so] they have a better chance of having developed functioning guilds…Yet many of those species will not have human uses or clearly desired ecological functions. The problem is that not including these species will leave holes in the ecological fabric of the mimic community's social structure…We can look for ecological analogs of the less useful native species by seeking more advantageous species that fill a comparable community niche in similar communities from the same or other regions." (Jacke 2005a, 168) Though mimicking natural plant communities improves our chances of representing symbiotic relationships, we still run the risk of inadvertently omitting key actors. As research on perennial polycultures becomes more available, we can feel more confident in how various plant combinations behave as they pertain to resource needs, competition, chemical dynamics, and the like.

Exclusion of mycorrhizal fungi discourse

The prospect of mycorrhizal fungi and its extensive application for improving agricultural practice has perhaps gone underutilized to this point. Remarkably, work by Perry (1994, 242) has demonstrated that mycorrhizal fungi have the potential to address the aforementioned apprehensions about interspecies competition, as "mycorrhizal fungi facilitate the movement of carbon compounds and nutrients between individuals of two different tree species, probably through the hyphal linkages that join them. Shaded trees in particular appear to obtain at least some carbohydrate from surrounding sunlit trees…" If the presence of mycorrhizal fungi can heighten resource sharing in polycultures, this would likely have an impact on system health and productivity—especially for shaded crops. Perry's findings showcased competitive interactions between Douglas fir and Ponderosa pine seedlings

that were rendered neutral or cooperative with the added influence of mycorrhizal fungi. Mycologist Paul Stamets has since expanded on the incredible possibilities for mycelial networks, developing four facets of mycorestoration: mycoremediation (restoring areas degraded by oil spills); mycofiltration (filtering water to improve ecological health); mycopesticides (for controlling hazardous pest population levels); and mycoforestry (to enhance forest or soil health). Further exploration of the potential for mycelial networks in permaculture scenarios should be given immediate attention, specifically in the realms of advancing carbon sequestration; mycoremediation and ecosystem recovery in both urban and rural scenarios; and expediting soil-building processes—not to mention increased system yields in the form of gourmet mushrooms. "About sixty-five times more energy goes to decomposers than goes to all herbivores combined…How can we take advantage of this huge decomposer energy flow to increase our yields? In one word: mushrooms." (Jacke 2005a, 148)

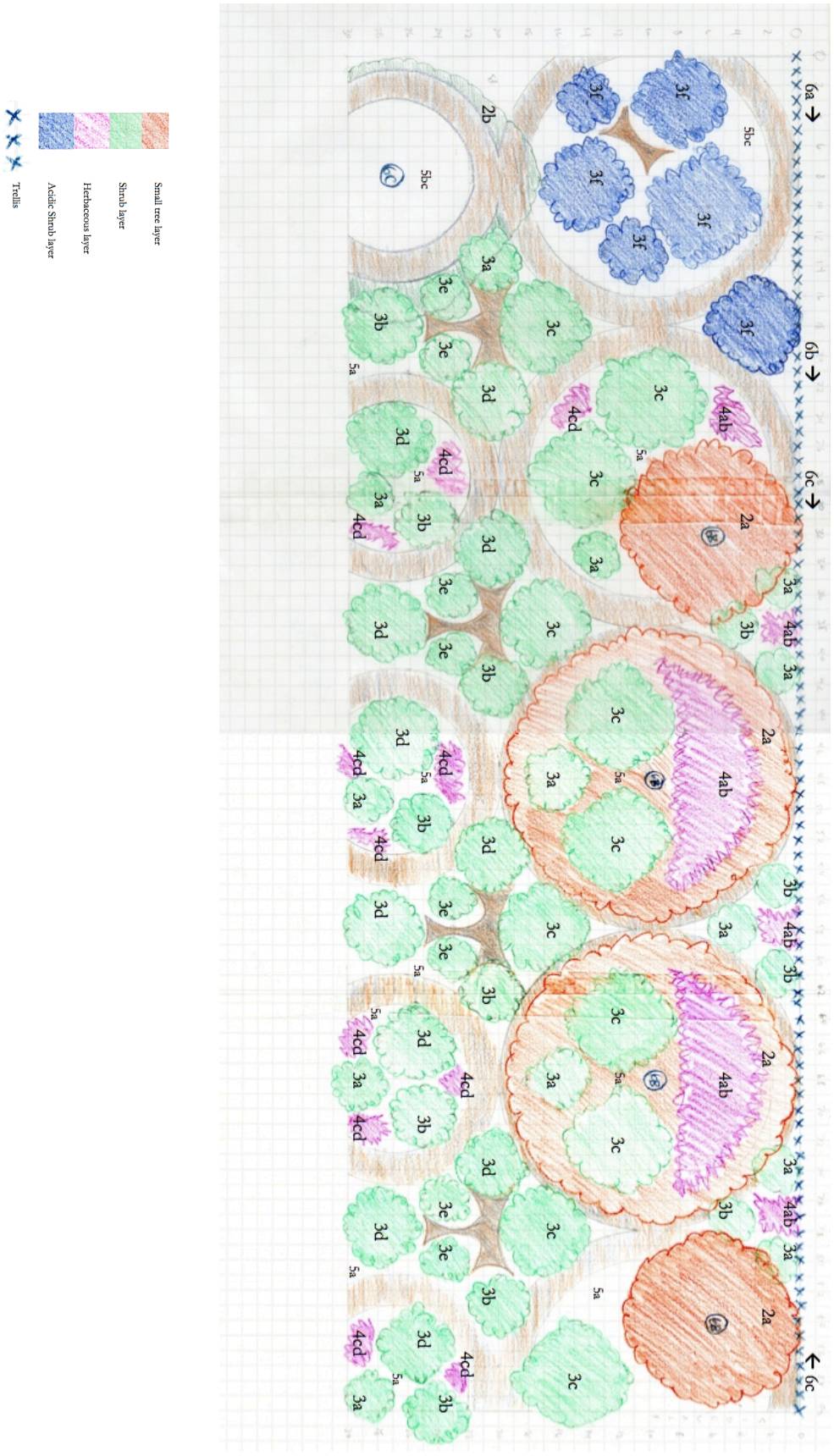
FUTURE CONSIDERATIONS AND CONCLUDING REMARKS

