Characterizing Plant Communities on Canadian Permaculture Farms

by

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CHARACTERIZING PLANT COMMUNITIES ON CANADIAN PERMACULTURE FARMS

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Permaculture is a promising sustainable agriculture model with representation in at least 51 countries worldwide including Canada. Little is known about the outcomes of this adoption, or permaculture generally, as empirical research has been very limited. This study is the first we are aware of to characterize plant communities on permaculture farms. Vegetation surveys were completed for 10 commercial permaculture farms in the Vancouver Island – Coast region of British Columbia, Canada in August 2016. Permaculture farms were characterized by high species diversity, which was divided among multiple unique polycultures. Farm-scale perennial species richness and abundance significantly exceeded annuals. Many ecological and agronomic studies highlight the benefits of species, functional, and landscape diversities to ecosystem services. It is strongly recommended that future research include systematic, multisite assessment of the impacts of permaculture management on ecosystem properties and functioning.

**Keywords:** Agroecology; biodiversity; community composition; diversity; ecological intensification; ecosystem services; functional diversity; landscape design; perennialization; perennials; permaculture; sustainable agriculture
Acknowledgements & Dedication

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This thesis is dedicated to the memory of the late Bill Mollison (deceased September 2016), whom I never got to meet, and to David Holmgren who I still one day hope to. Your dedication to the cause is an inspiration.
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Chapter 1

General introduction

Agroecology is gaining considerable momentum in contemporary sustainable agriculture research. At its root, agroecology is simply the integration of ecological thinking and principles into agriculture (McGranahan, 2014). As is commonly the case in biology, as the discipline expands there have been a profusion of new ecological terms and hypotheses added to the literature. Relevant additions to the vocabulary include: wild-life friendly farming (Kremen, 2015); ecological intensification (Bommarco, Kleijn, & Potts, 2013); functional biodiversity (Altieri, 1999); multifunctional agriculture (Asbjornsen et al., 2013; McGranahan, 2014); land sharing and land sparing (Kremen, 2015; von Wehrden et al., 2014); landscape ecology (McGranahan, 2014); Biodiversity-Ecosystem Function hypothesis (Srivastava & Vellend, 2005); insurance hypothesis (Hector & Bagchi, 2007; Yachi & Loreau, 1999; Hooper et al., 2005); and references to traditional farming systems and ecological knowledge (Altieri, 1999). Arguably, many of these recent terms and concepts were outlined in permaculture literature as early as 1978 (Mollison & Holmgren, 1978). Yet scholarly research about or even referencing permaculture is rare and application remains largely the domain of enthusiastic grassroots movements and networks (Ferguson & Lovell, 2014; Ferguson & Lovell, 2015).

This thesis is concerned ultimately with bridging the substantial knowledge gap between contemporary ecology and agronomy research with classic permaculture theory. Permaculture has been both heralded as the ultimate sustainable agriculture and criticized for redundant, unsubstantiated claims (Mollison & Holmgren, 1978; Mollison, 1979; Ferguson & Lovell, 2014). The intention behind this project is that permaculture be evaluated fairly, by drawing greater attention to the specific strengths and weaknesses of this alternative agricultural model.
Chapter 2 reviews the permaculture literature, defining the key characteristics and state of current research. This chapter further draws comparisons between permaculture principles and relevant evidence from contemporary agronomic and ecological research. The purpose of this comparison is to evaluate permaculture’s potential contributions to ecosystem services and food production. In particular, the contributions of species, functional, and landscape diversities to provisioning, regulating and supporting services are considered.

Chapter 3 characterizes plant communities on 10 commercial permaculture farms in the Vancouver Island – coast region of British Columbia, Canada. This study is the first we are aware of to deliver a systematic, multisite assessment of plant communities on permaculture farms including characterizations of community composition with respect to species, life cycle, growth form and landscape diversities at farm and sub-field scales. This analysis will allow us to consider whether practitioners consistently apply the theoretical permaculture principles of polycultures, perennial species, and zone design. Furthermore this analysis provides a useful framework for future empirical research on ecosystem function and properties on permaculture farms.

Finally, Chapter 4 is a general discussion reflecting on the challenges and opportunities posed by permaculture research. This chapter also recommends appropriate future applications for permaculture research and implementation.
Chapter 2

Literature review

Introduction

If there is a single claim, that I could make, in order to distinguish Permaculture from other systems of agriculture ... it is that Permaculture is primarily a consciously designed agricultural system . . . a system that combines landscape design with perennial plants and animals to make a safe and sustainable resource for town and country. A truly appropriate technology giving high yields for low energy inputs, and using only human skill and intellect to achieve a stable resource of great complexity and stability. (Mollison, 1979).

Permaculture is a promising system of alternative and sustainable agriculture. It is practiced in at least 51 countries, accounting for every inhabited continent (Schmidt, 2012), and yet still largely unrecognized and poorly understood by Canadian institutions. This literature review seeks to address the following research questions to better our understanding of the strengths and limitations of permaculture towards achieving sustainable agriculture. Firstly, what is permaculture? What are the basic characteristics of permaculture and how has this concept evolved since its inception? Secondly, what is the current state of peer-reviewed research on permaculture and what conclusions can we draw from this research? Finally, does contemporary ecological and agronomic research support claims that permaculture, as an agricultural management system, would benefit ecosystem service delivery?

Defining permaculture

The term “Permaculture” was first coined in 1978 by co-originators Bill Mollison and his graduate student David Holmgren, as an abbreviation of permanent agriculture or culture. Permanent in this context is more equivalent to today’s use of the term sustainable (Ferguson & Lovell, 2014). The working relationship of Mollison and Holmgren was a short-lived 2 years, during which time they produced the founding text of permaculture: Permaculture One. A Perennial Agriculture for Human Settlements
(Holmgren, 2011, p.19-20). Here, Mollison and Holmgren provide the earliest definition of their vision for agriculture:

Permaculture is...an integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man. It is, in essence, a complete agricultural ecosystem, modelled on existing but simpler models.

...We believe that a low-energy, high-yielding agriculture is a possible aim for the whole world, and that it needs only human energy and intellect to achieve this. (Mollison & Holmgren, 1978, p. 1)

Permaculture One, and all subsequent permaculture publications, echo the revolutionary spirit of the 1970s in emphasizing the need to draw inspiration from nature and to transition away from non-renewable energy sources. The “simpler models” described above refer to both Western agribusiness and peasant grain culture, which the authors criticized as being “destructive” and “drudgery”, respectively. Permaculture was proposed as an improvement to existing agricultural models, but also as an opportunity to experiment, “improve methods and techniques” (Mollison & Holmgren, 1978, p.9), and adapt “based on first-hand information” (p.65).

The basic characteristics of permaculture agriculture, as outlined in Permaculture One, are:

1. Small scale land-use patterns are possible.
2. Intensive, rather than extensive land-use patterns.
3. Diversity in plant species, varieties, yield, microclimate and habitat.
4. Long term: an evolutionary process spanning generations.
5. Wild or little-selected species (plant and animal) are integral elements of the system.
6. Integration with agriculture, animal husbandry, extant forest management and animal cropping become possible, and landform engineering has a place.
7. Adjustable to steep, rocky, marshy or marginal lands not suited to other systems.
   (Mollison & Holmgren, 1978, p. 6-7)

In subsequent publications, both Mollison and Holmgren acknowledge that this system of agriculture is not concerned with conforming to current socio-political paradigms of agriculture. Rather, the authors propose a shift towards a “post-industrial” and “Cultivated Ecosystem” where: “The structure of plant
systems is determined by the characteristics of the plant species in association with each other, under the specific local conditions of site and climate” (Mollison & Holmgren, 1978, p.27). The primary focus of permaculture is unarguably to provide for humans, however the approach is unique in emphasizing “observation and control rather than power functions” (p.9). Permaculture is thus oriented towards ecological knowledge and local observation over human or mechanical labour. In addition to introducing a novel agricultural philosophy, *Permaculture One* describes possible applications including: products from permaculture, site planning, system establishment, permaculture animals and fungi, and urban agriculture.

Mollison published the sequel to *Permaculture One* the following year: *Permaculture Two: Practical Design for Town and Country in Permanent Agriculture*. In this volume, the definition of permaculture expands to emphasize design:

*Permaculture... claims to be designed agriculture, so that the species, composition, array and organization of plants and animals are the central factor.*

*...functional design (not cosmetic array) is the central theme; for we have many more energy benefits from design than we have from random placement of species, beyond the intrinsic value of plants or animals.* (Mollison, 1979, p.1)

Mollison claims that a “consciously designed” landscape, including perennial species and animals, differentiates permaculture from other agricultural models (1979). Consistent with its title, *Permaculture Two* outlines practical design strategies for landscape, soil improvement, broad-scale techniques, difficult climates, structures, waterworks, free range poultry design and community.

The saga continues one decade later with the publication of the mammoth *Permaculture: A Designer’s Manual* (Mollison, 1988). In the interim Mollison taught permaculture as an “interdisciplinary earth science ...[and] applied design system” (Mollison, 1988, p. ix). The *Designer’s Manual* provides a much refined and detailed account of permaculture, with an unwavering dedication to its earliest concepts: sustainability, observation and functional design.
Permaculture (permanent agriculture) is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems...providing food, energy, shelter, and other material and non-material needs in a sustainable way.

...The philosophy behind permaculture is one of working with, rather than against, nature; of protracted and thoughtful observation rather than protracted and thoughtless action; of looking at systems in all their functions, rather than asking only one yield of them; and of allowing systems to demonstrate their own evolutions. (Mollison, 1988, p. ix-x)

The Designer’s Manual has become recognized as the permaculture reference book, elaborating on design principles and patterns, and giving special instruction towards adapting permaculture to a wide range of climate types. Additionally, it is here Mollison first formalizes the ethical basis of permaculture:

1. Care of the Earth: Provision for all life systems to continue and multiply.
2. Care of People: Provision for people to access those resources necessary to their existence.
3. Setting Limits to Population and Consumption: By governing our own needs, we can set resources aside to further the above principles.
   (Mollison, 1988, p.2).

The inclusion of these ethics has become compulsory in the permaculture curriculum, and any description or application of permaculture lacking this ethical framework is incomplete.

Twenty-five years after its inception Holmgren defines permaculture broadly as a way of thinking about and organizing agriculture and human settlements:

Consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre and energy for provision of local needs ... I see permaculture as the use of systems thinking and design principles that provide the organising framework for implementing the above vision. (Holmgren, 2002, p. xix)

Holmgren emphasizes that while individual techniques (for example swales and keyline ploughing) or species (e.g. comfrey, Jerusalem artichoke, or sea buckthorn) are frequently associated with permaculture, they are neither unique to nor required for its application (Holmgren, 1991).
Finally, while not involved in developing the concept, Ingram et al. (2014) contribute a useful description of permaculture:

*Permaculture has three main components: three underpinning ethics, a set of design principles and a set of design tools.... As the emphasis is on design principles, it does not prescribe a specific method of food production, although it is often referred to as agro-ecological farming and is commonly associated with perennial plants, agroforestry, organic systems, with forest gardening and polyculture* (Ingram et al., 2014).

**Current permaculture research**

Proponents enthusiastically promote permaculture for its claimed contributions to the agroecological transition. As outlined above, these claims range from the provision of direct human needs (food, energy, fiber, and shelter) to ecosystem service benefits (including soil quality, water regulation, and pest control) (Mollison, 1988, p. 4-6). However, permaculture theory has also been criticized for being unverified, outdated, and redundant, where “the majority of permaculture literature is written by non-scientists for a popular audience” (Ferguson & Lovell, 2014). The following reviews the current state of agroecological research on permaculture.

Ferguson and Lovell (2014) conducted systematic and bibliometric reviews of permaculture literature published before April 2013. They found the proportion of scholarly articles (122) published is increasing, accounting for 71% of new publications from 2008-2013, and 54.3% of the total reviewed permaculture literature. The proportion that are peer-reviewed remains small (13.9%). Scholarly articles spanned many disciplines, with only 23.1% classed as Life Sciences, which is considered most relevant to agriculture. This finding demonstrates that despite being initially proposed as an agricultural management system, academics have opted to explore a diverse range of permaculture applications. Remaining scholarly articles were divided among Social and Behavioural Sciences (33.9%), Architecture (19.0%), Education (11.66%), Engineering (3.3%), Physical Sciences and Mathematics (3.3%), Business (2.5%), Medicine and Health Sciences (2.5%), and Law (0.8%). The authors clearly demonstrate that
further academic research into the agronomy of permaculture is needed. Furthermore, they highlight that experimental design and statistical analysis are lacking “from almost all works”, even among peer-reviewed articles. Based on a qualitative content review, Ferguson and Lovell expressed concerns that some permaculture claims “exceed what has been documented in the scientific literature”, are anecdotal, are inappropriate applications of ecological principles, or do not reflect “contemporary scientific research”. The authors recommend that future research include “systematic multisite assessment of permaculture’s impacts” to address the above knowledge gaps and better ascertain what role, if any, permaculture may have in achieving sustainable agriculture.

