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Agroforestry systems in Sweden: niche innovations for multifunctional landscapes

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Agroforestry systems in Sweden: niche innovations for multifunctional landscapes

Abstract

Monocultural land-use systems, narrowly focused on production, need transformation toward practices that recognise and integrate multiple benefits. Agroforestry systems (AFS) – the deliberate integration of trees, crops, and/or livestock – offer such a model by linking agriculture and forestry while delivering environmental, economic, and social advantages.

This thesis aims to enhance understanding of AFS by: (i) analysing their benefits across agricultural, forested, and urban contexts using an ecosystem services framework; (ii) exploring farmers' motivations, perceptions, and challenges in practising agroforestry; and (iii) examining transitions from conventional land use to multifunctional AFS through the lens of niche innovation with real world examples on transitions.

Empirical material from 19 case studies across Sweden was gathered through participatory approaches, focus groups, semi-structured interviews, and conceptual analysis. Four main AFS types were identified: silvopasture, silvoarable systems, forest farming, and forest gardens. Multifunctionality was primarily driven by farmers' intentions to combine production with landscape stewardship, linking food and material provision to ecological and cultural benefits.

The study revealed that agroforestry in Sweden largely develops within experimental and adaptive niches – spaces where innovative practices, knowledge exchange, and farmer collaboration foster new forms of land stewardship. Niche innovations included novel silvopastoral and alley-cropping designs, diversified forest-farming models, the establishment of 12 novel temperate forest gardens, in addition one forest garden which integrates high-quality timber production with food.

The thesis advances knowledge of agroforestry as a multifunctional and evolving land-use practice, demonstrating how grassroots niche innovations contribute to resilience, diversification, and sustainable rural and urban transitions.

Keywords: agroforestry systems, silvopasture, silvoarable, forest farming, forest garden, temperate agroforestry, participatory approach, farmer´s perspectives, multifunctional land-use, niche-innovation

Agroforestry-system i Sverige: nischinnovationer för mångfunktionella landskap

Abstract

Dagens dominerande monokulturella markanvändning, med snävt fokus på hög produktion av oftast en produkt, behöver förändras till att istället omfatta fler nyttor och funktioner Agroforestrysystem (AFS) – integreringen av träd, grödor och/eller boskap- är en sådan modell som förenar jord- och skogsbruk samtidigt som systemen bidrar en rad miljörelaterade, ekonomiska och sociala funktioner och värden.

Denna avhandling syftar till att öka förståelsen för AFS genom att (i) dokumentera och analysera deras nyttor inom jordbruk, skogsbruk och stadsmiljöer med hjälp av ett ekosystemtjänstramverk, (ii) undersöka lantbrukares perspektiv på, motivation till, och utmaningar med agroforestry i praktiken, och (iii) undersöka omställning till mångfunktionell agroforestry genom att analysera AF-nischinnovationer.

Empiriskt material bygger på 19 fallstudier av lantbruk genom dels en deltagardriven forskningsansats, samt genom fokusgrupper, semistrukturerade intervjuer och konceptuell analys. Fyra huvudtyper av AFS – silvopastorala och silvoarabla system, skogsodling samt skogsträdgårdsodling – ingår i studien. Mångfunktionaliteten härrörde främst ur jordbrukarnas avsikt att kombinera produktion med landskapsförvaltning, och att livsmedels- och annan materialförsörjning kopplades till fler ekologiska och sociala funktioner. Nischinnovationerna inbegrep nya former av silvopastorala system, alléodlingssystem, nya modeller av skogsodling, etablering av 12 nya skogsträdgårdar, samt en skogsträdgård med fokus på högkvalitativ timmerproduktion integrerad med produktion av perenna grödor.

Avhandlingen bidrar till att öka kunskapen om agroforestry som mångfunktionell markanvändning i Sverige och ger insikter om dess potential att öka resiliens på olika nivåer, diversifiera produktionen och stödja övergångar mot ökad hållbarhet på landsbygden och i städerna.

Nyckelord: agroforestrysystem, silvopastorala system, silvoarabla system, skogsodling, skogsträdgård, agroforestry i tempererade områden, deltagardriven forskning, lantbrukarperspektiv, mångfunktionell markanvändning, nischinnovation

Dedication

Till min mamma Maj-Lis som väckte min lust att läsa böcker och som dessutom – genom ett livslångt samtal om kunskaper, förhållningssätt, och livet förr i tiden i en åländsk skärgårdsby – gett mig insikter om resursförvaltning, samarbete och strävan efter vad som idag kallas för att leva hållbart.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. A Björklund, J., Eksvärd, K., & **Schaffer, C**. (2019) Exploring the potential of edible forest gardens: experiences from a participatory action research project in Sweden. *AgroforestrySystems*, 1-12. https://doi.org/10.1007/s10457-018-0208-8

II. **Schaffer, C**., Eksvärd, K., & Björklund, J. (2019). Can Agroforestry Grow beyond Its Niche and Contribute to a Transition towards Sustainable Agriculture in Sweden?. *Sustainability*, *11*(13), 3522. https://www.mdpi.com/2071-1050/11/13/3522

III. **Schaffer, C**. Elbakidze, M., & Björklund, J. (2024). Motivation and perception of farmers on the benefits and challenges of agroforestry in Sweden (Northern Europe). Agroforestry Systems, 98(4), 939-958. https://doi.org/10.1007/s10457-024-00964-1

IV. Stoltz, J., & **Schaffer, C**. (2018). Salutogenic Affordances and Sustainability: Multiple Benefits with Edible Forest Gardens in Urban Green Spaces. *Frontiers in Psychology*, *9*, 2344 doi: 10.3389/fpsyg.2018.02344

During this doctorate study, Christina Schaffer also contributed to the following papers of relevance not included in the thesis:

I. Bennich, T., Maneas, G., Maniatakou, S., Piemontese, L., Schaffer, C., Schellens, M., & Österlin, C. (2022). Transdisciplinary research for sustainability: scoping for project potential. International Social Science Journal, 72(246), 1087-1104.

II. Focacci, M., Schaffer, C., de Meo, I., Paletto, A., & Salbitano, F. (2025). Exploration of the functions and potentials of urban forest gardens in Sweden. *Urban Forestry & Urban Greening*, 128990.

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Abbreviations

AFS	Agroforestry systems
AF	Agroforestry
AFTA	The Association for Temperate Agroforestry
CAP	Common Agricultural Policy
CCF	Continuous cover forestry
CP	The Ecosystem Service Coding Protocol
ES	Ecosystem services
EURAF	The European Agroforestry Federation
ICRAF	The Center for International Forestry Research and World Agroforestry
IPBES	The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
LER	Land Equivalent Ratio
LERM	Land Equivalent Ratio for Multifunctionality
LUCAS	Land Use Land Cover
MA	Millennium Ecosystem Assessment
MLP	Multi-level perspective
MSB	Swedish Civil Contingencies Agency
NCP	Nature's contributions to people
NGO	Non-governmental organisation
PAR	Participatory action research
PES	Payment for ecosystem services
PSD	Perceived Sensory Dimensions
RDP	Rural Development Program

SDG	UN Sustainable Development Goals
SES	Social-ecological systems
TDR	Transdisciplinary research

Introduction

1.1 Setting the scene

Farming and forestry are pillars of global sustainability, yet both are constrained by dominant, input-intensive models that prioritise single outputs. Extensive monocultures often drive biodiversity loss, degrade soils, and heighten vulnerability to climate change, while resource inefficiencies, social inequities, and policy misalignments further erode resilience (e.g., Reid, 2005; Foley, 2005, 2011; IPBES, 2018; World Inequality Report, 2022; Santiago-Freijanes et al., 2021). Addressing these challenges requires land-use systems that jointly advance biodiversity, viable livelihoods, and human well-being.

This thesis examines agroforestry - landscapes that integrate trees with crops and, in some cases, livestock – as a transformative approach to these shared challenges. Agroforestry systems (AFS) harness ecological synergies, offering multifunctional solutions that can enhance biodiversity, sequester carbon, improve soil health, and support diversified livelihoods. Since the 1990s, agroforestry has matured into a multifunctional landscape approach (van Noordwijk et al., 2018), and empirical research demonstrates its capacity to deliver multiple benefits for human well-being (e.g., Jose, 2009; McAdam et al., 2009; Plieninger et al., 2015; García de Jalón et al., 2018; Torralba et al., 2018; Kay et al., 2019; Castle et al., 2022).

Despite this evidence, agroforestry remains underutilised in Europe. Barriers include gaps in knowledge about ecological, economic, and sociocultural performance; contradictions and blind spots in policy; and managerial complexity. This thesis contributes to closing these gaps by bridging traditional and innovative practices to inform policy and land-management strategies. It investigates AFS established by pioneering farmers and foresters in Sweden, foregrounding their perspectives on opportunities and challenges.

The study focuses on the multifunctionality of AFS in Sweden as a case in the Nordic region, across arable, forested, and urban contexts. As McAdam (2009) notes, a central challenge in managing multifunctional AFS lies in the skills and knowledge of managers. Accordingly, this research explores management models in AFS adopted by pioneers in Sweden and the competencies required to sustain them.