Nature is an excellent communicator and if something is wrong, it becomes apparent sooner or later. Moreover, many of the challenges we encounter along the way can become the impetus for creative response and critical thinking—even providing a new avenue for growth, or at the very least, improved efficiency in the future. A major challenge for realizing alternative food systems is the relentless inertia of the present one. How do we incentivize these methods, at both small and large scales? "Rather than subsidies, which create dependency and distort values, payments for ecosystem services can promote sustainable use of soils and other natural resources while, also, creating another income stream for land managers. Incentive payments are especially crucial for the 1.3–1.5 billion resource-poor farmers and small landholders of the tropics, who cannot…invest in soil improvement because of low income…The strategy is to create a positive soil C budget by adopting recommended management practices such as no-till farming, cover cropping, agroforestry, complex rotations, integrated nutrient management and application of biochar…Payment for ecosystem services is…an important incentivization strategy. The way to facilitate soil C sequestration may involve measurement, monitoring and verification of the net SOC gains

over time. Standard operating procedures need to be developed for site-specific management options, measurement and monitoring and establishing the fair price based on the societal value of soil C." (Lal 2014, 454-5) This excerpt is now several years old, and how we can address concerns over quantifying carbon sequestrations is beginning to take shape. Almost twenty years ago, speculation began over the promise of carbon drawdown in agroforestry practices, though a "lack of reliable estimates" remained a constant deterrent. (Oelbermann et al 2004) If the key to transitioning to carbon farming is incentivizing and rewarding farmers accurately, Geocarb, a recent venture from NASA, may hold promise: "GeoCarb's oxygen spectral band, which is needed to convert abundances of carbon gases to concentrations, will also measure SIF [solar-induced fluorescence]. This faint glow, emitted by the chlorophyll molecules in the leaves of plants, is an indicator that photosynthesis -- the process by which plants convert sunlight into chemical energy and capture carbon from the atmosphere -- is occurring. GeoCarb will make daily, near wall-to-wall measurements of SIF under all weather conditions, allowing scientists and others to track the effects of drought on photosynthesis in forests, crops and grasslands." (Buis 2018) Perhaps it's premature to be hopeful about a project in its infancy, and perhaps it's fanciful to assume that adoption rates would be strong should such a program come to fruition. Harvest mechanisms for perennial polycultures are among other significant obstacles for scaling up such integrated food systems—though many do exist and more are being developed (Shepard 2013). Until we get there, it's hard to dispute the notion that an overhaul of the current food system is sorely needed. In the meantime, providing real-world examples of what a new food system might look like, taste like, and feel like, couldn't hurt. As Hemenway (2015) posits, "permaculture design, as an attempt to grasp and articulate the strategies that nature uses to create evolving, self-renewing systems, is turning out to be beautifully suited to urban contexts." So what better place to start a paradigm shift?

Appendix A: Project One Site Design Map

Appendix B: Project Two Site Design Map



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