Guitart, Byrne, and Pickering (2015) wrote one of the few publications that applied a systematic, multisite, and empirical approach to studying permaculture. These authors surveyed 57 management practices among 50 community gardens, including 21 permaculture gardens. The article concludes that permaculture gardens employed “lower-impact gardening practices”. However, this claim may be premature: only use of homemade fertilizers (p=0.027) and plant diversity (for weed, pest, and disease control; p=0.040) were reported as significantly higher for permaculture than non-permaculture gardens. All 21 surveyed permaculture gardens were organic/chemical free. Most permaculture gardens built their own soil (n=19), used homemade compost (20), used locally grown green manure (18) or locally sourced animal manure (16), companion planted (20), included specific plantings to attract beneficial insects (16), applied mulch (17), included worms in the garden (16), and used rainwater tanks (16) or mulching (17) for water conservation. This is the first peer-reviewed multisite assessment of management practices used by permaculturalists and provides an important baseline for comparing theory to application. Furthermore, Guitart et al. (2015) developed a useful tool for identifying and comparing permaculture gardens called the ‘Permaculture Index’. The authors state the intended purpose of this index is to “cross-validate reported gardening philosophy with the actual gardening practices used”. The 57 gardening practices surveyed were each assigned a positive (+1),
neutral (0) or negative (-1) value based on interpretations of permaculture philosophy as outlined by Mollison (1988, 1994) and Morrow (2006). Possible scores ranged from +30 to -23. As predicted, self-identifying permaculture gardens scored significantly higher on the permaculture index (10.3 ±1.7) than non-permaculture gardens (-7.5 ±2.2) (p<0.001). Guitart et al. (2015) do not indicate whether a given minimum value can be used to definitively identify a garden as permaculture, but these results indicate that gardening philosophy can be a measured quality and provides a framework for future comparisons. These authors echo Ferguson & Lovell (2014) in their recommendations that future research include directly evaluating the ecological impacts of permaculture.

Finally Hathaway (2015) provides a brief but comprehensive summary of permaculture, where this system is juxtaposed against agroecology and industrial agriculture. Permaculture and agroecology overlap in their emphasis of ecologically-oriented knowledge and management techniques, and Hathaway suggests permaculture might be the most widely recognized approach to agroecology. Permaculture has become relevant to a much broader audience, as evidenced by its multidisciplinary application (see above Ferguson and Lovell, 2014). Hathaway (2015) reviews contemporary evidence and suggests that ecological challenges could be addressed by minimizing chemical fertilizers and pesticide use, reducing energy consumption and greenhouse gas emissions, and conserving and protecting water. No studies are currently available which directly quantify the impacts of permaculture on these challenges. As such, Hathaway is limited to reviewing results from agroecological techniques which are commonly associated with permaculture including: reduced use of synthetic agrochemicals, reduced use of heavy machinery, use of perennial species, and use of biochar. Hathaway references a successful case study from Jordan where the acclaimed permaculture teacher Geoff Lawton restored diverse crop production to a “severely degraded” farm within one year. Using simple and inexpensive permaculture techniques, the farm was reported to consume only 20% as much water as neighbouring industrial farms.
While the increasing interest in permaculture is encouraging, this review supports other authors in calling for systematic, quantitative, and multisite assessment of permaculture. The credibility of permaculture is compromised primarily by a lack of scholarship, rather than any scholarly or empirical evaluations discrediting its claims.

**Permaculture and ecosystem services**

This section examines current agronomic and ecological literature for evidence that permaculture, as an agricultural management system, could affect ecosystem services. Mollison claims that permaculture management, compared to contemporary western agriculture, reduces soil loss (humus and mineral nutrients), pollution produced, and crop loss to pests (1988, p. 4-6). Furthermore, permaculture is advertised to improve water use efficiency, soil water storage, crop and livestock genetic richness, soil life, forest biomass, and wildlife richness. The majority of permaculture publications unfortunately lack rigorous experimental design and statistical analysis to support these claims (Ferguson & Lovell, 2014). As such, no contemporary and peer-reviewed evidence directly reporting the impacts of permaculture on a given ecosystem service is available. However, as Hathaway (2015) has demonstrated, it is useful to consider empirical studies recording impact results for management strategies relevant to permaculture. These comparisons improve our predictive power and better focus attentions towards the most viable pathways. Where permaculture encourages adopters to adapt most strategies to suit the local site, three primary themes are considered permanent components of permaculture agriculture: polycultures, perennial species, and zone design. These three components are featured prominently or repeatedly in all major founding permaculture publications (Mollison & Holmgren, 1978; Mollison, 1979; Mollison 1988). As such, this section will compare permaculture rationales against contemporary scientific research pertaining to ecosystem service impacts for each of these elements. The most relevant areas of current scientific study are species
diversity (polycultures), functional diversity (including life cycle and growth form for perennials), and landscape diversity (zone design).

**Species diversity (polycultures)**

The relationship between biodiversity and ecosystem services (provisioning, supporting, and regulating) has been an area of active research. In the ambitiously titled literature review, *Effects of Biodiversity on Ecosystem Functioning: A Consensus of Current Knowledge*, Hooper et al. (2005) outline the following as “certain” conclusions, some of which have implications for the contemporary significance of permaculture. Firstly, ecosystem properties are clearly impacted by the functional characteristics of and interactions among species. Furthermore, a species’ contributions to ecosystem properties is not always conditional on its relative abundance. Hooper et al. therefore caution against using relative abundance as the sole “predictor of the ecosystem-level importance of a species”. Thirdly, the stabilizing effect of functional diversity is acknowledged, sometimes referred to as the ‘insurance hypothesis’. This stabilization, or buffering, of ecosystem properties is observed among communities containing species with redundant functional roles. This review therefore recommends management practices which encourage species diversity, particularly with diverse functional effects and response types. Not only are these conclusions relevant in interpreting permaculture theory, but also when interpreting results from individual biodiversity - ecosystem service studies.

**Provisioning services**

Diversity of “plant species, varieties, yield, microclimate and habitat” is the third basic characteristic of permaculture (Mollison & Holmgren, 1978, p.6). Rationales given for the use of polycultures in permaculture commonly include greater net yield resulting from improved resource use or beneficial species interactions.
Mollison and Holmgren (1978) propose that a well-designed mixed species community more fully uses all available resources resulting in a greater “sum of yields” per unit area, even when individual species are not producing equal yield to a monoculture (p.7). Examples given include mixing species with different root structures or canopy heights to more completely access soil nutrients and light respectively. This process of resource or niche partitioning is known in contemporary ecology as *complementarity* (Hooper *et al.* 2005). The mechanism for increased productivity here is pairing species which experience minimal interspecific competition due to differing “patterns of resource use”. Hooper *et al.* (2005) state they are highly confident that complementarity does occur for specific species combinations. The other mechanism, beneficial interspecific interactions, is often referred to in permaculture as *companion plants* or *guilds*:

*When we design plant guilds, as we always try to do in polyculture, we try to maximize the benefits of each species to the others....A guild, then, is an harmonious assembly of species clustered around a central element (plant or animal). This assembly acts in relation to the element to assist its health, aid our work in management, or buffer adverse environmental effects* (Mollison, 1988, p. 60).

*Facilitation* is the current ecological term, describing the same beneficial interspecific interactions observed between permaculture companion plants or within permaculture guilds. Facilitation describes interactions where, “species alleviate harsh environmental conditions or provide a critical resource for other species” (Hooper *et al.* 2005). Hooper *et al.* further suggest that overyielding, where “plant production in mixtures exceeds expectations based on monoculture yields”, is primarily driven by either complementarity or facilitation. The permaculture claim, that a greater sum of yields can result from

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1 It has been voiced elsewhere that this use of the term guild differs from the commonly accepted ecological definition (Ferguson & Lovell, 2014; Simberloff & Dayan, 1991), however for the purpose of this discussion the term *guild* will follow Mollison, 1988.
polycultures designed to take advantage of resource partitioning (complementarity) and beneficial interspecific interactions (facilitation), is therefore compatible in theory with contemporary ecology.

Evidence of biodiversity enhancing provisioning services is provided by several studies. Quijas, Schmid, & Balvanera (2010) investigated the effect of biodiversity on provisioning of terrestrial plant products (food, fodder, wood, firewood) using both a quantitative meta-analysis (61 experimental studies, 197 records) and a vote-counting analysis (82 studies, 361 records). Both tools indicated a significantly positive effect of biodiversity on plant product provisioning as measured by aboveground biomass. Another meta-analysis by Iverson et al. (2014), including 26 agricultural studies and 301 observations, produced similarly positive results. This study found 40% increases in per-plant primary crop yield in polycultures (using substitutive designs) over monocultures of the same species. Importantly in additive designs, which would be subject to greater crowding, primary crop yields decreased by 24%. This loss was found to be mostly explained by polycultures lacking legumes: legume secondary crops did not reduce primary crop yield in either design. These results highlight an important challenge in designing productive polycultures: identifying appropriate interspecific densities is necessary to optimize yield.

Ecological succession planning is a prerequisite of permaculture design and another way of adding temporal diversity to the system. Mollison and Holmgren describe evolutionary change as “the essence of the support system” (1978, p. 29). The rationale here is that all plants fit into a natural succession sequence. Rather than fighting to keep the environment constant, perhaps by using external inputs or labour, permaculture embraces that this succession from one crop to the next can be planned and used to benefit the farm:

...pioneer species can be used to advantage in establishing a system, providing yields quickly and modifying the environment...By the time a Pecan shades out a gooseberry bush, many years of produce will have been harvested from the bush and nut yields will be increasing (Mollison & Holmgren, 1978, p. 31-32).
Because permaculture incorporates succession into its design, this system is necessarily long-lived and therefore permits longer time scales towards realizing the benefits of greater plant diversity.

Bonin and Tracy (2012) describe such a “strengthening of biodiversity effects with time”, in a four-year study comparing 10 prairie forage plants grown in monocultures and at five levels of polyculture combinations. Throughout the study the 10-species polycultures produced “the most consistently high and stable yields”, and in year 4 of the study polycultures over-yielded monocultures in 75% of plots. The strengthening effect was most apparent in plots demonstrating transgressive over-yielding: in the initial year of the study polycultures outperformed their highest yielding monoculture species in 25% of plots. This ratio improved to 54% of plots in year 4.

*Regulating and supporting services*

Guilds and companion planting are also proposed to improve the stability (or *self-regulating ability*) of the permaculture system, resulting in favourable regulating and supporting services:

*It is not the number of diverse things in a design that leads to stability, it is the number of beneficial connections between these components* (Mollison, 1988, p. 32).

*If we have a system with diverse plant and animal species, habitats, and microclimate, the chance of a bad pest situation arising is reduced...Healthy plants are less prone to disease and insect attack and more capable of competing successfully with weeds and coping with parasite attack...Provision of good site conditions enhance plant health* (Mollison & Holmgren, 1978, p. 32).

That strategically designed site conditions, utilizing “*beneficial functional connections*”, can provide crop protection from pest, diseases and weeds, is the sort of claim that makes permaculture critics cringe. However, evidence exists in contemporary studies that biodiversity does contribute to these regulating and supporting services.

Crop protection from pests, invaders and disease are important regulating services. Returning to Quijas *et al.* (2010), both meta-analysis and vote-counting approaches found significant and positive
effects of biodiversity on invasion resistance and pathogen regulation. Iverson et al. (2014) likewise describe polycultures as “promoting win-wins”. This meta-analysis found that for studies comparing both yield and biocontrol between monocultures and polycultures, polycultures increased biocontrol by 31% (substitutive design) to 36% (additive design). Significant biocontrol measures included reduced plant damage and pest abundance. Biocontrol effects were largest for maize (in additive designs) and ‘other’ crops2. Iverson et al. (2014) suggest that decreased resource concentration and enhanced natural enemies may explain this biocontrol, although predator abundance was not found to be a significant factor. In yet another meta-analysis, of 446 biodiversity effects measures, Balvanera et al. (2006) also found significant positive effects of biodiversity on pest control resulting in reduced plant damage. Balvanera et al. (2006) agreed with Quijas et al. (2010), that higher plant diversity resulted in “reduced invader abundance, survival, fertility and diversity”. Parker et al. (2016) investigated the effects of increasing plant diversity when using “trap crops” to protect broccoli from crucifer flea beetles. Crop yields in plots with two- and three-species trap crop mixtures were significantly greater than with single trap crop species or broccoli monocultures. Interestingly, while crop yield benefitted, there was no significant impact on flea beetle abundance, and authors suggest the strategically increased plant diversity altered the herbivores behaviour rather than quantity. Fungal infestation by Phytophthora on cacao fruit decreased when “evenness and cover of the herb layer was higher”, however infestation of M. roreri Cif. increased under the same conditions, suggesting this effect can be highly species specific (Kieck, Zug, Huamaní Yupanqui, Gómez Aliaga, & Cierjacks, 2016). Finally, Bonin & Tracy (2014) observed significant differences in weed biomass in prairie grass polycultures (3-28 g/m²) compared to monocultures (>100g/m²). Importantly this effect became more apparent with time: significant results for all species richness levels was observed in the fourth year of the study. This

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2 The ‘other’ crops category included wheat, cotton, tomato, zucchini, collards, broccoli and oilseed rape.
highlights the importance of long term studies when investigating perennial (or permaculture) communities.