A recent synthesis of biosphere research integrating ecology, sociology, and economics identifies eight pressing sustainability themes: climate-resilient forest landscapes; declining soil fertility and erosion; toxic and plastic pollution in remote ecosystems; water scarcity and ecosystem degradation; biodiversity collapse and ecological homogenisation; unsustainable food systems; displacement of Indigenous stewardship and knowledge; and threats to coastal ecosystems and seashores (Bohn et al., 2025). Agroforestry has credible potential to contribute to seven of these eight themes – coastal systems being the exception – for example, by integrating nature conservation with productive land use, enhancing climate-resiliency and supporting equitable livelihoods. Authored by 35 researchers, the review also underscores the need for interdisciplinary, integrative approaches – an orientation this thesis adopts.

1.2 Definitions

Agroforestry is a practice across both temperate and tropical regions and has been defined by various organisations according to their geographical and ecological focus. World Agroforestry (ICRAF), which primarily operates in tropical areas of the Global South, defined agroforestry until recently as "agriculture with trees" (Nair, 2021, p 23). The Association for Temperate Agroforestry (AFTA), based in North America, describes it as "an intensive land management system that optimises benefits from the biological interactions created when trees and/or shrubs are intentionally combined with crops and/or livestock" (AFTA, 2023). Similarly, the European AGFORWARD project defines agroforestry as "the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from resulting ecological and economic interactions" (Burgess and Rosati, 2018).

In this thesis, I adopt the definition by Nair (2021, p 24) "the purposeful growing or deliberate retention of trees with crops and/or animals interacting combinations for multiple products or benefits from the same management unit" This broad definition covers all types of AFS in Europe and can be applied across arable land, pastures, forests, and even urban contexts (Nair, 2021).

Agroforestry serves as an interface between agriculture and forestry (McAdam et al., 2009; van Noordwijk, 2021). AFS typically consist of four key components: (i) trees and shrubs (woody elements), (ii) crops (annual or perennial), sometimes (iii) domesticated animals, and (iv) farmers and foresters, who act as co-creators and designers of these systems (Nair, 2021; Mosquera-Losada et al., 2023). In Sweden, most producers combine farming with forestry. However, for simplicity, I refer to them collectively as "farmers" throughout the thesis (although the Swedish term lantbrukare more accurately captures both roles). Farmers and their practices are essential, making AFS inherently social-ecological systems (SES), where social and ecological dimensions are deeply interconnected (Folke & Berkes, 1998; Biggs et al., 2022).

Figure 1. The four components in agroforestry systems trees, crops, livestock in a continuum, together with humans, here farmers and foresters, as co-creators of several types of AFS. Inspired by Nair (2021). Illustration by Sophie Trygger.

SES are often complex and non-linear. Human interaction with nature now pervades the entire biosphere, to the extent that the term Anthropocene – coined by Paul Crutzen – has been proposed to describe this new epoch

(Crutzen, 2002; Steffen et al., 2007). While many forms of forestry and agriculture can be understood as SES, agroforestry is distinctive in its highly direct, site-specific integration of human and natural systems, occurring on farms and in forests embedded within broader landscapes. Sustained through history, these interactions have produced diverse AFS, which may also be understood as forms of biocultural heritage (Barthel et al., 2013; Eriksson, 2018).

AFS vary greatly in their diversity. Some, such as homegardens, support hundreds of species, including a rich mix of trees, shrubs, and crops (Sharma et al., 2022; Moereels et al., 2024). Others, such as alley cropping, may involve only two species – typically an annual crop and a tree planted in rows (McAdam et al., 2009; Lovell et al., 2018). As Nair et al. (2021, p. 24) observe, the essence of all AFS lies in “the purposeful growing or deliberate retention of trees with crops and/or animals in interacting combinations for multiple products or benefits from the same management unit.” Most systems are intentionally designed to harness beneficial ecological interactions (Jose, 2012).

Pasturing in woodlands is among the oldest agricultural practices worldwide (Eichhorn et al., 2006; Plieninger et al., 2015a; Smith et al., 2012; Nerlich et al., 2013). Although ancient, the term “agroforestry” was only formalised in 1977 by ICRAF, marking the institutionalisation and global research recognition of agroforestry (van Noordwijk et al., 2018; Nair et al., 2021).

In Europe, farmers have long engaged with forests, with evidence of AFS in Spain dating back to 2500 BC (Eichhorn et al., 2006). Silvopastoral systems have historically been dominant, involving livestock grazing in forests or on agricultural land (Herzog, 1998; Montagnini and Nair, 2004). Silvoarable systems also developed, combining the cultivation of nuts, fruits, or berries – sometimes with livestock – with hedgerows, windbreaks, or alley cropping (Herzog, 1998; Nerlich et al., 2013).

Many traditional European AFS hold cultural and historical significance, such as dehesa in Spain, montado in Portugal, bocage hedgerows in France and the UK, Alpine transhumance, summer farms in Sweden, and systems involving pollarding for hay and orchards, such as pré-verger in France and Straubst in Germany (McAdam et al., 2009; Nerlich et al., 2013; Plieninger et al., 2015a; Plieninger et al., 2019; Rolo et al., 2020). In Sweden, silvopastoral practices date back at least 2,500 years, when forests were cleared for grazing domesticated animals kept collectively in the outlands (Dahlström et al., 2006; Kumm and Hessle, 2023). Forests also provided hunting, firewood, and construction materials, while fencing developed to protect infields from livestock (Boserup, 1973; Ekstam and Forshed, 2000).

Much of the knowledge base for agroforestry, however, originates from tropical regions (Castel et al 2022; Quandt et al., 2023) where it plays a central role in supporting production on limited land (Smith et al., 2012). Tropical AFS are highly multifunctional, contributing to poverty alleviation, food security, biodiversity conservation, soil quality improvement, and climate adaptation (Jose, 2009; Sharma et al., 2022; van Noordwijk et al., 2018). While agroforestry in both the Global North and South offers environmental benefits, the motivations differ. In the Global South, agroforestry addresses food security and poverty alleviation, whereas in the Global North it focuses on environmental protection, such as soil and water conservation (Graves et al., 2009; Lorenz and Lal, 2014; Lovell et al., 2018). Against the backdrop of climate change, agroforestry has gained global relevance for its role in both carbon sequestration and adaptation strategies (IPCC, 2019; IPCC, 2022).

1.3 Distribution of Agroforestry Systems

Globally, AFS occupy approximately 1.6 billion hectares, of which 78% are located in tropical regions and 22% in temperate areas (Nair et al., 2021). Tropical agroforestry is primarily concentrated in Africa, Asia, and Latin America, and encompasses a variety of location-specific systems, including tree intercropping (e.g.alley cropping), silvopasture, protective systems (such as windbreaks, shelterbelts, and soil conservation hedges), and multistrata systems (such as homegardens and shaded perennial systems) (Nair et al., 2021).

In the European Union (EU), AFS currently cover 15.4 million hectares, representing 3.6% of the total EU area and 9% of agricultural land (den Herder et al., 2017). In Sweden, agroforestry occupies 1.1% of the national land area and 15.2% of utilised arable land, with approximately 99% of these areas consisting of silvopastoral systems (den Herder et al., 2017). The most common agroforestry practices in Sweden include traditional silvopastoral systems such as forest grazing, grazing on wood pastures, semi-natural grasslands, reindeer husbandry, and summer farm systems (Eriksson, 2012;

Axelsson Linkowski, 2017; Sandberg and Jakobsson, 2018; Valinger et al., 2018; Kumm and Hessle, 2023). Reindeer husbandry constitutes the largest agroforestry area in both Sweden and Europe (Valinger et al., 2018). More recently, novel forms of agroforestry, such as forest gardens, have also been introduced (Schaffer, 2016; Askerlund and Almers, 2016; Vlasov et al., 2018; Paper I and II).

Traditionally, agroforestry has been predominantly practiced in rural areas. However, it has recently gained popularity in urban settings across Europe (e.g.Park et al., 2018; Riolo, 2019; Moereels et al., 2024), including Sweden (Focacci et al., 2025), as well as in North America (e.g. Taylor and Lovell, 2021). In urban areas, one particular form of agroforestry – forest gardens or food forests – has been widely embraced (Park et al., 2018; Albrecht and Wiek, 2021). Although urban green spaces provide limited opportunities for cultivation, forest gardens can be adapted to smaller spaces and integrated with the built environment (Papers I and II).

However, the diversity and spatial distribution of AFS are declining across Europe due to agricultural intensification, farmland abandonment, and urban expansion (Eichhorn et al., 2006; Godinho et al., 2016; Plieninger et al., 2015; Barthel et al., 2019). Key challenges to maintaining agroforestry include management complexity, higher labour requirements, and increased costs for investment, maintenance, and administration (Liagre et al., 2005; Graves et al., 2017; Garcia de Jalón et al., 2018). Moreover, contradictory public policies can discourage farmers from adopting agroforestry practices aligned with sustainable land management (Almeida et al., 2015; Pinto-Correia and Azeda, 2017).

In spite of these challenges, agroforestry has garnered renewed attention in Europe in light of pressing sustainability concerns. Scholars emphasise the importance of integrating knowledge from both modern and traditional AFS to support transformative changes in land-use management (Jose et al., 2012; Smith et al., 2012; Wilson and Lovell, 2016; Wolz et al., 2017; Smith et al., 2022).

1.4 Classifications of Agroforestry Systems

AFS are highly diverse, and no universally accepted classification scheme exists. The most appropriate classification approach depends on the underlying purpose (McAdam et al., 2009; Burgess and Rosati, 2018; Nair, 2021,). For example, one European classification system, based on Land Use Land Cover (LUCAS) data, distinguishes three types of agroforestry: (i) arable agroforestry, (ii) livestock agroforestry, and (iii) high-value tree agroforestry (den Herder et al., 2017). Similarly, the AGFORWARD research project, spanning 13 European countries, identified four categories: (i) silvoarable practices, (ii) silvopastoral practices, (iii) agroforestry with high-value trees, and (iv) agroforestry with high nature and cultural value (ref). The latter encompasses traditional systems, such as wood pasture and hedgerows, embedded within cultural landscapes (Burgess and Rosati, 2018).

Nair (1990) proposes a stepwise classification, based first on system components and then on system purpose. McAdam et al. (2009) suggest a functional classification aligned with the four categories of ecosystem services identified by the Millennium Ecosystem Assessment (MA) (Reid 2005), themselves based on the framework developed by de Groot (2006).

AFS are could also be distinguished as “traditional” or “modern” (Smith et al., 2012; Nerlich et al., 2013). Traditional agroforestry refers to the “deliberate growing of woody perennials on the same area and at the same time as agricultural crops and/or fodder plants” (Nerlich et al., 2013, p. 475). Examples include wood pastures, hedgerows, and orchards. These systems often have long histories and are associated with high cultural and biodiversity values (Plieninger et al., 2015; Rolo et al., 2020). Modern agroforestry builds on these traditions but incorporates contemporary farming techniques. For example, while traditional silvoarable or silvopastoral systems typically feature large-crowned trees with short stems scattered across the landscape, modern systems may involve small-crowned, tall-stemmed trees planted in rows, sometimes intercropped with flower strips or integrated as windbreaks and riparian buffers (Nerlich et al., 2013).

Despite these distinctions, traditional and modern agroforestry are interlinked. Smith et al. (2012) highlight the importance of traditional ecological knowledge for modern systems, identifying four critical features that enhance both short- and long-term benefits: resource conservation, energy conservation, multifunctionality, and system diversity.

In this thesis, I adopt and adapt the classification proposed by Mosquera-Losada et al. (2018a) (see also section 7. Methods and Table 2). Their framework identifies five primary types of AFS: silvopasture, silvoarable systems, riparian buffer strips, forest farming, and homegardens. This typology was designed to simplify categorisation, aligning it with payment schemes under the Common Agricultural Policy (CAP) and thereby promoting wider adoption of agroforestry practices in Europe. Furthermore, it aligns with comparable classifications in temperate regions such as the United States, Canada, and Mexico (Mosquera-Losada et al., 2018a; AFTA).

This classification is particularly relevant for my research as it corresponds closely with the agroforestry types I identified in Sweden, thereby enabling a coherent discussion of my findings. It also accommodates AFS across diverse land types, including agricultural, forested, peri-urban, and urban areas, all of which are integral to my study. To contextualise it further for Sweden, I introduced specific adaptations, explained and justified in Section 7.

2. Key Research Concepts and Frameworks

2.1 Ecosystem Services

In this thesis, I use the concept of ecosystem services (ES), defined as "the benefits that people obtain from ecosystems" (Reid, 2005). The concept was popularised by the Millennium Ecosystem Assessment (MA), an UN-initiated project involving more than 1,300 researchers between 2001 and 2005. The MA highlighted humanity's dependence on ecosystems, warning that 60% of assessed ES were being overused. While provisioning services such as crop, fish, and timber production increased, many regulating and supporting services, including pollination and soil erosion control, declined (Reid, 2005).

The MA framework groups ES into four categories: supporting, provisioning, regulating, and cultural. These include tangible products (e.g. timber, water), indirect processes (e.g. climate regulation, pollination), and intangible benefits (e.g. health, aesthetic and spiritual values). Biodiversity underpins these processes, though the precise links between species richness and ES provision remain unclear. I employ the ES-framework, which primarily serves to discuss the benefits, challenges, motivations, and niche innovations associated with the AFS identified in Sweden.

I also draw on the concept of ES bundles, defined as "sets of ecosystem services that repeatedly appear together across space or time" (Raudsepp-Hearne et al., 2010, p. 5242). ES bundles can be positively associated (synergies) or negatively associated (trade-offs) (Mouchet et al., 2014). Applying a bundles approach helps identify landscapes with differing degrees of multifunctionality and to analyse the direct and indirect drivers underpinning these synergies and trade-offs (Saidi & Spray, 2018).

Further, regarding policy I also refer to payment for ES (PES) (Farley & Costanza, 2010). There is no market for many ecosystem services, as them from AFS, PES schemes aim to compensate providers for maintaining or enhancing those services, thereby aligning market incentives with public ecological benefits.

2.2 Salutogenesis and Urban Agroforestry

Health outcomes play part of the benefits people obtain from nature. However, urbanisation and digitalization, are two global trends threatening opportunities for people to interact with nature (Colding and Barthel, 2017; Barthel et al., 2019). The well-established connection between human health and well-being (e.g. Markevych et al., 2017), and exposure to nature is addressed by the Perceived Sensory Dimensions (PSD) as developed by Grahn and Stigsdotter (2010). However, there is a lack of clarity regarding which types of natural or green spaces generate the specific fine-grained qualities – affordances – that enable environments to promote human health and well-being. We therefore analysed the "match" between the detailed features of forest gardens and the PSD framework. This involved identifying the qualities that shape salutogenic affordances in such environments, which is also valuable for urban planning. Planners can better understand which needs are well supported and which require enhanced environmental design. This is the focus of Paper IV, which is guided by the concept of "salutogenic affordances."

The term salutogenesis refers to a focus on factors that support human health and well-being, contrasting with pathogenesis, which focuses on disease-causing factors (Antonovsky, 1996). Salutogenesis emphasises a continuum between health and disease, where stressors push individuals towards illness, while salutogens support optimal health and resilience. Antonovsky highlighted that human health and well-being depend on the ability to develop a "sense of coherence" and meaning, thereby enhancing one's capacity to manage life's stressors (Antonovsky, 1996). Salutogenic strategies complement pathogenic approaches by strengthening health-promoting factors rather than merely mitigating stressors (Becker et al., 2010).

The salutogenic potential of environments can be better understood using an ecological approach to perception and behaviour, which analyses how environments support particular affordances for individuals. Gibson (1979) introduced the concept of affordances as the perceived and actionable potential for certain behaviours provided by environments. In this study, affordances are approached as relationships between individuals and their environment, following the development of the concept by Chemero (2003, 2009). This perspective emphasises the situational interplay between individuals' abilities and needs (the "inner" aspects) and the surrounding socio-material environment (the "outer" aspects). In this study, details in urban forest gardens constitute such environments. Thus, the effect of any environment is determined by the dynamic relationship between the individual and the setting (Gibson, 1979; Chemero, 2003, 2009).

To analyse the salutogenic affordances of forest gardens, we applied the Perceived Sensory Dimensions (PSD) theory, developed by Grahn and Stigsdotter (2010), in which ecologically valid salutogenic green space qualities categorises into eight dimensions. Grahn and Stigsdotter (2010) identified these dimensions as: (1) Serene, (2) Nature, (3) Rich in Species, (4) Space, (5) Prospect, (6) Refuge, (7) Culture, and (8) Social.

We analysed each dimension within the context of forest gardens. For example, the "Serene" dimension emphasises peace, silence, natural sounds, and a lack of disturbances. We examined how features of forest gardens, such as mature trees attracting birds and insects, as well as the sound of wind through foliage, can support these qualities. This detailed analysis was extended to all eight dimensions, with findings elaborated in Paper IV.

Multiple factors influence the use of urban green spaces, and the salutogenic effects of such spaces are often linked to the amount of time people spend there (Grahn and Stigsdotter, 2003). Proximity to green spaces significantly affects usage rates; for example, use drops substantially when green spaces are located more than 100–300 metres from an individual's dwelling (Grahn and Stigsdotter, 2003; Nielsen and Hansen, 2006). Accessibility, therefore, plays a critical role in promoting the use of urban green spaces. Additionally, perceived biodiversity within a green space is another key factor that encourages visits and engagement (Gyllin and Grahn, 2015; Sandifer et al., 2015).

2.3 Multifunctional Landscapes

This thesis focuses on multiple ES generated by different types of AFS at both plot and farm levels. However, my research is conceptually situated within the broader landscape scale to explore synergies and trade-offs among beneficial ecosystem functions that emerge beyond individual farms (cf. Plieninger et al., 2020).

In my research, I apply the concept of "multifunctional landscapes," which encompasses biophysical, socio-cultural, and perceptual dimensions of landscapes (Antrop, 2006). Multifunctional landscapes have been defined in multiple ways. This thesis adopts the definition of Lovell and Johnston (2009), who describe such landscapes as providing environmental, social, cultural, and economic functions within a sustainability framework. Otte et al. (2007) and Plieninger et al. (2019) emphasise the importance of incorporating the perspectives of land users and stakeholders in prioritising landscape functions, aligning with the aims of this thesis. Managing multifunctional landscapes typically involves minimising trade-offs and enhancing synergies among ecosystem services (Foley et al., 2005; Renting et al., 2009; Plieninger et al., 2019; Fagerholm et al., 2020).