Supporting ecosystem services are predicted by permaculture, and also evidently impacted by plant diversity. Erosion control is expected to be improved in polycultures, resulting from the significant positive effects of plant diversity on “belowground plant and microbial biomass” (Balvanera et al., 2006; Quijas et al., 2010). Nutrient cycling and soil fertility are also expected to benefit from significantly enhanced decomposer and mycorrhizal activity and diversity (Balvanera et al., 2006). Soil fertility benefits from additional nitrogen when increased plant diversity includes legumes (Crews et al., 2016). Added diversity has also shown to benefit pollinators: the restoration of flowering native perennial hedgerows increased pollinator persistence and colonization resulting in increased pollinator richness within 6 years (Gonigle et al., 2015). Holzschuh et al. (2012) demonstrate that a 150% increase in sweet cherry fruit set can result from increasing high-diversity bee habitat from 20% to 50% within a 1 km radius. The same results are shared for blueberries: crops adjacent to wildflower plantings produced higher “percentage fruit set, average berry weight, and number of mature seeds” by the third and fourth year post-planting (Blaauw & Isaacs, 2014). Such ecosystem services can benefit farmers economically: the cost of seeding diverse ground cover vegetation under tart cherry trees was recuperated by the second year due to reduced need for fertilizers (-50%), herbicides (-100%), and orchard visits (-67%), while maintaining yields (Sirrine et al., 2008).

Functional diversity (perennials, trees)

The study of species diversity has highlighted that it is the community composition, rather than the total number of species present, which most influences ecosystem properties (Hooper et al., 2005). The study of functional diversity further suggests that the influence of a given species on its
environment actually results from specific functional traits (Wood et al., 2015). Two functional traits particularly relevant to permaculture are life cycle (i.e. perennial species) and growth form (i.e. trees).

Permaculture from the outset has promoted perennial species as a core component of permanent or sustainable agriculture:

*Permaculture is...an integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man... This study [Permaculture One] is therefore intended as a pioneer effort in the collection and analysis of the elements and principles of perennial agriculture* (Mollison & Holmgren, 1978, p. 1).

The originators even subtitled their first publication to reflect this emphasis: *A Perennial Agriculture for Human Settlements* (Mollison & Holmgren, 1978, title). Permaculture, as a “Cultivated Ecosystem”, strives to mimic and function as a natural ecosystem does. The dominance of perennial species in a permaculture is largely motivated by observations of ecological succession in natural ecosystems, whereby short-lived pioneer species are gradually replaced by long-lived late succession species (Mollison & Holmgren, 1978, p. 29-32). Permaculturalists would prefer to allow and plan for this succession, rather than waste energy and resources trying to hold the environment permanently suspended in the pioneering stage required for annual crops. A newly established permaculture does include annual species, preferably perennial forms, for short-term yields before perennials are providing reliably. Short-, mid-, and long-term yielding crops are selected and designed to succeed each other over the life time of a permaculture system. This also contributes to temporal diversity in species and products. Annual labour and maintenance are predicted to be lower in a perennial system.

Establishment is intensive but infrequent, and effort is focused towards observation, “Rather than the menial and repetitive labour of sowing, ploughing and reaping in a labour-intensive annual crop system” (Mollison & Holmgren, 1978, p. 9). More relevant from an ecosystem properties perspective is the claim that replacing annual tillage with perennials provides permanent cover, which in turn promotes soil building, and reduces compaction, erosion and disruption of soil biota (Mollison, 1988, p. 215).
Growth form diversity is an important consequence of perennial agriculture, and permaculture considers trees to be both the ultimate multifunctional tool and the logical climax community:

...a permaculture system is dominated by trees. Although trees are no more important than smaller elements in the system, their size, longevity, and the extensive nature of tree culture (number of plants/unit area), means that they determine the limits of the system... the proportion of land without large trees and not under self-established pasture could be considered small (Mollison & Holmgren, 1978, p. 29).

*Permaculture: A Designer’s Manual* dedicates an entire chapter to “Trees and their energy transactions”, which outlines the many useful functions of trees include provisioning, supporting and regulating services (Mollison, 1988, p.137-151). Trees provision humans with abundant biomass used for food, timber, and fuel, while providing windbreaks and shade for crops and workers. Trees provide habitat for wildlife and facilitate mycorrhizal associations and decomposer activity, which releases nutrients to the soil. Importantly for agriculture, trees can effectively modify local temperatures, microclimates, and hydrologic cycles. The canopy and deep roots, which are infrequently disturbed compared to annual agriculture, both act to protect the soil from erosion. Permaculture advocates both for the end of broad-scale deforestation and for the incorporation of trees into agricultural ecosystems.

*What I hope to show is the immense value of trees to the biosphere...The planting of trees can assuredly increase local precipitation, and can help reverse the effects of dryland soil salting...Trees not only build but conserve the soils...* (Mollison, 1988, p. 137).

*Natural succession (and perennial grains)*

An immediate and important question arises when promoting permaculture: how do we satisfy our current annual grain-based diet in a perennial agriculture? Researchers working with perennial grain breeding projects are finding “promising early results” for perennial wheat, rice, sorghum, pigeon pea and oilseeds (Crews *et al.*, 2016). This research is motivated, at least in part, by a renewed interest in applying ecological succession planning to agriculture. Crews *et al.* (2016), in the cleverly titled review
“Going where no grains have gone before: From early to mid succession”, emphasizes this important trend:

...due to recurring tillage events or herbicide applications, annual crop ecosystems remain arrested in a disturbed, less regulated state of early secondary succession...Few if any terrestrial ecosystems experience the cumulative disturbance impact that characterize annual agroecosystems when frequency, extent and magnitude are considered together (Crews et al., 2016).

The current agronomic literature generally recognizes the ecosystem service advantages of using such techniques as continuous plant cover, cover crops, perennial buffer strips, and hedgerows to reduce the bare soil exposure that results from this disturbance (Peigné et al., 2015; Sun, Tang, & Xie, 2008). Crews et al. (2016) suggest that transitioning to a perennial (or mid-succession sere) agriculture reduces the incidence of disturbance, which will more effectively enhance ecosystem service benefits compared to the above individual practices. While perennial grains are still in development, these species may increase the viability and attractiveness of permaculture in the future.

Ecosystem services

Correy (2016) claims that: “No individual or array of practices can achieve the same levels of conservation that perennial cover does”. Asbjornsen et al. (2013) supports this claim in an excellent and comprehensive review of perennialization literature. This summary highlights successful international examples and evidence from contemporary studies demonstrating how perennial plant communities contribute to agricultural ecosystem services. This includes improved provisioning (forage, grains, biofuel, medicinal products), regulating (hydrologic cycles, water quality, carbon sequestration and storage, pest control) and supporting (soil quality, pollination) services. Functional traits of perennial species credited for the delivery of these services include longer life spans, growing seasons, and reduced disturbance frequency. These features were associated to enhanced evapotranspiration,

3 Perennialization: the strategic inclusion of more perennial species
carbon sequestration, and provision of habitat and forage resources for pollinators, biocontrol species, and soil biota. Another important feature is deep and complex root systems. Perennial roots have shown to influence soil structure by increasing soil porosity, thereby improving storage, infiltration, and runoff cycles. Perennials typically invest more biomass below ground than annuals (Crews et al., 2016), contributing to soil organic matter, and more efficient use of nitrogen (Asbjornsen et al., 2013). A study on perennial hedgerows intercropped with maize and peanuts, found that soil nutrients (nitrogen, potassium, and organic matter) were higher under the hedgerow than under the crop alley, and the authors concluded that competition for these nutrients was not occurring (Sun et al., 2008). While clearly a scenario with many variables, and highly species specific, these examples support permaculture claims that the strategic inclusion of perennial species can result in significant benefits.

Landscape diversity (zone design)

While the adoption of polycultures and perennial species is common to other forms of agroecology (Altieri, 1999; Crews et al., 2016; Hathaway, 2015) permaculture includes a highly unique approach to strategic landscape diversity, termed Zone design. Permaculture includes five management “zones”, each containing a prescribed functional plant community (Table 2.1). The rationale for imposing these zones is that energy and labour can be conserved by grouping plants, and other elements, based on the amount of attention needed:

*Zoning (distance from centre) is decided on two factors: 1. The number of times you need to visit the plant, animal or structure; and 2. The number of times the plant, animal or structure needs you to visit it* (Mollison 2002 p. 49-50).

Efficiency is gained by positioning, for example, intensely managed annual vegetables near to the house (or central structure on the farm) and infrequently visited nut orchards further away (Mollison &
Importantly, these zoned plant communities include a diversity of growth forms and functions beyond just cultivated crops, resulting in high habitat heterogeneity:

A mix of forest, clearing, hedgerow, field, woodland and intensive crop cultivation would be far more capable of diverse productivity at high net yields/ha. (Mollison & Holmgren, 1978 p. 41).

The end result is that a permaculture landscape should contain at least five compositionally dissimilar polycultures resulting in both high alpha (within zone) and high beta (between zone) diversities. Finally, due to the prescription for zone 5, all permaculture landscapes should include natural areas.

Table 2.1. Permaculture Zones: plant community, cultivation, and use prescriptions. Adapted from: (Mollison & Holmgren, 1978, p.53-56; Mollison, 1979, p. 10; Mollison, 2002).

<table>
<thead>
<tr>
<th>Permaculture Zone</th>
<th>Plant Community, Cultivation, and Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>- Most-intensive cultivation</td>
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<tr>
<td></td>
<td>- Fully-mulched and pruned vegetable gardens</td>
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<tr>
<td></td>
<td>- Propagation, seedlings &amp; young trees for outer zone placement</td>
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<tr>
<td></td>
<td>- Rare and delicate species; Green houses</td>
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<tr>
<td></td>
<td>- Domestic sufficiency; Culinary herbs</td>
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<tr>
<td>Zone 2</td>
<td>- Intensively cultivated</td>
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<tr>
<td></td>
<td>- Spot-mulched orchards</td>
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<tr>
<td></td>
<td>- Main-crop beds</td>
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<td></td>
<td>- Hedges and trellis</td>
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<tr>
<td></td>
<td>- Home orchards</td>
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<tr>
<td></td>
<td>- Small domestic stock &amp; orchard</td>
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<tr>
<td></td>
<td>- Few large trees</td>
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<tr>
<td></td>
<td>- Dense and complex herb layer and understory, especially small fruits.</td>
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<tr>
<td>Zone 3</td>
<td>- Broad-scale and hardy farming systems</td>
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<tr>
<td></td>
<td>- Main commercial crops; natural or little-pruned trees, especially nuts</td>
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<tr>
<td></td>
<td>- Animal forage and harvested feed</td>
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<tr>
<td></td>
<td>- Tough understory and self-perpetuating herb layer or pasture</td>
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<td></td>
<td>- Thickets, hedgerows and windbreaks</td>
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<tr>
<td>Zone 4</td>
<td>- Extensive tree culture and open pasture with tough hedge plants</td>
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<tr>
<td></td>
<td>- Bordering on forest or wilderness</td>
</tr>
<tr>
<td></td>
<td>- Forage, pasture, range, timber, forestry, wild gathering</td>
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<tr>
<td></td>
<td>- Hardy, unpruned, or volunteer trees</td>
</tr>
<tr>
<td>Zone 5</td>
<td>- Natural, uncultivated and unmanaged environment</td>
</tr>
<tr>
<td></td>
<td>- Occasional foraging, recreation, timber and hunting</td>
</tr>
</tbody>
</table>
**Scale, habitat heterogeneity, and natural resources**

Developing landscapes which jointly sustain agricultural production, ecosystem service delivery and biodiversity conservation is a complex and multi-scalar challenge. The scientific community is increasingly recognizing the value of an integrated and diverse landscape in achieving these goals (Altieri, 1999; Kremen, 2015; McGranahan, 2014; Srivastava & Vellend, 2005). Scale, habitat heterogeneity (including complexity and connectivity), and access to nature reserves, are all important considerations when establishing multifunctional landscapes.

Local (alpha) diversity exerts a range of influence proportionate to the various species and services in question. This point becomes clear when comparing pollination to climate mitigation. Floral diversity has shown to benefit pollinator richness but the effect diminishes at scales greater than 500-1000m (Földesi *et al.*, 2016; Garibaldi *et al.*, 2011). By contrast, for land use and management to impact climate mitigation much larger scales are required. For example, the high potential for agroforestry to mitigate climate in non-Annex 1 countries is based primarily on calculations of the 630 × 106 ha available for conversion (Verchot *et al.*, 2007). Von Wehrden *et al.* (2014) emphasize the importance of recognizing scale-dependent effects of management practices, and recommend that landscape (gamma) diversity offers better long-term predictions of species interactions and consequently ecosystem function. This is extremely relevant to agroecosystems, where large-scale biodiversity losses have occurred due to the amalgamation, expansion and simplification of individual farms (Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005). While this pattern has created many problems, the flip side is that larger farm acreages impact broader landscapes, and so individual farmers may actually be in a position to affect larger scale ecosystem functions using appropriate management. Similarly, many small permaculture farms within a regional watershed may result in landscape effects exceeding the sum of individual contributions (Lynch, Sumner, & Martin, 2014, p. 359).
The benefits of habitat heterogeneity, especially set-asides and hedgerows, to biodiversity conservation and ecosystem services, have been well documented. A meta-analysis of 127 studies from North America and Europe demonstrated “unequivocally” that land set-aside from conventional production increases biodiversity for bird, insect, spider and plant species (Buskirk & Willi, 2004). Sun, Tang, and Xie (2008) reviewed 70 studies investigating the adoption of contour hedgerow intercropping on arable slopes in China and found soil loss and surface water runoff were reduced by as much as 97% and 66% respectively. However management practices which contribute to landscape diversity also compete with crops for space, which is assumed to reduce yields, and so implementation is often viewed as a tradeoff.

In a multifunctional agriculture, such as permaculture, intercropping secondary crops as hedgerows could contribute jointly to ecosystem services, biodiversity conservation, and net yield. Importantly, the efficacy of this intercropping depends heavily on the species and interactions involved. Returning to the Sun et al. (2008) review, contour hedgerows contributed economically by increasing maize and peanut yields (by as much as 24%) in addition to the orchard fruits and livestock fodder yields from the hedgerow. Tree intercropping with annual crops (soybean and winter wheat) in Canada likewise benefitted soil organic carbon, bird and insect (including parasitoids and detritivores) diversity, reduced fertilizer requirements, and sustained or improved crop yields compared to monocultures (Thevathasan & Gordon, 2004). While this study did not assess the secondary crop value, the tree species used (including maple, hazlenut, red oak, and black walnut) could be harvested to provide additional products (maple syrup, nuts, or timber), and therefore higher net yields. These examples demonstrate the potential available to incorporate landscape diversity which benefits biodiversity and ecosystem services while maintaining or increasing net yield.

To effectively support biodiversity conservation and ecosystem services, agricultural landscape mosaics should include adequate connectivity to nature reserves (Kremen, 2015; Tscharntke et al.,
Kremen (2015) recommends: “large protected areas surrounded by a relatively wild-life friendly matrix promoting connectivity through a combination of favourable land uses and corridors”. Similarly, Tscharntke et al., (2005) conclude that: “agricultural landscapes must be a mosaic of well connected early and late successional habitats”. Natural areas serve as refuges which are important for recruitment and dispersal of pollinating and biocontrol species (Tscharntke et al., 2005). A review of 29 studies demonstrated that proximity to natural (uncultivated) areas enhance visitation rates and species richness for pollinating insects (excluding honeybees) as well as resulting fruit set (Garibaldi et al., 2011). This review found that all of these indicators were reduced beyond 1km from natural areas, highlighting again the importance of scale and connectivity. Inclusion of natural areas in agricultural landscapes contribute to habitat heterogeneity, particularly the “late-successional” habitats advocated for by Tscharntke et al. (2005). Moreover, natural areas offer a range of functions which are expected to exceed that of simple hedgerows or early-succession set-asides. That said, hedgerows have been found to successfully support typical forest species (Wehling & Diekmann, 2009), which may be a way to introduce connectivity features consisting of native, late-succession, and perennial species into agricultural landscapes. Further research into the efficacy of natural patches and hedgerows on farms, as wildlife corridors between nature reserves or as wildlife-friendly mosaics, would be highly valuable.

**Conclusion**

Permaculture was proposed in 1978 as a sustainable alternative to industrial agriculture, which aims to integrate ecology, landscape design, and ethics to achieve multifunctional and highly productive agricultural systems. Peer-reviewed research on permaculture is scarce, and largely lacking empirical design, but what is available suggests that permaculture uses lower-impact management practices. Parallel contemporary agronomic and ecological research highlight that the permaculture practices of implementing polycultures, perennial species, and zone design may benefit many ecosystem services if
they enhance species, functional, and landscape diversities. This is particularly true for the provisioning of diverse crop yields; regulation of pests, climate, and nutrient cycles; and supporting services such as soil health and pollination.

**Objectives and hypotheses**

In order to begin addressing this substantial knowledge gap, we have designed what is believed to be the first study characterizing plant communities on active permaculture farms. The objective of this study is to provide a baseline description of applied permaculture, which can be used to design future empirical studies on the ecosystem service impacts of permaculture. It is predicted that independent permaculture farms will consistently apply the permaculture principles of polycultures, perennial species, and zone design. Subsequently, it is predicted that permaculture plant communities will be characterized by the following properties. Firstly, permaculture farms will exhibit high plant species diversity relative to typical regional farms. Secondly, permaculture farms will demonstrate functional diversity by including both annual and perennial species across a range of growth forms. It is further predicted that perennial species will dominate permaculture plant communities. Finally, it is predicted that the application of zone design will contribute to landscape diversity at the farm-scale. This will be evidenced by the occurrence of multiple, compositionally-distinct, plant assemblages within a given site. The application of zone design is further expected to demonstrate a high degree of consistency with the permaculture literature, as outlined in Table 2.1. Specifically, zones are predicted to be characterized as follows: 1) most intensively cultivated herbs and annual crops, greenhouses, rare and delicate crops, and seedlings; 2) main crop beds, small fruits, and orchards; 3) main commercial crops, especially low maintenance trees; 4) wood lots, pasture, and foraging; 5) uncultivated natural or semi-natural area.
Chapter 3

Characterizing plant communities on Canadian permaculture farms

Introduction

Grassroots movements have enthusiastically applied, adapted, and evaluated permaculture in more than 50 countries over the last 40 years (Schmidt, 2012). This has led to an unprecedented opportunity for observational research on applied permaculture under a range of timelines and management intensities. This study takes advantage of this availability by surveying vegetation on 10 commercial permaculture farms in the Vancouver Island – Coast region of British Columbia, Canada. The objective of these surveys is to characterize species, functional, and landscape diversities in order to evaluate how consistently independent adopters interpret and apply permaculture theory.

Materials and methods

Study area

In order to find active permaculture farms to use as study sites, participants were recruited initially via the World-Wide Opportunities on Organic Farms (WWOOF) Canada members website (WWOOF Canada, 2017). WWOOF is an online forum which networks organic farmers with volunteer workers in many countries including Canada. The organization facilitates grassroots mentorship, practical experience, and affordable labour for members. British Columbia returned the greatest number of responses to the filter “permaculture” on the WWOOF Canada members website (Figure 3.1a), and so recruiting effort was focused there. All online members of WWOOF Canada located in British Columbia were emailed an informative recruitment letter describing the goals of the study and requesting participants. The Vancouver Island-Coast region was selected as a practical study area given...
the high density of 89 potential participants (Figure 3.1b) and volume of immediate email responses to the recruitment letter.

The Vancouver Island-Coast region climate is Mediterranean-like and coastal, characterized by mild, wet, winters and warm, dry summers (Government of Canada, 2017). Average daily temperatures range from approximately 5°C (January) to 17°C (May-August), and 185 frost free days is typical. Precipitation is rarely snow, peaking November-January (15-20mm/ month), and minimal in summer months (<5mm/month). The Plant Hardiness Zones here are 8a or 8b (Natural Resources Canada, 2017).

**Study sites**

Of the initial respondents, the participant pool was further narrowed by verifying that all study sites were commercially operating farms and applying permaculture practices currently. A Google search for permaculture farms in the Vancouver Island-Coast region identified additional suitable candidates who were contacted directly via publicly available email addresses. Ten sites were found to be appropriate based on the above criteria and were distributed as follows: Vancouver Island (5), Denman Island (2), Gabriola Island (2) and Hornby Island (1) (Figure 3.2). All sites self-identified as practicing permaculture, and informal interviews with farmers verified familiarity with fundamental permaculture theory (Mollison & Holmgren 1978; Mollison, 1979; Mollison, 1988).

All sites were currently engaged in commercial production but marketed products, services and production volume varied. Distribution channels for products also varied but were typically locally-oriented including: farmers’ markets, community supported agriculture (CSA) shares, road-side or farm stands, and local stores. Total farm area for sites was generally small at less than 10 acres (n=6) or 10-40 acres (n=4). Farm areas always included uncultivated portions, but this area was not explicitly measured or recorded. Land use adjacent to sites included residential, agriculture, or natural; the proportions of each varied and were not measured. Each site was visited once between August 11th and August 17th, 2016.
Figure 3.1. Distribution of permaculture farms in Canada (A) and British Columbia (B). Search completed using the WWOOF Canada members website (WWOOF Canada, 2017). A: Responses returned for “permaculture” filter (n=202 responses). B: Responses returned for “permaculture” + “British Columbia” filters (n=89 responses). Vancouver Island - Coast region returned the greatest density of responses (n=45) and was selected as the study area. Numbered circles represent the number of responses returned, and are positioned to represent the relevant region.
Figure 3.2. Distribution of permaculture study sites across the Vancouver Island – Coast region of British Columbia, Canada. Vegetation surveys completed once per site (n=10 sites) between August 11th-17th, 2016. Black pins mark approximate farm locations. Exact locations are not given out of respect for participants’ privacy.
Vegetation sampling

Plant community sampling was observational and non-destructive. Plant communities are limited to species emergent during late summer, and as such our characterizations may underrepresent the total diversity present in a given growing season. At each farm the manager was asked to identify up to five unique management zones and assign them 1-5 based on their interpretation and application of permaculture zone design. For each of the zones, species richness and relative abundance was measured visually along two 1-meter-wide strip transects. Zones 1-3 were typically a smaller area, contained smaller individual plants, and were more densely planted than zones 4-5 (personal observation). To accommodate this, sampling effort was expanded in peripheral zones. Strip transects were 5 meters long for zones 1-3, and 10 meters long for zones 4-5. Transects were spaced approximately equal distances from the outer edge and from each other within the zone to best cover the space while minimizing edge effects. If the zone included disconnected patches, transects were placed in the center of the two largest patches. If the zone contained planted crop rows, transects were aligned perpendicularly to these rows whenever possible. This approach was non-random to most comprehensively represent species richness in a “consciously” designed agroecosystem (Mollison, 2002).

Plant common names were recorded in the field and binomial names were determined later. The relative abundance of each species in a sample was recorded as the number of individuals. Multi-stemmed individuals were counted as one, not as the number of stems visible. Life cycle was categorized as annual or perennial. Biennial species were organized by harvesting period: annual if harvested in the same year as planted or perennial if allowed to complete a natural life cycle⁴. Growth form was categorized according to USDA plant growth habit definitions, as summarized by Figure 3.1 (United States Department of Agriculture, n.d.). Growth form assumed size at maturity and made no

⁴ Based on personal communications with farmers,
distinction for actual size when sampled (i.e. seedlings). For simplicity, the only vine surveyed (Vitis spp.) was classed as a shrub.

**Table 3.1. Growth form descriptions and definitions.** Adapted from ‘Growth Habits Codes and Definitions’ (United States Department of Agriculture, n.d.).

<table>
<thead>
<tr>
<th>Growth form description</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous</td>
<td>Vascular plant with non-woody stem</td>
</tr>
<tr>
<td>Shrub</td>
<td>Multiple woody stems; usually less than 5 meters in height</td>
</tr>
<tr>
<td>Tree</td>
<td>Single woody stem; usually greater than 5 meters in height</td>
</tr>
</tbody>
</table>

**Community composition indices and analysis**

Field notes were compiled in a master dataset in MS Excel, with the following information for every species of each sample: site, zone, transect, common name, binomial name, abundance, life cycle, and growth form. Plant binomial names were identified to species when possible, or to genus if species could not be confidently determined from the common name recorded during sampling. All analysis was performed using the lowest taxonomic rank available and binomial names. Abundance counts were combined for duplicates when a species was recorded under multiple common names within the same sample.

From the master dataset, two subsets were manipulated to analyze farm-scale and management zone effects separately. For farm-scale effects, sites were used as replicates (n=10). The 10 samples for each site (two transects each for five zones) were pooled together to analyze one farm-scale plant community as one replicate. To analyze the effect of management zones, zone was treated a factor with 5 levels and 10 replications (sites) each. The two transect samples within each zone were considered subsamples and pooled. Multiple observations of the same species for pooled samples were combined and abundances summed.
For both farm-scale and zone effects, the following species diversity indices were calculated using TrueDiversity-18.12.12 (Goepel, 2012): species richness ($R_t$), Shannon entropy ($H'$), Shannon’s equitability ($H'/H_{\text{max}}$), and Simpson’s dominance ($\lambda$). Species richness density ($R/m^2$) and abundance density per zone were calculated by dividing species richness and abundance respectively by sampling area (Zone 1-3: 5m$^2$, Zone 4-5: 10m$^2$), to acknowledge uneven sample areas. Means and standard deviation were calculated in MS Excel.

Frequency of shared species was calculated as a count of the number of sites which shared observations of a given species, indicating how common or rare this species was among the surveyed farms. Abundance-ranked species frequencies were calculated the same way: species were ordered first by the number of sites they were observed at, and secondly by the total number of individuals observed among all sites. Results at the farm-scale were recorded separately for cultivated (intentionally grown by the farmer) and non-cultivated (volunteers, native or naturalized) species. To analyze life cycle and growth form, species richness and abundance were proportioned into annual-perennial and herb-shrub-tree respectively. For example, species richness of a sample might be proportioned into 60% perennial species and 40% annual species. For analyses of zone effects on life cycle, only the proportion of perennial species richness and perennial abundance were included, as the sum of perennial and annual proportions always equalled one.