Conventional land management approaches often transform natural landscapes for a single function, such as food or timber production, leading to homogenisation (Jongman, 2002; Fischer & Lindenmayer, 2007; García-Martín et al., 2021), or convert urban green spaces into lawns (Hedblom et al., 2017). By contrast, multifunctional landscapes integrate human production and use into wider ecological frameworks, maintaining essential ecosystem functions, service flows, and biodiversity (O'Farrell & Andersson, 2010). Sustainable multifunctional landscapes combine production and conservation, highlighting opportunities to support biodiversity through the intentional design of multifunctional elements (Lovell & Johnston, 2009).

The concept of multifunctionality has deep roots, particularly in Europe and Asia (Lovell & Johnston, 2009). The European Commission formally acknowledged multifunctional agriculture in its 1988 report The Future of Rural Society, defining it as land use that supports economic development, environmental stewardship, and the viability of rural communities. The concept gained further prominence at the United Nations Earth Summit in 1992 (Renting et al., 2009; Song et al., 2020).

Policy frameworks such as the European Landscape Convention (Council of Europe, 2000), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) established in 2012, the European Commission's Nature-Based Solutions approach in 2015 (Bauduceau et al., 2015), and the Millennium Ecosystem Assessment (Reid, 2005) have all contributed to mainstreaming multifunctional landscape approaches.

Since the MA, the concept of ES has been widely used to capture landscape multifunctionality. Unlike ES, however, the multifunctional landscape concept not only highlights the diversity of benefits but also stresses the need to identify beneficiaries (Otte et al., 2007; Fischer et al., 2017).

Multifunctionality extends beyond ES to encompass cultural heritage, social well-being, and rural livelihoods (García-Martín et al., 2016). Studies show that many valued landscape functions do not fit neatly into the ES framework (Fagerholm et al., 2020; Bieling et al., 2014). Some scholars argue that relational aspects of human–nature interactions are central to understanding multifunctionality (Fagerholm et al., 2016b), with cultural values, practices, and relationships playing a decisive role (Stephenson, 2008). The concept of "nature's contributions to people" (NCP), introduced by IPBES, explicitly recognises tangible and intangible benefits, emphasising cultural and local/indigenous knowledge in human–nature relations (Díaz et al., 2018). Incorporating land users' and producers' perspectives is essential to achieving multifunctional landscapes (Hart et al., 2015).

In Europe, local initiatives promoting multifunctionality often prioritise nature conservation, cultural heritage, sense of place, landscape aesthetics, social well-being, and tourism benefits (García-Martín et al., 2016). Civil society movements supporting these aims have been described as "integrated landscape initiatives" (Estrada-Carmona et al., 2014) or "landscape stewardship initiatives" (Plieninger et al., 2015b).

In an agroforestry context, nature conservation is combined with production instead of separating them. Forest gardens could constitute green edible infrastructure (Russo et al 2017). In both urban and rural areas, multifunctional forest gardens could also function as ecological restoration (Park et al 2018). For example, van Noordwijk et al (2018) state AF is not only integration of agriculture and forestry, AF is multifunctional landscapes. In addition, AF could offer a coherent policy for a wide variety of land-use, since it is central for all groups of the SDGs. Further, van Noordwijk et al., 2018 mean it is needed to look beyond the ideas about land-sharing and land-sparing and instead address functions important for human needs.

Landscape multifunctionality is connected to its heterogeneity and biodiversity, which are influenced by farm- and plot-level complexity, often derived from diverse practices and land uses (Tscharntke et al., 2021), such as agroforestry (Santos et al., 2022).

2.4 Niche-Innovation Research and the Multilevel Perspective (MLP)

In this thesis, the adoption of innovative agroforestry practices across forest and agricultural land is examined. These novel interventions are analysed through the lens of niche innovation and the multilevel perspective (MLP) to highlight their role in a land use sustainability transition.

Sustainability transitions research explores large-scale societal transformations in response to major challenges. This thesis applies this lens to examine transitions from conventional land-use in forestry, agriculture, and urban green spaces towards multifunctional AFS in Sweden. Emphasising pioneering agroforestry farmers, the focus is on innovations in AFS practices, the drivers of adoption, and their potential to contribute to sustainable, multifunctional land-use systems.

Gell-Mann (2010) identifies sustainability transformations as involving interconnected demographic, technological, economic, social, institutional, informational, and ideological shifts (see also Olsson et al., 2014). Transitions have been defined as "shifts from one socio-technical system to another" (Grin, Rotmans and Schot, 2010, p. 11) and as "nonlinear shifts from one equilibrium to another" (Loorbach et al., 2017, p 600). Markard et al. (2012, p. 956) describe them as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption." These processes are defined by scope rather than speed (Grin et al., 2010).

This thesis analyses real-world agroforestry case studies using the MLP to understand AFS dynamics and their broader potential. The MLP examines interactions between the socio-economic landscape (macro-level), the dominant socio-technical regime (meso-level), and emerging alternatives or niches (micro-level) (Kemp et al., 1998; Geels, 2002; Loorbach et al., 2017). These nested levels interact dynamically, with transitions resulting from both internal and cross-level processes (Grin et al., 2010).

At the niche level, small, often unstable networks of entrepreneurs and innovators experiment with novel ideas and practices. These niches provide protected spaces for alternative socio-technical configurations (Smith & Raven, 2012). The regime level, by contrast, comprises stable networks of established practices, technologies, institutions, routines, and cultures (Loorbach et al., 2017), governed by cognitive, normative, and regulative rules (Geels, 2004). The landscape level refers to broader societal, economic, and environmental trends, such as global markets, climate change, urbanisation, political ideologies, and cultural values. These dynamics exert pressure on regimes and create openings for niche innovation (Grin et al., 2010; Lachman, 2013).

This thesis emphasises niches as critical spaces for experimentation, learning, and momentum-building for alternative practices (Schot & Geels, 2008). Niches enable new actor configurations, beliefs, and values (Darnhofer, 2015). However, alignment with regime and landscape dynamics is necessary for broader diffusion and impact (Grin et al., 2010). In this research, novel agroforestry practices in Sweden are treated as niche innovations. Regimes include conventional monofunctional forestry, agriculture, and urban green space practices – such as timber production, cereal cropping, and lawn maintenance – and associated institutions such as higher education, extension services, and policy frameworks (e.g., the EU CAP). The socio-technical landscape is also relevant, particularly in relation to climate change, though not further analysed here. Importantly, the MLP's "landscape" should not be confused with "multifunctional landscapes" as used throughout this thesis.

Since the MLP focuses on socio-technical systems, it encompasses broader societal dynamics beyond technology. Transition outcomes depend on niche–regime–societal landscape interactions (Grin et al., 2010). Perspectives within the MLP now consider both building up new systems and dismantling old ones (Loorbach et al., 2017).

Transition research includes socio-technical, socio-ecological, and socio-institutional approaches, all emphasising nonlinearity, multilevel dynamics, co-evolution, and emergence (Loorbach et al., 2017). The socio-technical approach is most common, especially in energy, waste, and mobility transitions (Loorbach et al., 2017), as well as in agriculture (Grin et al., 2012; Hermans et al., 2016; El Bilali, 2020) and forestry (Hertog et al., 2022). It differs from the socio-ecological approach, which focuses on outcomes in agriculture, forestry, fisheries, and biodiversity (e.g., Olsson et al., 2014). The socio-institutional approach, by contrast, addresses regional and community transitions, such as grassroots movements (Seyfang & Smith, 2007; Seyfang & Haxeltine, 2012; Loorbach et al., 2017). Agroforestry can be studied through any of these lenses; herein, the socio-technical approach is used to examine grassroot innovations shaping a land use transition from monofunctional to multifunctional practices. This should not, however, be confused with the earlier definition of agroforestry as a social-ecological system.

More precisely, this thesis utilises the MLP model to explore how agroforestry niche innovations have historically developed in Sweden, drawing on case studies (Papers I–III) that illustrate challenges and opportunities for a sustainable land-use transition. By conceptualising agroforestry as a niche innovation, the analysis considers interactions among pioneering practices, dominant regimes, and broader societal (landscape) dynamics.

3. Agroforestry in Global, European Union, and National Strategies and Policies

Agroforestry has been integrated into global strategies led by organisations such as the Food and Agriculture Organization (FAO), the Intergovernmental Panel on Climate Change (IPCC), The IPCC *Climate Change and Land* report (2019) highlights agroforestry as a crucial land-based response capable of supporting both climate change adaptation and mitigation while maintaining food production. The IPCC reaffirmed this in its 2022 report, emphasising agroforestry's potential to reduce environmental impacts, curb land degradation, prevent desertification, and improve food security (IPCC, 2022).

As part of its mission to end global hunger, the FAO calls for sustainable food systems to meet the needs of a growing global population. Agroforestry is recognised as one of the leading innovations and a transformative approach for achieving this objective (HLPE 2019). It delivers a wide range of benefits, including reducing agriculture's contribution to climate change and its vulnerability to climate impacts, improving water quality and availability, increasing and diversifying farm incomes while providing access to more nutritious food, empowering women, validating Indigenous knowledge, and enhancing rural livelihoods (Buttoud, 2013). The FAO recognises agroforestry practices as contributing to Climate-Smart Agriculture (CSA) (FAO, 2021).

These global polices are often the base for European policies (Santiago-Freijanes et al., 2021) and European initiatives addressing agriculture, climate (such as CSA), forestry (European Forest Strategy), and biodiversity (Biodiversity Strategy) (Mosquera-Losada et al., 2023).