**Statistical analysis**

All statistical analyses were completed using R (version i386 3.3.2). One-way parametric ANOVAs were used to analyze the effects of zone as a factor for: species density, abundance density, Shannon’s entropy, Shannon’s equitability, Simpson Dominance, perennial richness, perennial abundance, richness by growth form, and abundance by growth form. One-way ANOVAs were additionally used to analyze the distribution of species richness and abundance for each life cycle and
growth form at the farm-scale. For all one-way ANOVAs, normality and variance assumptions were verified using the Shapiro-Wilks and Levene’s tests, respectively. Non-parametric Kruskall-Wallis one-way ANOVAs were used when parametric ANOVA assumptions were not satisfied for variance (Shannon entropy, Shannon’s equitability, Simpson dominance, perennial richness, cultivation ratios) or normality (species density, abundance density, Shannon’s equitability, Simpson dominance, perennial richness), and could not be improved with transformations. For all such cases, the Kruskall-Wallis supported the original ANOVA and results are therefore considered robust. Pair-wise comparisons among zones, life cycles, and growth forms were calculated using Tukey HSD with a critical value of $\alpha=0.05$.

Sample-based (incidence) species accumulation curves were calculated using the vegan package in R. Farm-scale species accumulation calculated as the number of species per additional site (n=10) where subsamples (zones and transects) are pooled per site. Total species accumulation was calculated as the number of species per additional sample (n=100, all sites, zones and transects treated equally). Species accumulation per zone (not adjusted for sample area) was calculated as the number of species per sample per zone (n=20, sample = $5m^2$ for zones 1-3 & $10m^2$ for zones 4-5). Species accumulation per zone (adjusted for area) calculated as the number of species per sample per zone (sample = $10m^2$, pooled transects per site for zones 1-3).

Non-metric multidimensional scaling (NMDS) ordination plots, using the Bray-curtis index, were calculated using the vegan package in R. For species incidence per site, species counts were pooled per site, and a given species was recorded as present or absent for that site irrespective of relative abundance or frequency of occurrences among pooled samples. For species frequency per zone, species counts were pooled per zone where abundance represents the number of sites containing at least one observation of a given species in that zone.
Results

Species diversity

At the farm-scale, permaculture sites were characterized by diverse plant communities, as demonstrated by multiple diversity indices. Permaculture farms exhibited a high mean species richness (59 species), Shannon entropy (3.4), and Shannon’s equitability (0.8), and low mean Simpson’s dominance (0.06) per farm. Field notes suggest that many more species were present at most sites but unaccounted for as they occurred outside the sampled area.

The plant species observed at each site tended to be dissimilar and included many rare species, as demonstrated by Figure 3.3. Of the 255 species identified, 71% were considered rare, having been observed at only one or two sites. Only *Malus* spp. Mill. was common to all 10 sites (Table 3.2), and this value may be inflated as apple species were recorded to genus rather than to species.

Species accumulation curves, using either sites (Figure 3.4a) or individual samples (3.4b) as the accumulator, demonstrate that richness increased rapidly with increased sampling effort. This supports earlier observations of high inter-site heterogeneity in species composition, where the site mean (59 species) represents only 23% of observed species richness. The growth rate of both curves slows but does not reach a clear asymptote. This suggests that sampling effort was sufficient to provide a reasonable estimate of richness but fell short of recording total richness for permaculture farms in this region.

(L.) Huds.). The two most common native species were *Alnus rubra* Desf. ex Steud. and *Pseudotsuga menziesii* (Mirb.) Franco, observed at 90% and 80% of sites respectively.

When species richness is partitioned into cultivated and uncultivated species, two trends become clear (Figure 3.5). Firstly, cultivated species richness was significantly greater than uncultivated richness, averaging 42 species per site and ranged from 23 – 73 among the various locations in the study. Secondly, at the farm-scale, all 10 sites included uncultivated species. Uncultivated species richness ranged from approximately 11 to 26 species per site, and included native, naturalized, volunteer, and weed species. It is important when interpreting these values to recognize that many permaculture farmers tolerate and even harvest uncultivated species that might otherwise be considered weeds. Common examples for the Vancouver Island region are Himalayan and trailing blackberries, which are widely considered nuisance weeds but are edible and frequently harvested by permaculturalists (Figure 3.6). Furthermore, permaculture farmers often cultivate support species which can occur voluntarily; clover, for example. It is not always possible to accurately identify from a site survey whether a given species is a cultivated cover crop, harvested volunteer, tolerated natural species or weed. As such, the proportion of cultivated to uncultivated species here is approximate, but provides a data supported baseline demonstrate that cultivated species contribute significantly greater species richness among surveyed permaculture farms.
Figure 3.3. Frequency of shared plant species among permaculture sites (n=10 sites). Vegetation surveys (n=100 strip transects) completed August 2016 in British Columbia, Canada resulting in 255 total identified species. Most species (71%) were rare and were observed at only one or two sites. Only apples (Malus spp.) were observed at all 10 sites.
Figure 3.4. Permaculture farm plant species accumulation curves for all sites (A) and all samples (B).
Species accumulation curves are sample-based using plant species incidence data from vegetation surveys completed August 2016 in British Columbia, Canada. A: the number of newly discovered plant species per additional site surveyed (n=10 sites), where subsamples (zones and transects) are pooled per site. B: the number of newly discovered plant species per additional sample (n=100 transect samples), where all transect samples are treated equally, irrespective of site or zone.
Table 3.2. Abundance-ranked plant species frequencies for species observed at ≥ 50% of surveyed permaculture sites. Vegetation surveys for 10 permaculture farms were completed August 2016 in British Columbia, Canada. Cultivated species include crops and support plants and uncultivated crops include natural and naturalized species, volunteers and weeds. Frequency (F) represents the number of sites (n_s=10 sites) observing a given species. Abundance (A) represents the total number of observed individuals (n_T=3789) of that species pooled for all subsamples (zones and transects).

<table>
<thead>
<tr>
<th>Cultivated Species</th>
<th>F</th>
<th>A</th>
<th>Uncultivated Species</th>
<th>F</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malus spp. Mill</td>
<td>10</td>
<td>51</td>
<td>Alnus rubra Desf. ex Steud.</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td>Brassica spp. L.</td>
<td>9</td>
<td>92</td>
<td>Pseudotsuga menziesii (Mirb.) Franco</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>Solanum lycopersicum L.</td>
<td>9</td>
<td>61</td>
<td>Mahonia aquifolium Nutt.</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>Beta vulgaris L.</td>
<td>9</td>
<td>53</td>
<td>Thuja plicata Donn</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>Lactuca sativa L.</td>
<td>8</td>
<td>94</td>
<td>Rubus armeniacus Focke</td>
<td>6</td>
<td>111</td>
</tr>
<tr>
<td>Symphytum spp. L.</td>
<td>8</td>
<td>42</td>
<td>Polystichum munitum (Kaulf.) C.Presl</td>
<td>6</td>
<td>57</td>
</tr>
<tr>
<td>Fragaria × ananassa L.</td>
<td>7</td>
<td>122</td>
<td>Acer macrophyllum Pursh</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Tropaeolum spp. L.</td>
<td>7</td>
<td>46</td>
<td>Rosa acicularis Lindl.</td>
<td>5</td>
<td>38</td>
</tr>
<tr>
<td>Ribes spp. L.</td>
<td>7</td>
<td>19</td>
<td>Achillea millefolium L.</td>
<td>5</td>
<td>33</td>
</tr>
<tr>
<td>Rubus idaeus L.</td>
<td>6</td>
<td>5</td>
<td>Abies grandis Lindl.</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Brassica oleracea L.</td>
<td>6</td>
<td>59</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helianthus annuus L.</td>
<td>6</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucurbita spp. L.</td>
<td>6</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trifolium spp. L.</td>
<td>5</td>
<td>252</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitis spp. L.</td>
<td>5</td>
<td>65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phaseolus vulgaris L.</td>
<td>5</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mentha longifolia (L.) Huds.</td>
<td>5</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capsicum spp. L.</td>
<td>5</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Papaver somniferum L.</td>
<td>5</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calendula officinalis L.</td>
<td>5</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corylus avellana L.</td>
<td>5</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prunus spp. L.</td>
<td>5</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hippophae rhamnoides L.</td>
<td>5</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.5. Boxplot diagram comparing the farm-scale proportion of cultivated to uncultivated plant species richness on permaculture farms (n=255 species). Vegetation surveys were completed on 10 permaculture farms August 2016 in British Columbia, Canada. Boxplots represent farm-scale species richness for cultivated species (including crops and support plants) and uncultivated species (including native, naturalized, volunteers and weeds) for 10 sites. Multiple observations of the same species within a given site are counted once, such that species richness reflects the total number of unique species observed for that site. One-way ANOVAs calculated from site data (n=10 sites), where all subsamples (transects irrespective of zone) for that site are pooled. Means not sharing the same letter are significantly different (Tukey HSD, P < 0.05).
Figure 3.6. Wild weed or cultivated crop? Permaculture farms frequently tolerate or harvest native and naturalized species, such as *Rubus armeniacus* Focke, which is being used here as a hedgerow and windbreak in addition to yielding blackberries. Photo by Sarah Hirschfeld.
Functional diversity

Life cycle

At the farm-scale, perennial plant species significantly exceeded annual plant species in both mean richness (p<0.001) and mean abundance (p<0.01), as demonstrated by Figure 3.7.

Figure 3.7. Boxplot diagram showing farm-scale plant species richness (A) and relative abundance (B) by life cycle for permaculture farms. Vegetation surveys completed August 2016 in British Columbia, Canada. One-way ANOVAs calculated from site data (n=10 sites), where all subsamples (transects irrespective of zone) for that site are pooled. Means not sharing the same letter are significantly different (Tukey HSD, P < 0.05). A: Farm-scale perennial species richness exceeds annual species richness. B: Farm-scale perennial abundance exceeds annual abundance. Abundance refers to the number of individuals observed, where individuals for all species are pooled per site.
**Growth form**

Figure 3.8a shows that at the farm-scale, mean species richness for herbaceous vegetation was significantly greater than for shrubs or trees (p<0.001). Herbaceous individuals were most abundant and trees least abundant (Figure 3.8b).

![Boxplot diagram showing farm-scale plant species richness (A) and relative abundance (B) by growth form for 10 permaculture farms. Vegetation surveys completed August 2016 in British Columbia, Canada. One-way ANOVAs calculated from site data (n=10 sites), where all subsamples (transects irrespective of zone) for that site are pooled. Means not sharing the same letter are significantly different (Tukey HSD, P < 0.05). A: Plant species richness for herbaceous growth forms significantly greater than for shrubs or trees. B: Plant abundance highest for herbaceous growth forms, and lowest for trees. Abundance refers to the number of individuals observed, where individuals for all species are pooled per site.](image-url)
Landscape diversity

Field-scale analysis suggests that species and functional diversities were not distributed evenly across the landscape, but rather partitioned among zones which were characterized by distinct community compositions. At least five separate management zones could be identified by farmers for every surveyed site. However, analysis for species diversity (richness, abundance, Shannon entropy) and functional diversity (perennial richness, perennial abundance, growth form richness) partitioned zones into two significantly different clusters of inner (1 & 2) and outer (4 & 5) zones. Importantly, for all zone diversity measures a gradient, which followed zoned designations, was clearly and consistently observed. Zone 3 was typically intermediate: spanning the gap between inner and outer clusters.

Species diversity

Zones differed significantly in species density and abundance density (Figure 3.9). Both species richness and the number of individuals, per square meter, were significantly higher for inner zones (1-2) compared to outer zones (4-5). Zone 3 is comparable with inner zones for species richness but is intermediate for both measures and not significantly different from either zone cluster for abundance. Shannon entropy (Figure 3.9c) demonstrated a similar trend, whereby inner zones (1-2) were significantly more diverse than outer zones (4-5) and zone 3 was intermediate. The results for Simpson’s dominance (Figure 3.9d) were however less clear: only zone 4 was significantly different from inner zones, but also exhibited far more variability than any other zone. Zone 5 was not significantly different from inner zones, and so did not share the clustering trend observed by other diversity indices. No significant differences existed among zones for Shannon’s equitability (not shown).

Figure 3.10 compares species accumulation curves for each zone, before (A) and after (B) adjusting for sampling area. The rate of species accumulation was not consistent among zones and appeared to compliment the above trends in landscape diversity by partitioning zones into two clusters.
Species richness per sample was greater for inner zones and the rate of growth suggests more sampling effort is required to adequately characterize species richness in these zones. By contrast, species density per sample is lower for outer zones (4 & especially 5) and sampling effort appears to have sufficiently characterized richness. The area-adjusted curves highlight that unequal sampling effort likely underestimated species richness in the inner zones.