The main policy for agriculture within the EU and with a longer history, is the Common Agricultural Policy (CAP), which serves as the primary funding mechanism for member states. Its objectives include increasing agricultural productivity, safeguarding farmer livelihoods, stabilising markets, securing food supplies, and maintaining reasonable consumer prices (European Commission,2025a).

The CAP 2014-2020 expanded the definition of agroforestry to include woody vegetation, reinforcing its relevance to environmental and rural development objectives. However, constraints remained: a limit of 50 trees per hectare-later raised to 100 trees or 10% tree cover-was imposed to maintain eligibility for direct payments (Mosquera-Losada et al., 2018b). Land with more than 100 trees per hectare became ineligible for direct payments, leading to unintended consequences such as tree removal on farms and the loss of critical landscape elements (Santiago-Freijanes et al., 2018). In Sweden, for example, wood pasture biodiversity was higher in areas with more trees, indicating that such restrictions may have undermined ecological objectives (Jakobsson and Lindborg, 2015). In response, the CAP (2021-2027) removed restrictions on the number of trees on arable land, granting member states flexibility to make decisions on tree density. Mosquera-Losada et al. (2023) outline how agroforestry could fulfil seven post-2020 CAP goals, here in brief; climate mitigation and adaptation, sustainable development, protection of biodiversity, support for viable farm incomes, enhanced market orientation and competitiveness, improved positioning of farmers within the value chain, and attraction of young farmers and facilitation of business development in rural areas.

Under the 2023-2027, the CAP, aligned with the European Green Deal, agroforestry is increasingly recognised for its role in achieving sustainability goals linked to the Farm to Fork and Biodiversity Strategies (Donham et al., 2021; European Commission, 2025b). Since 2021, EU member states have ensured that agricultural land under agroforestry is fully eligible for direct payments (Mosquera-Losada et al., 2023). In order to receive support for all farmers, called conditionality, by the EU, (European Commission,2025c) there are 13 statutory management requirements (SMRs), a set of rules on public, animal and plant health, animal welfare, and the environment. For farmers receiving support under the CAP, good agricultural and environmental conditions (GAECs), is another requirement. Agroforestry aligns with several SMRs and provides an effective pathway to achieve CAP objectives more sustainably than many conventional agricultural practices (Mosquera-Losada et al., 2018b; Santiago-Freijanes et al., 2021; Mosquera-Losada et al., 2023).

The EU’s *Farm to Fork Strategy* (2020) recognises agroforestry as a key sustainable practice. It highlights that new eco-schemes within the CAP 2023-2027 will provide significant funding streams to promote sustainable methods such as precision agriculture, agroecology (including organic farming), carbon farming, and agroforestry. Member states and the European Commission are tasked with ensuring that these schemes are appropriately resourced and effectively integrated into strategic plans. The strategy also calls for a minimum ring-fenced budget for eco-schemes, signaling a strong commitment to their implementation (European Commission, 2020).

Agroforestry also aligns with broader European initiatives such as the *Pan-European Biodiversity and Landscape Strategy* and the *European Landscape Convention* (Forest Europe, 2018), demonstrating its value for biodiversity conservation, landscape management, and sustainable development across Europe (Santiago-Freijanes et al., 2021).

The *EU Biodiversity Strategy for 2030,* emphasises increasing support for agroforestry under rural development program, acknowledging its potential to deliver multiple benefits for biodiversity, human well-being, and climate mitigation. Since 2024, a key component of the *EU Biodiversity Strategy* has been the *EU Nature Restoration Regulation (NRR)*, a comprehensive law designed to enable the EU to achieve its climate and biodiversity goals while strengthening food security. The regulation requires member states to restore at least 30% of the habitats covered by the legislation (ranging from forests, grasslands and wetlands to rivers, lakes and coral reefs) from poor to good condition by 2030 (European Commission, 2021)

Additionally, the *EU Forest Strategy*, which complements both the Green Deal and the Biodiversity Strategy, includes agroforestry as a critical measure for achieving the goal of planting three billion trees by 2030. This strategy highlights the significant role of agroforestry and other trees outside traditional forests in reaching climate neutrality and calls for enhanced research and innovation in these systems (Donham et al., 2021).

Europe is addressing climate change through forest policy frameworks. The Madrid Ministerial Declaration and Ministerial Resolution 2 on forest protection highlight the urgent need to combat climate change. Agroforestry has been identified as a strategic approach to both mitigation and adaptation in the Forest Europe Work Programme (2016–2020) (Forest Europe, 2018). Key recommendations include strengthening coordination between forestry and agriculture at all levels, promoting national networks and focal points for agroforestry, fostering collaboration among farmers, landowners, foresters, and other stakeholders, organising smallholders into larger interest groups to facilitate Payment for Ecosystem Services (PES) for agroforestry services, and promoting agroforestry within regional rural development networks (Forest Europe, 2018)

Policies supporting PES and carbon offset initiatives are particularly relevant to agroforestry, as these systems generate numerous non-market benefits. However, several approaches to PES exist, and the more market-oriented variants are contested for their potential contribution to the commodification of nature (Farley and Costanza, 2010; Gómez-Baggethun et al., 2010). Unlike agricultural production, forestry lacks a payment system comparable to the CAP (Mosquera-Losada et al., 2018b).

While agroforestry is increasingly acknowledged within European policies, implementation remains limited. Policy-related issues are one of four key challenges, alongside technical, economic, and educational barriers (Mosquera-Losada et al., 2023).

Since 2024, in Sweden, only trees on arable land defined as *trädjordbruk* by the Swedish Board of Agriculture, are eligible for CAP payments (Swedish Board of Agriculture). Shrubs are not eligible for support, despite offering comparable ecosystem services to trees (Mosquera -Losada et al., 2018b), and not either trees on pastures are eligible support. The same year, The Swedish Board of Agriculture also published its first brochure named *Trädjordbruk i Sverige* for inspiration, in which several types of AF is included (Swedish Board of Agriculture).

Before and after 2024, with relevance for agroforestry, also semi-natural grasslands, forest pastures, mosaic pastures, mountain pastures, hay meadows and pastures with special values and traditional silvopastoral practices such as summer farms and reindeer herding were eligible for support under the CAP system.

There are, however, important nuances and restrictions. Forest pastures and mosaic pastoralism are not eligible for basic single payment schemes, whereas semi-natural pastures, mown meadows, and mountain grazing areas are (Donham et al., 2021). CAP payments stipulate that tilling must not occur for five years; this condition, however, does not apply to pastures in Sweden, where no tilling is permitted at all. From 2025, restoration of meadows, pastures and pollarded trees can get financial support (Swedish Environmental Protection Agency).

Eligible grazed forests must predominantly contain naturally occurring trees, exhibit a diversity of tree ages, and include some old-growth trees (Swedish Board of Agriculture). However, fencing to protect livestock from predators poses difficulties, as it conflicts with Sweden’s *Right of Public*

Access (*Allemansrätten*), which guarantees public access to forests and woodlands for recreational use (Donham et al., 2022).

Agroforestry is also addressed to some extent within other environmental policy contexts. The government's investigation on climate change strategies, *The Pathway to a Climate-Positive Future* (SOU 2020:4), identified agroforestry as a tool within the Land Use, Land-Use Change, and Forestry (LULUCF) sector. This proposal was jointly submitted by the Swedish Board of Agriculture and the Swedish Environmental Protection Agency (Klimatpolitiska vägvalsutredningen, 2020). Furthermore, a joint report by the Swedish Board of Agriculture and the Swedish Forest Agency, *Underlag för strategisk planering för ökad kolsänka* (*Strategic Plan for Enhanced Carbon Sequestration*), dedicates a chapter to agroforestry's contribution to carbon sequestration within both forestry and agriculture (Swedish Forest Agency, 2022).

National policies for urban areas do not explicitly address agroforestry practices such as forest gardens. However, urban green spaces are increasingly recognised for their multifunctional social and environmental benefits. Since 2022, cities such as Lund, Västerås, and Örebro have initiated forest garden projects that support human well-being, social interaction, and environmental education (Focacci et al., 2025). In Gothenburg's peri-urban areas, adult education programmes on agroforestry and social integration have also been introduced by the County Administrative Board (Focacci et al., 2025).

Summing up**,** while agroforestry is acknowledged across European policies, alignment between them remains weak. Agroforestry could meet multiple EU policy goals, but implementation remains limited and faces challenges in not only policy but also in technical, economic, and educational domains (Mosquera-Losada et al., 2023). One general consideration regarding policies, biophysical and socioeconomical conditions are different, for example the emphasis on combating hunger or on environmental protection in the Global South respectively in the Global North. Conditions are also different within Europe, for example Sweden and neighboring countries, Finland and Norway are forested countries and have less arable land. Therefor policies and ambitions for example regarding the increase of trees on arable land must be adapted to various contexts and countries.

4. Current knowledge on multifunctionality of agroforestry systems

4.1 Benefits

AFS are increasingly recognised for their multifunctionality, simultaneously providing provisioning, regulating and cultural ecosystem services while enhancing biodiversity (e.g.Jose, 2009; Wilson & Lovell, 2016; Torralba et al., 2016; García de Jalón et al., 2018; Sollen-Norrlin et al., 2020;). Historically, most research has focused on tropical regions, with relatively fewer studies addressing temperate zones, particularly in the Nordic Region (Castle et al., 2022; Quandt et al., 2023). Within Europe, the literature is dominated by studies from southern countries such as Spain, Italy and France, while Nordic countries remain underrepresented (Fagerholm et al., 2016a).