Figure 3.3 and Table 3.2 demonstrated that at the farm-scale, individual sites have very few shared species, suggesting that species compositional similarity is low among surveyed permaculture farms. Figure 3.11 however, suggests that community composition is ordered among zones. Zones 1 and 2 are most closely clustered, suggesting they share higher compositional similarity. Outer zones (4 & 5) exhibit lower compositional similarity to each other or to inner zones. Zone 3 is, as it is so often, intermediate. The details of these observations are further explored in Table 3.3. Of the 10 most frequently observed species among sites, Zone 1 and 2 share five: *Lactuca sativa* L., *Brassica* spp. L., *Beta vulgaris* L., *Tropaeolum* spp. L., and *Symphytum* spp L.. Generally, inner zones more frequently exhibit annual, herbaceous, vegetables and supporting companion plants. Zone 3 and 4 are characterized more frequently by perennial berries shrubs and fruit trees, including: *Rubus* spp. L., *Malus* spp. Mill, and *Prunus* spp. L. Zone 3 more frequently includes vegetables (i.e. *Solanum lycopersicum* L.) while Zone 4 more frequently includes native species (i.e. *Alnus rubra* Desf. ex Steud., *Pseudotsuga menziesii* (Mirb.) Franco, and *Polystichum munitum* (Kaulf.) C.Presl). Finally Zone 5 is almost entirely characterized by native and naturalized species including: *Thuja plicata* Donn, *Mahonia aquifolium* Nutt., and *Acer macrophyllum* Pursh.
Functional diversity

All zones were dominated by perennial species (Figure 3.12a) and perennial individuals (3.10b). The proportion of perennial species richness and abundance is significantly higher in outer zones (4 & especially 5), which are characterized almost exclusively by perennials.

In terms of growth form, Figure 3.13 demonstrates that inner zones (1-2) include a significantly greater proportion of herbaceous species than outer zones (4-5), while outer zones were characterized by significantly more tree species. No significant difference in the number of shrub species was observed among zones. Trends in relative abundance were less conclusive: the abundance of herbaceous plants was significantly higher for inner zones than zone 5, and significantly lower for shrubs in zone 1 relative to zone 5.
Figure 3.9. Boxplot diagram showing plant diversity by zone on 10 permaculture farms: (A) Species density, (B) abundance density, (C) Shannon entropy and (D) Simpson's dominance. Diversity indices calculated from vegetation surveys completed August 2016 in British Columbia, Canada. Plant species diversity compared among zones using one-way ANOVAs (n=10 sites), where transect data (two per zone per site) was pooled for species richness and abundance. Means not sharing the same letter are significantly different (Tukey HSD, P < 0.05). Diversity for the five zones frequently orders along a gradient but separates into only two significantly different clusters for all indices.
Figure 3. Comparison of species accumulation curves by zone for plant species (A) and adjusted for sample area (B) on 10 permaculture farms in British Columbia, Canada (August 2016). Species accumulation curves are sample-based using plant species incidence data from all transect samples per zone, irrespective of site (n=20 transect samples per zone). A: the number of newly discovered species per sample per zone, where one sample = 5 m$^2$ for zones 1-3 & 10 m$^2$ for zones 4-5. B: the number of newly discovered species per sample per zone adjusted for sampling area, where all samples = 10 m$^2$. Transects per site (n=2 transects) were pooled for zones 1-3, resulting in half as many 10 m$^2$ samples for inner zones.
Table 3.3 Abundance-ranked 10 most frequent plant species per zone on permaculture farms (n=10). Vegetation surveys were completed for 10 permaculture farms in the Vancouver Island – Coast region August 2016. (F) Frequency represents the number of sites containing at least one individual of the i-th species (n=10). (A) Abundance represents the sum of individuals of the i-th species observed per zone (n=1248, n2=1249, n3=489, n4=493, n5=310, n6=3789, where all transect samples for all 10 sites were pooled per zone (n=20 samples per zone).

<table>
<thead>
<tr>
<th>Species</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>F</td>
<td>A</td>
<td>F</td>
<td>A</td>
<td>F</td>
</tr>
<tr>
<td>Lactuca sativa L.</td>
<td>6</td>
<td>51</td>
<td>6</td>
<td>34</td>
<td>6</td>
</tr>
<tr>
<td>Helianthus annuus L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brassica spp. L.</td>
<td>6</td>
<td>29</td>
<td>5</td>
<td>34</td>
<td>4</td>
</tr>
<tr>
<td>Symphytum spp. L.</td>
<td>6</td>
<td>19</td>
<td>5</td>
<td>29</td>
<td>3</td>
</tr>
<tr>
<td>Solanum lycopersicum L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rubus armeniacus Focke</td>
<td>4</td>
<td>9</td>
<td>3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Prunus spp. L.</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Trifolium spp. L.</td>
<td>4</td>
<td>18</td>
<td>3</td>
<td>145</td>
<td>3</td>
</tr>
<tr>
<td>Petroselinum crispum (Mill.) Nyman</td>
<td>4</td>
<td>18</td>
<td>3</td>
<td>145</td>
<td>3</td>
</tr>
<tr>
<td>Vitis spp. L.</td>
<td>3</td>
<td>57</td>
<td>3</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>Phaseolus vulgaris L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calendula officinalis L.</td>
<td>3</td>
<td>56</td>
<td>3</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Fragraaria x ananassa L.</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Figure 3.11. Compositional dissimilarity of plant communities for 10 permaculture sites (A) and five permaculture zones (B) based on nonmetric multidimensional scaling (NMDS) ordination of plant species incidence. NMDS calculated from vegetation surveys completed in August 2016 for 10 permaculture farms in British Columbia, Canada. A: Compositional dissimilarity of sites based on abundance counts for species (n=10 sites). Sub-site samples (all transects regardless of zone) were pooled. B: Compositional dissimilarity of zones based on frequency counts for species among 10 sites (n=5 zones). All sub-zone samples were pooled (2 transects and 10 sites).
**Figure 3.1.** Boxplot diagram comparing the proportion of perennial species richness (A) and abundance (B) per zone on permaculture farms. Vegetation surveys were completed on 10 permaculture farms August 2016 in British Columbia, Canada. Zones compared using one-way ANOVAs (n=10 sites), where within zone transects (n=2 transects) were pooled per site. Means not sharing the same letter are significantly different (Tukey HSD, P < 0.05).

A: Perennial species accounted for over half of total species richness in all zones, but were significantly greater in outer (4 & 5) zones. Within zone perennial species were pooled per site.  

B: Abundance of perennial individuals mirrors results for species richness, and is also significantly greater in outer zones. Abundance refers to the number of individuals observed. Within zone perennial individuals were pooled per site.
Figure 3.13. Boxplot diagrams comparing the distribution of plant species (A) and individuals (B) among permaculture zones by growth form on permaculture farms (n=10 sites). Vegetation surveys were completed August 2016 in British Columbia, Canada. Calculated using one-way ANOVAs for 10 sites, where within zone transects (n=2 transects) were pooled per site. A: Distribution of plant species richness by growth form for permaculture zones (n=5 zones). B: Distribution of plant abundance by growth form for permaculture zones (n=5 zones), where abundance is the number of individuals.
**Discussion**

This study is the first we are aware of to systematically catalogue plant communities, including both species and functional diversity, on permaculture farms. Using these results, we aim to identify how permaculture compares and contrasts to a “typical” farm for the region. Secondly, this study asks if independent, self-identifying permaculture farmers consistently apply the permaculture practices of emphasizing polycultures, perennial species, and zone design. This information is expected to be useful in developing a baseline for future experimental and multisite assessments for the impacts of permaculture management on ecosystem services.

**Regional agricultural profile**

This study was completed in the Vancouver Island – Coast region (hereafter Vancouver Island) of British Columbia, Canada. Sites were surveyed between Victoria and Nanaimo, Denman Island, Hornby Island, and Gabriola Island. Farm areas are smaller here than on average for British Columbia and Canada, as shown in Table 3.4. Surveyed permaculture farms (n=10) are generally consistent with or a little smaller than regional trends: 60% of permaculture farms are less than 10 acres, and 40% are 10-69 acres. The largest surveyed permaculture site was 40 acres.

**Table 3.4. Farms classified by total farm area and region based on 2016 census data.**
*(Statistics Canada, 2017b).*

<table>
<thead>
<tr>
<th>Farm area</th>
<th>Canada</th>
<th>British Columbia</th>
<th>Vancouver Island - Coast</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 acres</td>
<td>13,193</td>
<td>5,487</td>
<td>1,311</td>
</tr>
<tr>
<td>10-69 acres</td>
<td>32,036</td>
<td>6,198</td>
<td>1,103</td>
</tr>
<tr>
<td>&gt;70 acres</td>
<td>148,263</td>
<td>5,843</td>
<td>372</td>
</tr>
<tr>
<td><strong>Total number</strong></td>
<td><strong>193,492</strong></td>
<td><strong>17,528</strong></td>
<td><strong>2,786</strong></td>
</tr>
</tbody>
</table>
Of the 2,786 farms in the Vancouver Island – Coast region recorded by the 2016 census, 857 (31%) reported growing fruits, berries or nut crops and 717 (26%) reported growing vegetable crops (Statistics Canada, 2017bde). By comparison, 100% of surveyed permaculture farms included both fruit, berries, or nuts and vegetable crops, indicating these are predictable features on permaculture farms. More permaculture farms reported cultivating fruit and berry crops specifically indicated by the 2016 census, than either all farms or fruit-reporting farms in the region (Figure 3.14). Apples and raspberries were especially favoured by permaculture farms, compared to the regional norm, occurring at all 10 permaculture sites. The popularity of fruit and berry crops among permaculture farms is consistent with the permaculture literature’s emphasis on perennial and climate-appropriate species (Mollison & Holmgren, 1978, p.65). Vegetable crops were also reported by a higher proportion of permaculture farms than by total farms in this region, though not higher than all vegetable farms (Figure 3.15). Permaculture farms appear to favour tomatoes, brassicas (cabbage and broccoli), beets, onions, lettuce, peppers and squash more so than other regional vegetable farms.

Hay and field crops are far less common in this region than for the remainder of British Columbia or Canada. Wheat, oats, barley, rye, and sunflowers were reported by only 1% of Vancouver Island farms, corn by 2%, potatoes by 5%, and canola and soybeans each by only 1 farm (Statistics Canada, 2017c). Hay and field crops were similarly sparse among Vancouver Island permaculture farms, although corn (30%), rapeseed (20%), potatoes (30%) and sunflowers (60%) were all higher. No wheat, oats, barley or soybean were recorded by permaculture site surveys. It is predicted that the low incidence of field crops in this region results from a combination of smaller farm acreages, climates favourable to fruit and vegetable production, and isolation from the mainland which may include limited commodity supply chains, although farmer motivations have not been explicitly quantified. The higher frequency of readily consumable field crops (potatoes, corn, and sunflowers) among permaculture farms is consistent with the literature’s emphasis for subsistence and low-energy products (Mollison, 1988, p.5).
Figure 3.14. Proportion of Vancouver Island – Coast farms cultivating select fruit, berry and nut crops by farm type. Permaculture: (n=10) based on vegetation surveys completed in the Vancouver Island – Coast region August 2016. Vancouver Island - All: (n=2786) the total number of farms reported by the 2016 census in the Vancouver Island-Coast region (Statistics Canada, 2017b). Vancouver Island - Fruit: (n=857) the total number of farms reported by the 2016 census in the Vancouver Island-Coast region cultivating fruits, berries, and nuts (Statistics Canada, 2017e).
Figure 3.15. Proportion of Vancouver Island – Coast farms cultivating select vegetable crops by farm type. Permaculture: (n=10) based on vegetation surveys completed in the Vancouver Island – Coast region August 2016. Vancouver Island - All: (n=2786) the total number of farms reported by the 2016 census in the Vancouver Island-Coast region (Statistics Canada, 2017b). Vancouver Island - Vegetable: (n=857) the total number of farms reported by the 2016 census in the Vancouver Island-Coast region cultivating vegetables (Statistics Canada, 2017d).
Figure 3.16. Proportion of Vancouver Island – Coast farms with livestock by farm type. Permaculture: (n=10) based on site visits completed in the Vancouver Island – Coast region August 2016. Vancouver Island - All: the proportion of all farms reported by the 2016 census in the Vancouver Island-Coast region (n=2786) keeping livestock (Statistics Canada, 2017a,b,f-k). *No data available for Vancouver Island farms for ducks or geese.
While this study is primarily concerned with plant communities, integrated livestock is considered a vital component of the permaculture system (Mollison & Holmgren, 1978, p.80-83), and 80% of the surveyed permaculture farms both cultivated crops and kept livestock (Figures 3.16 & 3.17). Many of these farms included more than one kind of livestock. Figure 3.16 demonstrates that, as with most crops, the proportion of permaculture farms keeping select livestock animals was greater than typical for the region (Statistics Canada, 2017afghijk). It cannot be discerned from census data how many farms in this region practice integrated livestock farming, however in another survey of six farms in the study area only 50% reported both crops and livestock (Dobb & MacNair, 2014). It is predicted from the low relative values for each of fruit, berries and nuts (31%), vegetables (26%), and livestock in Figures 3.14-16, that integrated livestock agriculture is more common among permaculture farms. Future research is needed to verify this.

Figure 3.17. Integrated livestock on permaculture farms: chickens foraging in a mixed species orchard. Photo by Sarah Hirschfeld.
Theory to practice: evaluating consistency

The adoption of permaculture provides an interesting case study in assessing the efficacy of grassroots networks and movements (Ferguson & Lovell, 2015). In contrast to organic agriculture (Government of Canada, 2016), there are no federally legislated standards or accredited certification bodies regulating permaculture in Canada. Permaculture Design Courses (PDCs) adhere to a well-established curriculum, however there is no formal requirement for permaculture farmers to have completed this or any other course. Because permaculture has a strong internet presence and many secondary authors (Ferguson & Lovell, 2014), individual adopters can easily and inexpensively access an extensive and multi-disciplinary library online or at any major bookstore. There is effectively no mechanism to ensure individuals claiming to practice permaculture do so in a manner consistent with the original literature (Mollison and Holmgren 1978; Mollison 1979; Mollison 1988; Mollison, 1991; Holmgren 2002) or even other adopters.

Guitart et al. (2015) were the first to evaluate consistency in permaculture application, and developed a ‘Permaculture Index’ to “cross-validate reported gardening philosophy with the actual gardening practices used”. This index includes 57 gardening practices, each assigned a positive (+1), neutral (0) or negative (-1) value based on their interpretations of permaculture philosophy. In surveying 50 community gardens in Australia, this study found that self-identifying permaculture gardens scored significantly higher Permaculture Index scores than non-permaculture gardens. While this pioneering effort is indisputably useful, the current index does not acknowledge that certain practices are emphasized in the literature more so than others. To better reflect permaculture theory, a second edition of the Permaculture Index could consider applying a weighting factor to the assigned value of each practice. In particular, the incorporation of polycultures, perennial species, and zone design likely deserve greater emphasis in the index. Where permaculture encourages practitioners to adapt most techniques to suit local site conditions, these three themes are permanent fixtures, repeated
enthusiastically in every primary permaculture text (Mollison & Holmgren, 1978; Mollison, 1979; Mollison, 1988). Our study is the first to quantify the scale of polyculture, perennial species and zone design application by independent, self-identifying permaculture farms. We found positive results for all three measures, suggesting that despite a lack of formal standards or government regulation, individuals interpret and apply permaculture with a high degree of consistency.

**Species diversity (polycultures)**

Diversity in “plant species, varieties, yield, microclimate and habitat” is considered a basic characteristic of permaculture (Mollison & Holmgren, 1978, p.6), and this study confirmed that individual permaculture adopters consistently applied this principle using plant polycultures. Spatial configurations for polycultures varied by farm, but intercropping most commonly occurred either in rows or as permaculture “guilds” (personal observation) (Figure 3.18). Contrary to the conventional ecological usage, in permaculture the term “guild” refers to a central element (a fruit tree for example) surrounded by supporting or secondary crops (Ferguson & Lovell, 2014; Mollison, 1988, p.60; Simberloff & Dayan, 1991). These observations demonstrate that permaculture polycultures represent true in-field diversity, rather than crop rotations or multiple single-crop fields.

Vegetation and especially crop species richness observed on permaculture farms in the Vancouver Island – Coast region was high compared to other agricultural surveys in Canada. Richness on permaculture farms ranged from 41 to 99 species per site, with a total of 255 species identified across 10 sites. By comparison, a survey including both organic and conventional farm sites in Ontario yielded a total of only 193 plant species across 30 sites (Boutin, Baril, & Martin, 2008). Species accumulation curves (Figure 3.4) indicate that sampling effort was insufficient and that these values underrepresent total species diversity. Furthermore, as only late summer emergent species were sampled, full season diversity is expected to much greater than reported here.
Figure 3.18. Common spatial configurations for in-field diversity on permaculture farms. A: intercropped rows. B: permaculture guild (centered around an apple tree). Photos by Sarah Hirschfeld.
Cultivated species richness (i.e. crops) on surveyed permaculture farms was significantly greater than for uncultivated species, with an average of 42 crop species per site (Figure 3.5). This signifies that the high plant diversity on permaculture farms is largely explained by cultivated polycultures and not merely inflated by the inclusion of hedgerows, set-asides, or weeds. In Boutin et al. (2008) only nine crop species were cultivated across all 30 sites while 193 native and exotic plant species were surveyed. More relevant to the study area, a survey of four farms in the Vancouver Island region yielded an average of only seven crop species per site (Dobb & MacNair, 2014). This data represents a subset taken from a larger study which surveyed 29 farms across six regions in British Columbia. Of the full dataset, only two farms produced greater than 13 crops, both of which were vegetable farms in the Thompson-Okanagan region. Census data for over 20 000 prairie farms (including British Columbia, Alberta, Saskatchewan, and Manitoba), likewise demonstrated lower crop diversification with an average of 4.12 crops per farm in 2002 (Bradshaw, Dolan, & Smit, 2004). Multisite surveys directly comparing plant communities between permaculture and non-permaculture farms in multiple regions is still needed. However, based on these limited datasets, crop diversity on Vancouver Island permaculture farms is estimated to be 5-10 times greater than average for this and other select regions in western Canada. This trend is consistent with permaculture theory, which encourages both high biodiversity and emphasizing species which directly service human needs for food, fuel and fibre (Mollison, 1979). Individual sites cultivated many rare species and shared a low number of species between sites. This specialization contributes to regional-scale ($\gamma$) diversification (Bradshaw et al., 2004).

The value of biodiversity for many ecosystem services is well established including: the provisioning of plant and crop products (Bonin & Tracy, 2012; Iverson et al., 2014; Quijas et al., 2010), crop protection from pests (Balvanera et al., 2006; Parker et al., 2016), erosion control and soil fertility (Crews et al., 2016), and pollination (Blaauw & Isaacs, 2014; Holzschuh, Dudenhöffer, & Tscharntke, 2012; Kremen & Gonigle, 2015). Future research is needed to quantify permaculture crop yields;
however it is predicted from the above trends that permaculture offers great potential in jointly satisfying production and ecosystem service enhancement goals. The application of multifunctional design in permaculture is particularly relevant; one example is the use of many flowering fruit and berry species, which jointly provide crop yields, pollinator resources, perennial root systems, and windbreaks (Figure 3.6).

Importantly, intercropping studies often consider much smaller species assemblages than are observed on permaculture farms: analyses of two-species interactions are frequent but studies rarely include more than 15 species (Blaauw & Isaacs, 2014; Bonin & Tracy, 2012; Parker et al., 2016; Thevathasan & Gordon, 2004a). As such, while current agronomic research largely supports that biodiversity enhances numerous ecosystem services (Hooper et al. 2005), the applicability of these finding to the large and complex plant communities observed on permaculture farms is unknown. For these reasons further observational research on active permaculture farms, and experimental research on much larger species assemblages, is strongly recommended.

Functional diversity (perennials, trees)

Permaculture was introduced in 1978 under the title: “A Perennial Agriculture for Human Settlements” (Mollison & Holmgren, 1978). The authors claimed that transitioning from a frequently disturbed, early-succession annual agriculture to a permanently covered perennial system would promote soil building and reduce habitat quality for invaders (Mollison, 1988, p.5 & 64). A perennial agriculture, where ecological succession is permitted and planned for, was predicted to produce a greater diversity of products while requiring less annual labour or energy (Mollison, 1988, p.5).

The strategic inclusion of perennial species in agricultural landscapes has since then been shown to benefit many ecosystem services including: hydrologic regulation and water quality, soil quality and nutrient cycling, biotic regulation (including pollination and pest control), climate regulation and climate
change mitigation (Asbjornsen et al., 2013). Perennial grain breeding projects currently underway on wheat, rice, sorghum, and oilseeds are likewise motivated by the ecosystem benefits received in a mid-succession seres (Crews et al., 2016). Perennial species accounted for over 60% of both species richness and abundance, indicating that individual adopters are consistently applying this permaculture practice.

In looking at the community composition, perennial species are largely accounted for by fruits, berries, and nut crops (especially Malus spp. Mill, Rubus spp. L., Prunus spp. L., Ribes spp. L., Fragaria spp. L., Vitis spp. L., and Corylus avellane L.) and native species (especially Alnus rubra Desf. ex Steud., Pseudotsuga menziesii (Mirb.) Franco, Acer spp Pursh., Mahonia aquifolium Nutt., and Thuja plicata Donn). Many farmers also consciously included perennial forms of annual crops: examples include perennialized cress, leeks, and nasturtium. Importantly, all surveyed farms included a combination of annual and perennial species. Likewise, all farms included a diversity of growth forms. The proportion of trees was lower than predicted, given that permaculture is described as a “system dominated by trees” (Mollison & Holmgren, 1978, p. 29), however combined trees and shrubs accounted for nearly half of species richness. More importantly, it is believed that the sampling procedure was biased towards herbaceous growth forms. Sample areas were 5 or 10m²: this rarely included more than two mature trees given the additional space required by these individuals. By contrast, 5m² plots occasionally yielded over 80 herbaceous individuals. As such, the conclusion that herbaceous growth forms exceeded shrubs and trees more likely reflects acceptable planting densities rather than a lack of adherence to permaculture philosophy. Furthermore, the relative area of each zone on the farm was not measured. Uncultivated areas (zone 5), as well as extensively cultivated orchards and wood lots (zones 3 and 4), contained a much higher proportion of trees and often covered larger areas than intensively cultivated inner zones (personal observation). It is predicted that weighting samples by relative zone area would greatly increase (and more accurately represent) the proportion perennial shrubs and trees.
**Landscape diversity (zone design)**

Permaculture would have all agroecosystems include “a mix of forest, clearing, hedgerow, field, woodland and intensive crop cultivation” (Mollison & Holmgren, 1978, p. 41). The configuration of this landscape diversity is carefully prescribed by five management “zones”, a design feature unique to permaculture. This portion of the study was interested firstly in whether zone design on permaculture farms consistently resulted in five separate plant communities, and secondly whether the composition of these communities agreed with the literature’s prescriptions (see Table 2.1).

Commitment to zone design varied among surveyed sites. Some farmers had detailed formal master plans as shown in Figure 3.19. Other farmers could identify differently managed areas and assign zones but were less confident in their legitimacy (personal communications).

Our results support that zones contained compositionally distinct plant assemblages. Firstly, Shannon entropy was higher (and correspondingly Simpson dominance was lower) at the farm-scale than for any individual zone. This suggests that in addition to within zone diversity (α-diversity), heterogeneity between zones (B-diversity) greatly contributed to total farm-scale diversity. Multiple diversity measures ordered zones along a gradient, but also into clusters. Most commonly, zones were clustered as inner (1 & 2) and outer (4 & 5) (Figure 3.9). The NMDS ordination (Figure 3.11) closely clustered zones 1 and 2, but not zones 3, 4 and 5, suggesting these zones were compositionally dissimilar. By contrast, species accumulation curves (Figure 3.10), clustered zones 2 and 3 but indicated that zones 1, 4, and 5 were largely independent. Taken together these findings support that independent adopters are effectively applying zone design resulting in landscapes with at least two, but possibly five, significantly distinct plant communities. In other words, permaculture farms are not merely polycultures, but rather consistently include multiple unique polycultures.

The gradient observed is compatible with theoretical zone arrangement: permaculture management zones are frequently visualized (as in Figure 3.20) as concentric circles of decreasing
cultivation intensity outwards from the centre. In practice, zones are positioned to best make use of site conditions and characteristics (as in Figure 3.19), but the zone numbering system reflects this theoretical layout. Overall, individual interpretations and applications of zone design were consistent with permaculture theory (Mollison & Holmgren, 1978, p.53-56; Mollison, 1979, p. 10; Mollison, 2002).

Zone 1 is the innermost and most intensively cultivated management zone, and should include: vegetable and herb gardens, rare and delicate species, propagation and seedlings, and greenhouses. In practice, the most frequently observed species for zone 1 were annual, herbaceous vegetables (lettuce, brassicas, beets and peas) and culinary herbs (oregano and parsley). Most sites had both greenhouses and nurseries for propagation or delicate species (Figure 3.21). Some interesting rare species observed in zone 1 greenhouses included bananas, oranges, lemons, and kiwi. Notable rare herbs in zone 1 included curry, mugwort, and hyssop.

Zone 2 is described in the literature as intensively cultivated, and includes: main crop beds, dense herbaceous layer and understorey, small fruits and domestic orchards. The minor distinction between “vegetable gardens” in zone 1 and “main crop beds” in zone 2 may explain the high degree of compositional overlap observed (especially brassicas, lettuce and beets). Regardless, zone 2 appeared more dedicated to small commercial crops (Figure 3.22). Common crop species included tomatoes, beans, and sunflowers. Small fruits and domestic orchard species were less frequent but some observed in zone 2 included: raspberries, blueberries, grapes, nectarines, and plums.

Zone 3 is designated for main commercial crops, but focuses on hardy and low maintenance trees. This zone was dominated by fruits and berries, especially: apples, plums, raspberries, blackberries, strawberries, currants, and sea buckthorn (Figure 3.23). Many farms included at least one nut species such as hazelnut, walnut, chestnut and heartnut. These were not exclusive to zone 3 but were often intercropped with fruit orchards.
Zone 4 is predicted to border on forest or wilderness and activities include foraging, pasture, timber and forestry. The observed composition of zone 4 supports this prescription, containing a mix of: perennial hardy crops (apples and hazelnut), uncultivated edge species (especially wild blackberry, Red alder, Douglas fir, and ferns), and open pasture (Figure 3.24).