AFS contribute significantly to biodiversity by creating structurally diverse habitats through the integration of trees, shrubs, crops and, in some cases, grazing animals (McAdam et al., 2009; Jose, 2012; Torralba et al., 2016; Udawatta et al., 2019; Santos et al., 2022). Planned and associated biodiversity within AFS supports ecosystem resilience and productivity, although the magnitude of benefits varies depending on system complexity and age (Malézieux et al., 2009; Mupepele et al., 2021). In Mediterranean and Pannonian regions, agroforestry systems show stronger positive effects on biodiversity than in boreal climates (Torralba et al., 2016).

In terms of productivity, intercropped agroforestry systems often outperform monocultures on a per-area basis, particularly when measured through the land equivalent ratio (LER) (Graves et al., 2007; Pent, 2020; Ivezić et al., 2021). However, results differ by region, system type and management practices, with some Northern European alley-cropping systems (e.g. Germany and the UK) showing lower LER values (Ivezić et al., 2021). Contemporary design principles increasingly seek to optimise species complementarities to enhance resource-use efficiency (Smith et al., 2012).

AFS also play a critical role in improving soil health by reducing erosion, enhancing soil organic matter and promoting nutrient cycling (Lorentz & Lal, 2014; Tsonkova et al., 2012; Udawatta et al., 2019). Tree litter inputs and reduced tillage contribute to improved soil structure and fertility, while deeper tree roots facilitate nutrient pumping from lower soil horizons, buffering nutrient losses and regulating water flows (Allen et al., 2004; Tsonkova et al., 2012).

Climate change mitigation through carbon sequestration both above and below ground in AFS is well documented, (Plieninger, 2011; Abbas et al 2017; Howlett et al 2019; Mayrinck et al., 2019), compared with research on climate adaptation that is more fragmented (Mosquera-Losada et al., 2023), and there is more focus on Global South over Global North (Quandt et al., 2023). However, the creation of favorable microclimates with shade, windbreak, lower mean temperature and improvements in water retention also suggest agroforestry's potential for climate adaptation (Quandt et al., 2023).

In a changing climate, AFS also exhibit synergies from silvopastoral systems since grazing animals could lower wild fire risks and trees shelter from both heat and rain could enhance animal welfare. A well-managed system with grazing animals could contribute to biodiversity habitats, convert otherwise inedible biomass (such as leaves, grass) into food (meat) consumable for humans (McAdam et al., 2009; Moreno et al., 2014; Garcia de Jalon et al., 2018; Öllerer et al., 2019). In addition, mixed vegetation could provide better fodder, which could reduce medicinal treatments to livestock (Roellig et al., 2016).

Beyond biophysical advantages, socio-cultural benefits such as food security, cultural identity, recreation and human well-being are increasingly acknowledged, though they remain under-researched (Fagerholm et al., 2016a; Sollen-Norrlin et al., 2020; Castle et al., 2022). Examples include traditional wood pastures in Romania and reindeer husbandry among the Sámi people in Sweden, which illustrate strong links between agroforestry and cultural heritage (Hartel et al., 2017; Valinger et al., 2018).

Despite growing interest in urban agroforestry (Taylor & Lovell, 2021) and novel types, such as forest gardens in temperate areas – research remains sparse (Park et al., 2018; Albrecht & Wiek 2021). Farmers' perspectives, particularly in Sweden and in the Nordic region, are underrepresented, with only a few case studies (Roellig et al., 2017; Sandberg & Jakobsson, 2018 ;). Participatory research approaches are therefore needed to bridge science–practice gaps and support transition pathways towards wider adoption (Lovell et al., 2018; Quandt et al., 2023).

In summary, agroforestry integrates nature conservation with productive land use and represents a promising land use to support biodiversity, enhance soil health, build resilience to climate change and foster rural development. These synergies and their role in advancing the EU's climate objectives are emphasised by Hernández-Morcillo et al. (2018), who propose the term "agroforestry-based solutions". Globally, the IPCC has also recognised the multifunctionality and climate relevance of AFS (IPCC, 2019; IPCC, 2022).

Innovation is essential to enhance resilience, increase productivity and address evolving socio-ecological challenges such as climate change, land degradation and shifting market demands (Lehmann et al., 2020; Lovell et al., 2018; Wolz et al., 2017). Innovations occur in both traditional and novel AFS. Examples include food and energy co-production by combining willow, alder and hazel with wheat in Denmark (Lehmann et al., 2020), or multipurpose woody polycultures designed to provide both crops and fodder (Lovell et al., 2018; Wolz et al., 2017). Similarly, adaptive management models and new technologies such as GPS collars and invisible fencing have been suggested to support reindeer herding across northern Scandinavia and Russia (Valinger et al., 2018; Rolo et al., 2020). These examples highlight the role of innovation in ensuring the viability, efficiency and resilience of AFS in the face of environmental and socio-economic pressures. Kumm and Hessle (2023) illustrate that the utilisation of a mosaic of forest and semi-natural pastures can increase domestic production of lamb and beef in Sweden, whilst simultaneously contributing to the achievement of biodiversity and climate change mitigation objectives.

Lovell et al. (2018) contend that agroforestry, including tree crops, represents a transformative approach to diversifying food systems beyond grain production. Polycultural alley cropping has been identified as one such strategy (Wolz et al., 2017). A further transition from annual to perennial vegetables may enhance crop biodiversity and carbon sequestration (Toensmeier et al., 2022), while their high nutritional value has the potential to address malnutrition in the Global South and dietary deficiencies linked to industrialised food systems in the Global North (ibid.). In addition, perennial crops, in particular nuts and berries could be important for diet-related diseases (Lovell et al., 2023).

These examples underscore the importance of innovation in ensuring that AFS remain viable, efficient, and resilient in the face of environmental and socio-economic pressures. By adopting perennial, multifunctional AFS and promoting innovation, diversification, and landscape-level integration, agroforestry plays a pivotal role in fostering a more sustainable and resilient future for both local and global communities (Wilson & Lovell, 2016; Wolz et al., 2017; Lovell et al., 2018).

Plieninger et al. (2020) and Sharma et al. (2022) highlight the transformative potential of agroforestry in achieving global policy objectives, such as the Sustainable Development Goals (SDGs), as these ultimately involve land use (van Noordwijk et al., 2018). In particular, sustainable landscape management through agroforestry represents a critical strategy for addressing challenges across agricultural and forestry production landscapes worldwide (Plieninger et al., 2020).

While the multifunctional benefits of agroforestry are increasingly recognised, substantial knowledge gaps remain – particularly in underrepresented regions such as the Nordic region, and in underexplored themes such as socio-cultural benefits, novel and urban AFS, niche innovations and participatory co-production of knowledge. These gaps, which are discussed further in Section 5, highlight the urgent need for context-specific research and innovation.

4.2 Challenges of Practicing Agroforestry

AFS face a variety of challenges across Europe. Commonly reported barriers include increased management complexity, knowledge gaps, labour and mechanisation issues, economic viability, biophysical constraints, and policy or administrative obstacles (Graves et al., 2009; Rois-Díaz et al., 2018; Hernández-Morcillo et al., 2018; García de Jalón et al., 2018; Rolo et al., 2020; Mosquera-Losada et al., 2023).

AFS often require specialised management knowledge and skills, which can act as a barrier to adoption. Educational opportunities are limited across Europe, from vocational training to higher education and extension services, while awareness among government agencies such as county administrative boards also remains low. The labour-intensive nature of AFS, particularly during the establishment phase, further complicates adoption. Species-rich systems, for instance, frequently require greater initial labour inputs and entail higher management costs (Graves et al., 2009; García de Jalón et al., 2018; Sollen-Norrlin et al., 2020). Mechanisation is further constrained by the lack of suitable machinery designed for agroforestry, resulting in inefficiencies and additional costs.

Economic viability is another critical concern. High establishment costs and significant administrative burdens often discourage farmers from adopting AFS. The dual nature of AFS –combining forestry and agriculture – creates difficulties in aligning with existing subsidy frameworks, which are typically structured to support either forestry or agriculture but not both. McAdam et al. (2009) highlighted this structural issue and called for better integration of agroforestry into national and EU-level policy frameworks. A lack of clear definitions and categorisation further hinders visibility, eligibility for subsidies and recognition as a climate change mitigation strategy (García de Jalón et al., 2018; Mosquera-Losada et al., 2023).

Biophysical constraints vary significantly across Europe. In Northern Europe, limited sunlight is a major challenge for designing effective systems, while in Southern Europe, water scarcity is a dominant constraint (Torralba et al., 2016). These regional differences necessitate tailored solutions to optimise performance. System design, including species selection, planting density and management approaches, must be adapted to local ecological conditions to minimise trade-offs and maximise benefits (Smith et al., 2012; Nerlich et al., 2013; Rigueiro-Rodríguez et al., 2009).

Terminology and awareness also differ between regions. In Sweden, for instance, traditional practices such as wood pasture are widely known under their Swedish names, yet the term agroforestry itself remains unfamiliar to many farmers and foresters. The Swedish Board of Agriculture recently introduced their own term *trädjordbruk* (“tree agriculture”) in 2024 for adoption of trees on arable land. Despite this, there remains a shortage of demonstration plots, forums or sites where farmers can develop management skills or learn from viable examples of AFS. Both Sollen-Norrlin et al. (2020) and Smith et al. (2012) emphasise the importance of such initiatives for advancing practical application.

Challenges also differ by system type. In silvopastoral systems, predation losses are a major concern (García de Jalón et al., 2018). In Northern Sweden, in Sápmi, forestry operations pose substantial challenges for reindeer husbandry (Rolo et al., 2020), as mining, windmills and climate change (Österlin & Raitio, 2020).

In silvoarable systems, some farmers perceive negative effects of trees on crop yields (Graves et al., 2009). Addressing these issues requires not only technical innovations but also enhanced education, awareness and support structures.

Although AFS are increasingly recognised for their multifunctional benefits relative to monofunctional systems, realising these advantages is not straightforward. Successful implementation depends on proper system design, careful management of trade-offs and long-term planning. Van Noordwijk et al. (2018) proposed the Land Equivalent Ratio for Multifunctionality (LERM) as an advanced metric for guiding the design and management of AFS, integrating their multifunctional potential into decision-making.

In conclusion, while agroforestry holds considerable promise for sustainable land use and climate change mitigation, its successful expansion in Europe requires overcoming substantial challenges. Addressing barriers related to education, policy, economic viability, biophysical constraints and practical support is essential. Tailored solutions, increased awareness and stronger policy alignment will be necessary to foster widespread adoption and unlock the full potential of AFS across Europe.

5. Knowledge gaps in agroforestry research

This thesis identifies seven key knowledge gaps in agroforestry research:

1. Limited knowledge on AFS in the Nordic region.

Agroforestry research has predominantly focused on tropical regions (Castle et al 2022; Quandt et al., 2023), while studies in temperate areas remain fewer, particularly in high-income countries. Existing research in these contexts has mainly been conducted in the United States and European countries such as Spain, the UK, Italy, France and Portugal (Castle et al., 2022). In Sweden, the few existing studies focus largely on silvopastoral systems (Jakobsson & Lindborg, 2015; Garrido et al., 2017; Elbakidze et al., 2021; Kumm & Hessle, 2023). There are single studies for example on ecological dynamics in wood pastures in Finland (Oldén et al., 2016, 2017). In Norway, one study address the effectiveness of grazing between sheep breeds in mountain pastures (Steinheim et al 2005), and another address the economy and productivity of wooded hay meadows (Rydgren et al 2017).

According to Fagerholm et al. (2016a), research hotspots include the Mediterranean, the UK and France, leaving Nordic countries underrepresented. Specifically, only six studies have been conducted in Sweden and three each in Finland and Denmark out of a total of 290 studies in Europe and Central Asia (Castle et al., 2022).

2. Insufficient knowledge of the socio-cultural dimensions of agroforestry.

While the provisioning and environmental benefits of agroforestry are well documented, socio-cultural dimensions – such as human health, well-being and cultural values – remain underexplored (Fagerholm et al., 2016a; Torralba et al., 2016; Sollen-Norrlin et al., 2020; Castle et al., 2022). Only ~5% of agroforestry studies have focused on well-being aspects, including income, household expenditure and cultural well-being (Castle et al., 2022), but broader socio-cultural outcomes remain largely absent from the literature.

3. Limited knowledge of Swedish farmers' perspectives on AFS.

Farmers are crucial stakeholders in agroforestry, yet their perspectives are underrepresented in the Nordic region. Existing European studies tend to focus on specific systems, such as Estonian farmers' views on wood pastures (Roellig et al., 2016) or Swedish farmers' perceptions of wood pastures (Sandberg & Jakobsson, 2018). One quantitative study on behavioral factors among Swedish farmers indicate that their network membership decided on adoption or non-adoption of AFS (Leduc & Hansson, 2024). Farmer´s perspectives in a European context are addressed (e.g. Graves et al., 2009; Hartel et al., 2017; Rois-Díaz et al., 2018; Felton et al., 2022) however, studies on other forms than on wood pastures in the Nordic region remain limited. For example, Graves et al., (2009) do not include farmers perspectives from countries further north than Germany.

4. Lack of knowledge on novel AFS.
Research in high-income countries has primarily addressed traditional silvoarable (69%) and silvopastoral (22%) systems (Castle et al., 2022). In Sweden, studies have concentrated on traditional systems such as reindeer husbandry (Axelsson Linkowski, 2017; Valinger et al., 2018), summer farms (Eriksson, 2013; Axelsson Linkowski, 2017), and wood pastures (Garrido et al., 2017; Sandberg & Jakobsson, 2018). By contrast, there is limited research on recently introduced novel systems such as forest gardens (Vlasov et al., 2018; Askerlund & Almers, 2016; Almers et al., 2018), and virtually no research on newly established forest farming or novel silvoarable and silvopastoral models, particularly in Sweden and the Nordic region.

5. Limited research on urban agroforestry.
Agroforestry research has traditionally focused on rural areas, particularly agricultural and forested landscapes. However, there is growing interest in agroforestry in urban contexts, particularly in North America and Europe, often in the form of forest gardens/food forests (Park et al., 2018; Riolo, 2019; Albrecht & Wiek, 2021; Taylor & Lovell, 2021). Despite this emerging trend, Castle et al. (2022) identified only five studies on urban agroforestry in high-income countries.

6. Insufficient participatory research on AFS.
Stakeholder perspectives, especially those of farmers, are critical for understanding and developing AFS (see Knowledge Gap 3). Yet 99% of agroforestry studies lack active stakeholder involvement (Fagerholm et al., 2016a). While studies such as Sereke et al. (2015) demonstrate the potential

of participatory research, many lack methodological transparency. Long-term collaborations between researchers and farmers, employing systematic transdisciplinary (TDR) approaches, could significantly improve knowledge co-production and the relevance of findings (Lovell et al., 2018). There remains a clear need for more participatory research that explicitly integrates diverse stakeholder knowledge and applies transparent TDR methodologies to improve adoption, legitimacy and impact.

7. Limited knowledge on niche innovation and transition pathways.

Agroforestry is often presented as a promising practice for sustainability (Wilson & Lovell, 2016; Wolz et al., 2017; Plieninger et al., 2020), but there is little empirical research on how farmers and land managers transition from conventional monocultures to agroforestry. The enabling factors and barriers influencing these transitions remain poorly understood, as do the processes by which AFS function as niche innovations in sustainability transitions. Further research is needed to clarify how adoption unfolds in practice and which policy, social or ecological conditions best support successful transitions.

By addressing these knowledge gaps my thesis will contribute valuable insights into the multifaceted roles of agroforestry in sustainable land management, with relevance for urgent sustainability transitions such as climate mitigation and adaptation, biodiversity conservation and socio-economic development in Sweden, Europe and beyond.

6. Aim and objectives

The overall aim of this thesis is to enhance understanding of AFS as multifunctional land-use practices by:

1. Identifying and assessing the diverse ecosystem services they provide across agricultural, forested and urban landscapes.
2. Investigating their role as niche innovations contributing to sustainable land-use transitions.

Through empirical studies in temperate and boreal regions of Europe – with a particular focus on Sweden – this research pursues the following objectives:

Thesis objectives:

1. Document and analyse the tangible and intangible benefits of various AFS in agricultural, forested and urban contexts. This involves assessing the ecosystem services provided by these systems using an ecosystem services framework (Papers I–IV).
2. Explore farmer perspectives by investigating the motivations, perceptions and challenges of farmers practising agroforestry. This includes examining the factors that drive adoption, farmers' lived experiences, and the challenges that constrain expansion (Papers I–III).
3. Examine land-use transitions from conventional practices to multifunctional agroforestry. This objective focuses on niche-innovations in real-world examples of adoption and experimentation of agroforestry (Papers I–III).

Case studies in Sweden serve as representative models for Northern Europe and encompass:

- (i) Novel systems: Forest gardens (Papers I–IV) and novel silvoarable systems (Papers II–III).
- (ii) Silvopastoral systems: Both traditional and innovative models (Papers II–III).

- (iii) Forest farming models: Emerging examples within the Swedish context (Paper III).
- (iv) Urban agroforestry: Forest gardens in urban settings (Paper IV).

Through these objectives and case studies, this thesis contributes to a broader understanding of agroforestry as a transformative land-use practice. It highlights the potential of AFS to advance sustainability transitions in Sweden and across Northern Europe, while addressing critical gaps in current research.

7. Methods

7.1 Overview

The methods employed in this thesis include participatory action research (PAR) and applied agroforestry, as well as qualitative methods such as semi-structured interviews, focus groups, field observations, and conceptual analysis. These methods were applied in the different papers (Table 1).

Table 1. Overview of methods used in the thesis

Method		**Studied farms**	**Paper**
Participatory action research (PAR) and applied agroforestry	9 farmers on farm workshops, 15 phone meetings, including 18 farmers. Documentation of each farm on establishment.	12	I
		12	II
Qualitative methods	13 semi-structured interviews, including 21 farmers, focus groups and 13 study visits and field observations.	13	III
Conceptual analysis	Analysis of urban agroforestry, based on the framework Perceived Sensory Dimensions and findings from Paper I&II	Not appli-cable	IV

7.2 Participatory Action Research

Papers I and II are grounded in knowledge and experience generated through facilitated participatory action research (PAR) aimed at advancing novel AFS in Sweden. PAR is a research approach and a form of transdisciplinary research (TDR), incorporating practices that integrate indigenous and local knowledge with Western science and citizen science (Knapp et al., 2019).