Zone 5 was most obviously consistent with permaculture theory: on every surveyed farm zone 5 was entirely uncultivated, though occasionally used for timber, wild gathering, recreation or hunting. Zone 5 was characterized by common native and naturalized species for the Vancouver Island region including: Western red cedar, Big-leaf maple, Oregon grape, Grand fir, and Douglas fir (Figure 3.25).

Proximity to, or inclusion of, natural areas on farms has been recommended by multiple authors towards achieving better ecosystem service provision and conservation (Kremen, 2015; Tscharntke et al. 2005; Garibaldi et al., 2011). However, in the last five years Canadian agricultural landscapes have been characterized by an increase in the total number of acres in crops with a corresponding decline in the number of farms and the number of total acres dedicated to natural pasture land, woodland and wetlands (Statistics Canada, 2017b,l). Fewer than half of all farms in the Vancouver Island – Coast region reported dedicating land use to natural or semi-natural areas on the 2016 census (Figure 3.26). This indicates that permaculture farms in this region are above average, as 100% of surveyed farms included natural areas. Permaculture thus appears to be a promising management strategy for enhancing landscape mosaics (as per Kremen, 2015.)

While farmers often adapted to suit local site conditions and production demands, this study provides substantive evidence that individual adopters interpret and apply permaculture zone design theory in a consistent fashion. Furthermore, when species and functional diversities were characterized at multiple spatial scales, the adoption of zone design contributed to increased landscape diversity on permaculture farms.
Figure 3.19. Example of permaculture master plan and zone design. Provided by one of the surveyed sites.

Figure 3.20. Typical visualization of a permaculture zone layout. The five permaculture zones are typically described as concentric circles with zone 1 as the innermost (most intensively cultivated) ring and zone 5 as the outermost (uncultivated) ring. In practice, this configuration is modified to suit local site conditions. Image from: Organic Buyers Group (n.d.).
This zone included the most intensive cultivation, including green houses, propagation and seedlings, and rare and delicate species. It was typically closest to the central structure (house or barn) on the farm. Photos by Sarah Hirschfeld.
Figure 3.22. Photos of Zone 2 on permaculture farms. Zone 2 is typically characterized by intensive cultivation, main crop beds, dense and complex herb and understory layers, including small fruit. Photos by Sarah Hirschfeld.
Figure 3.23. Photos of Zone 3 on permaculture farms. Zone 3 included broad-scale and hardy farming systems, main commercial crops, and natural or little pruned trees, especially nuts. Photos by Sarah Hirschfeld.
Figure 3.24. Photos of Zone 4 on permaculture farms. Zone 4 activities include extensive forage, pasture, range, timber, forestry and wild gathering. It typically bordered on forest or wilderness. Photos by Sarah Hirschfeld.
Figure 3.25. Photos of Zone 5 on permaculture farms. Zone 5 was typically natural and unmanaged, with occasional foraging, recreation, timber and hunting activity. Photos by Sarah Hirschfeld.
Figure 3.26 Comparison of select agricultural land uses for different regions in Canada. Adapted from 2016 census data (Statistics Canada, 2017b,l). Bars represent the number of farms reporting a given land use, as the proportion of all farms reported in that region in 2016, with standard error bars calculated in MS Excel. Trends are similar for Canada, British Columbia, and the Vancouver Island-Coast region: natural or semi-natural land uses (pastures, woodland, wetlands, or Christmas trees) are reported by only 34-50% of farms.
**Conclusions**

This study demonstrated that self-identifying farmers consistently applied the permaculture principles of polycultures, perennial species, and zone design. As predicted, these practices resulted in high species, functional and landscape diversities on surveyed permaculture farms. Most observed species were limited to only one or two sites, and no site or zone was dominated by a single species. All sites contained uncultivated species and natural space, however the majority of species richness was explained by cultivated crops. Perennial species accounted for a greater proportion of species richness, especially in outer zones. Permaculture zones represented five compositionally distinct plant communities, resulting in high landscape-scale species diversity for these farms. Individual zone plant assemblages demonstrated predictable trends which were consistent with permaculture design prescriptions. Fruits, berries, and vegetables were observed across all sites, making these crops more common among permaculture farms than was typical for the region. Similarly, the inclusion of natural or semi-natural land uses was more common among permaculture farms. This characterization indicates that permaculture farms can be described as perennialized agroecosystems containing multiple, diverse polycultures.
Chapter 4

General discussion

In previous chapters we established two important trends. Firstly, that diversity in species, function and landscape benefit a range of ecosystem services including provisioning, regulating and supporting. Secondly, that independent, self-identifying permaculture farmers consistently apply the permaculture management practices of polycultures, perennial species, and zone design. These practices are expected to contribute to species, functional and landscape diversities, and therefore it is predicted that permaculture management can benefit multiple ecosystem services. The services most likely impacted by permaculture include: provisioning of diverse crop products, reduced soil erosion, enhanced soil porosity and hydrologic regulation, diversity and functioning of below-ground biota, climate mitigation, microclimate regulation, reduced crop loss to pests, wildlife conservation, and pollination. As other authors have repeatedly pointed out, these benefits are probable but require validation, and preferably multisite systematic evaluation (Ferguson & Lovell, 2014; Hathaway, 2015; Guitart et al., 2015). In this chapter, we will discuss some of the opportunities and constraints towards completing this necessary research. The chapter will conclude with recommendations for future permaculture applications.

Permaculture research: challenges and opportunities

Permaculture credibility has been greatly hindered by a lack of peer-reviewed, empirical, agronomic research (Ferguson & Lovell, 2014; Guitart et al., 2015). However, as interest in the topic increases, researchers will find that permaculture agronomic studies can be particularly difficult to
design and perform. Key challenges include permaculture definitions, experimental design, and data collection. On the other hand, many opportunities for observational research are available.

Initially, this study struggled to establish a working definition of permaculture which could be used to differentiate and compare permaculture farms to other types, such as organic or conventional. Permaculture has a well-established curriculum, but it reads more like a Mary Poppins’s bag of best management practices and ethics, rather than a concrete definition. We found however, that self-identifying farmers were very consistent in their application of key permaculture principles, namely polycultures, perennial species and zone design. Additional key characteristics in theory and practice were the inclusion of uncultivated or natural space, organic or chemical-free management, small-scale farm acreages, and minimized use of large machinery\(^5\) (personal observation). Integrated livestock was common but not universal. This suggests that for observational studies, researchers who are familiar with permaculture theory can be reasonably confident in identifying permaculture farms based on farmer interviews and ground-truthing of these characteristics. Researchers are further encouraged to use and adapt the Permaculture Index developed by Guitart et al., (2015), to cross-validate farm practices against philosophy. As outlined in Chapter 3, the Permaculture Index is a useful but imperfect tool, and should be used in combination with site visits and best judgement.

Given the lack of precise definition, our study chose to use an observational rather than experimental approach to characterize permaculture farms and investigate their potential ability to deliver ecosystem services. The initial concern was whether experimentally established farm plots could accurately represent authentic permaculture. Now that baseline garden management practices (Guitart et al., 2015) and plant communities (this study) have been characterized, experimental research studies are more accessible. Future researchers are strongly cautioned however that given the emphasis on site specific adaptation, experimental research with carefully controlled variables may be representative of

\(^5\) Excluding initial earth works such as construction of swales, terraces, and keyline ploughing.
or relevant to only a small subset of applied permaculture farms. One important example is uncultivated species tolerance: this study observed that while some sites meticulously removed weeds, many permitted or even harvested them. A second example is earthworks: permaculture literature strongly encourages farmers to establish swales or keyline ploughing for hydrologic regulation (Mollison, 1979, p. 29), however this is far from universally adopted. Experimental studies require researchers to decide which variables they are going to control and with so few empirical baselines available this process is very likely to bias results. We propose that observational research remains a more appropriate and useful approach for the time being.

One advantage in using observational designs, is the large number of existing permaculture projects in Canada and internationally. Based on the WWOOF Canada website, at least 200 member farms currently list permaculture as a key feature in this country (Figure 3.1) (WWOOF Canada, 2017). An international online survey by the Permaculture Association identified permaculture projects in 51 countries (Schmidt, 2012). Canadian responses represented only 3%, while many more permaculture projects were reported in Australia, Belgium, France, Germany, the United Kingdom, and the United States. Permaculture projects were also reported in South America, Asia, and Africa. This demonstrates the scale of available potential for observational permaculture studies. The authors of this survey further highlighted that internationally, 410 known organizations, including 30 universities, participate in permaculture research. This indicates that there should be many opportunities for researchers to collaborate.

Another advantage of observational studies is the ability to control for temporal scales. Early permaculture literature emphasizes that the transition to permaculture, and therefore the productivity and other ecosystem service benefits attributed to perennial species and natural succession, take time (Mollison, 1988, p.4). This observation is echoed by contemporary academic studies. One study on perennial prairie forage found that yields were low in the establishing year but increased by 2.5 times by
year four (Bonin & Tracy, 2012). Furthermore, this study found that forage biomass in year four was lower for monocultures, and weed biomass higher, compared to polycultures and to earlier years. Similarly, indicators of crop pollination (including percentage fruit set and berry weight) were significantly greater 3-4 years post establishment (Blaauw & Isaacs, 2014). These examples support the permaculture claim that temporal scale is a significant factor, and highlight the need to account for establishment date when conducting permaculture research. Future research considering the effects of permaculture on ecosystem services would do well to compare permaculture sites by, for example: less than 5 years, 5-10 years, 10-15 years, and greater than 15 years. Studies which do not control for establishment timelines are predicted to observe more inconsistent or ambiguous ecosystem impacts.

As a plant community characterization study, we experienced challenges specific to vegetation sampling, including: diversity, density, configuration, and identification. Chief among these was that due to the very high diversity of plant species on permaculture farms, including rare species and varieties, sampling can be an especially time-consuming process. Sampling effort thus becomes a logistical trade-off between diversity and density of species versus sampling area. This compromise was alluded to in Chapter 3: inner zones were typically characterized by very dense and diverse assemblages of small herbs, while outer zones contained fewer, larger individuals per unit area. Consequently, sampling area needed to be expanded from two 5x1 to two 10x1 metres long transects in outer zones to more fairly represent the lower planting density. Inner zones, especially zone 1, often consisted of small disconnected patches (such as raised beds or greenhouses) which could not accommodate 10m transects. Additionally, sampling 5m transects in inner zones usually took much longer than the 10m transects in outer zones; as such sampling area is not a strong indicator of sampling effort on permaculture farms. Based on the species accumulation curves (Figure 3.10) however, expanding sampling area to a total of 20m² per zone is predicted to provide a more representative species richness index and is the minimum sampling area recommended. This will most likely be accomplished through
additional short transects. Alternatively, using differently sized transects or quadrats for each growth habit or canopy layer might be more appropriate. Configuration was another challenge when sampling permaculture vegetation. Plantings were often concentrated within zones, such as in raised beds, gardens, or orchards. This study was interested in comparing species richness and evenness among zones, and so transects were placed strategically to best represent this diversity. While randomization is generally preferred for statistical analysis, this is predicted to severely underestimate richness on a permaculture farm unless sampling effort and area is greatly increased. A final practical consideration for larger-scale permaculture studies, is the diversity of species present. This includes many rare agronomic varieties, as well as native and naturalized species. If sampling effort is expanded, it is critical that data collectors have strong plant identification skills or are assisted directly by the farm manager, in order to make accurate assessments.

Future permaculture applications

Implementing permaculture requires a significant paradigm shift. Permaculture tasks adopters to plan according to longer time-scales, to design each element to yield multiple functions, and to fully integrate ethics into agriculture. This may be an immediately uncomfortable proposition; however, it is helpful to remember that the current industrial or “conventional” system of agriculture is both relatively recent and that its reliance on external inputs and subsidies is inherently limiting. It is unrealistic, and contrary to the spirit of permaculture, to expect a permaculture system to match current industrial yields of corn for animal feed and biofuel. However, there is a range of scenarios where permaculture may be a more productive and practical option than the current North American model of agribusiness. Key examples are low-income smallholders, low-income urban residents, remote communities, and particularly remote communities in challenging climates. For these groups, the varieties and machinery popular in industrial agriculture can be economically or geographically inaccessible, and environmental
and social consequences unacceptable. While considerable reductions in the proportion of food insecure people globally have been observed since 1990 (13.4%), notable exceptions to this trend are countries facing “natural and human-induced disasters or political instability” (FAO, 2017). Insecurity in these countries is often aggravated by disrupted access to food even when it is available. In developed countries, urban agriculture has been recommended to address inner-city “food deserts” (Lovell, 2010).

This study (Chapter 3) has demonstrated that a high density of diverse crop species can be grown using permaculture (Figure 4.1). As such it is recommended that future permaculture applications firstly target local self-sufficiency projects, particularly in situations where industrial agriculture is impractical, inaccessible, or undesirable. Future research should monitor and evaluate these and existing permaculture projects for contributions to ecosystem services, yields, and nutritional values. From here, successful case studies and empirical research may provide the necessary evidence directing contemporary agriculture towards the most viable pathway.

![Figure 4.1. High-density and diversity of yields provided by permaculture farming.](image)

Visible yields include Asian pear, rosehips, blackberries, leaves for mulch and livestock forage, shade, windbreak, and wood. Ecosystem service benefits predicted to result from perennial polycultures. Photo by Sarah Hirschfeld.
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