TDR has been defined as “a reflexive, integrative, method-driven scientific principle aiming to solve or transition societal and related scientific problems by differentiating and integrating knowledge from diverse scientific and societal sources” (Lang et al., 2012, p. 26). Another definition describes it as “a practice that transcends disciplinary boundaries to co-create knowledge relevant for concrete problem-solving through collaboration among researchers from different disciplines and non-academic actors” (Fernández-González et al., 2021, p. 523). European TDR traditions typically emphasise cross-disciplinary collaboration and stakeholder participation, while U.S. approaches tend to focus more on interdisciplinary academic research (Knapp et al., 2019).

TDR has proven to be an effective approach for addressing complex sustainability challenges and identifying viable solutions (Wiek et al., 2012; Miller et al., 2014; Leemans, 2017). As Fernández-González et al. (2021) emphasise, it seeks to “include a plurality of views to produce socially robust and contextualised knowledge.” Within agroecology, PAR has gained increasing recognition over the last decade, although it remains relatively new in Europe (Méndez et al., 2017; Fernández-González et al., 2021).

Paper I employ a PAR approach carried out by a team, referred to throughout the thesis as the PAR group, composed of researchers, including myself, and farmers. The team included two researchers and one doctoral student with expertise in environmental science, agroecology, and participatory methodologies. Potential farmer participants were identified through a preparatory workshop involving individuals with agroforestry experience in southern Sweden. The workshop, open to anyone interested in exploring applied agroforestry in the Swedish context, formed the basis for the recruitment of participants.

The paper focuses on the learning processes associated with the establishment of forest gardens. Eighteen farmers – both full-time and part-time – participated from 12 farms across central and southern Sweden, representing a range of climatic conditions. These farms varied in size (3–200 hectares) and land use, including pastures, arable fields, and forest areas, with production systems spanning subsistence, commercial, and mixed models.

Forest gardens were co-designed by the PAR group using a multi-layered model of intercropped edible perennials. Each 60 m² plot contained more than 30 species, mimicking young woodland or forest-field edge zones.

Layers included large and small trees, shrubs, herbaceous perennials, ground cover, climbers, and underground plants. Designs followed agroecological principles of functional design, biodiversity, multifunctionality, appropriate scale, and nutrient cycling (Gliessman, 2014).

The research process was participatory at all stages. Establishing forest gardens was a new experience for both farmers and researchers, including the facilitators, who engaged in applied forest gardening for the first time. Research questions were co-developed, and participants took part in national meetings, international conferences, and the creation of public materials. The process was guided by principles of experiential learning (Kolb, 1984) and social learning (King and Jiggins, 2004), enabling both individual and collective learning tailored to each farm's specific conditions.

Data collection consisted of nine workshops, 15 telephone conferences, and individual documentation. Each farm recorded vegetation and soil parameters, inputs, outputs, and working hours, supplemented by photographs and diaries. Workshops addressed a wide range of topics, including collaborative approaches, documentation requirements, practical challenges, and reflective discussions. Key decisions and outcomes were jointly analysed, and results were made publicly available (Eksvärd et al., 2016).

Paper II examines the wider learning outcomes of the PAR project, including its processes, inputs, outputs, and results. It explores three types of AFS – forest gardens, silvoarable systems, and silvopastoral systems – focusing on their benefits, practices, uses, and potential for scaling. Transition theory and the multi-level perspective (MLP), as adapted to agriculture (Geels, 2005; Grin et al., 2010; Ingram, 2015), were employed as heuristic tools to support analysis of scaling and system transitions. This framework enabled exploration of societal influences on AFS across niche, regime, and landscape levels.

The farms involved in the project were diverse in size (0.5–200 hectares), production orientation (full-time/part-time; subsistence/commercial), and organisational context (smallholdings, community projects, ecovillages, and volunteer-managed sites). Despite these differences, all participants were categorised as farmers, since they engaged in food production.

Workshops and collaborative activities enabled participants to jointly design research, exchange experiences, and develop new ideas, such as establishing hazelnut orchards. Each workshop, hosted in turn at a participant's farm, provided opportunities for hands-on learning and collective reflection. Experts were invited to address emerging issues, such as soil health, mycorrhizal associations, and nutrient management. Notes and recordings were systematically analysed and organised thematically, with findings shared and discussed among participants.

7.3 Qualitative Methods

Paper III draws on three qualitative methods: semi-structured interviews, focus groups, and field observations conducted with agroforestry farmers across Sweden practicing a range of AFS. To address the research questions, three criteria guided the careful selection of farms for in-depth study.

First, farms were selected on the basis of experience, with a minimum of five years of active engagement in agroforestry. This time frame was considered necessary to generate meaningful insights, particularly regarding the establishment and management of tree components within newly developed AFS.

Second, the sample was designed to ensure diversity, with farms chosen to represent the range of agroforestry practices in Sweden. This approach sought to provide a comprehensive understanding of how different AFS function across varied contexts.

Third, farms were included only if their production extended beyond the household level, thereby reflecting the broader food security dimensions of agroforestry. This criterion recognises that approximately 50% of Sweden's food is imported and primarily distributed through shops and extended value chains; thus, agroforestry production must extend beyond subsistence to meaningfully contribute to national food security.

A snowball sampling approach was employed to identify eligible farms, drawing on contacts established during agroforestry conferences and events in Sweden, with additional support from an expert in silvopastoral systems at the Swedish University of Agricultural Sciences.

In total, 13 farms (F1–F13) across 13 municipalities in eight counties of central–southern Sweden were selected. These farms represented four categories of agroforestry – silvopasture, silvoarable systems, forest farming, and forest gardens (see detailed descriptions in Section 5.). These categories were adapted from Mosquera-Losada et al. (2018a). Ten of the 13 farms practised multiple forms of AFS.

In total, 26 individuals involved in agroforestry practices across the 13 farms were interviewed. For the purposes of this thesis, all participants are referred to as "farmers," given their engagement in food production. The farmers represented a broad demographic: 14 were aged 30–45, eight were 55–65, and four were 70–80. Five participants had young children, five aged 50+ lived without children, and three did not reside permanently on their farms. Ten farmers owned their land, two leased, and one operated on land owned by a foundation. Several farms also had distinctive features: for example, F13 integrated silvopasture into a nature reserve, F11 functioned as a university research site, and F6 was used for educational programmes.

The data collection included one focus group session with five farmers, men and women, representing three farms (F1–F3). The session explored objectives, experiences, challenges, and opportunities for scaling AFS. In addition, semi-structured interviews were conducted with men and women from ten farms (F4–F13). The interview guide covered AFS types, tree and plant varieties, productivity, motivations for adoption, opportunities and challenges for scaling. Field observations were also conducted to obtain a deeper understanding of the farms' agroforestry systems and overall operations. Discussions during these visits focused on the establishment of perennial crops and trees, choice of location and landscape suitability, intercropping designs, harvesting challenges, pest pressures (e.g.voles), and other relevant issues.

All interviews, focus group notes, and field observations were analysed using qualitative content analysis (Bryman, 2008). Transcribed data were imported into NVivo for coding. No explicit questions were asked about concepts such as ecosystem services, climate change, or financial constraints; rather, these themes emerged spontaneously.

In Paper III, qualitative data on the perceived benefits of agroforestry farms were categorised according to ecosystem service types. The Ecosystem Service Coding Protocol (CP) developed by Wilkinson et al. (2013) was applied to ensure consistency. The CP classifies ecosystem services into four categories: supporting (A), provisioning (B), regulating (C), and cultural (D) (MA, 2005). Appendix 3 provides an overview of how respondents' statements were coded into ecosystem service categories. For comparative purposes, the benefits documented in Papers I, II, and IV were also translated into ES using the same coding approach as in Paper III.

7.4 Conceptual Analysis of Salutogenic Affordances in Urban Forest Gardens

Paper IV is framed by the concept of salutogenic affordances. “Salutogenic” refers to factors that promote human health and well-being (Antonovsky, 1996), while “affordances” denote the relational interplay between an individual’s internal psyche (“inner”) and the external environment (“outer”) that creates possibilities for action (Chemero, 2003, 2009). Affordances are context-dependent, shaped by the interaction between individual abilities and needs and the surrounding environment.

The analysis combines insights from multiple fields: agroforestry (particularly forest gardens, examined in Papers I and II), urban agriculture (with an emphasis on community gardening), and urban sustainability studies. A further theoretical lens is provided by Perceived Sensory Dimension (PSD) theory, which identifies natural features that support human health and well-being, particularly through psycho-physiological stress recovery. Since PSDs are not yet fully operationalised, the study examines whether they align with the features of urban forest gardens and evaluates their multifunctionality in relation to urban sustainability.

At the time of writing Paper IV, no theoretical or empirical studies on urban agroforestry were available. The paper is theoretical, in the sense field work was not conducted particularly for this analysis, but is drawing on knowledge and experience gained through participation in the PAR project (2012–2016, described in Papers I and II). The author had acquired both theoretical and practical expertise in agroforestry, particularly forest gardens, including applied work on their own farm. In addition, a study of four urban forest gardens in Stockholm was conducted and published as a conference paper (Schaffer, 2016). This study involved interviews, observations, and site visits to community-managed forest gardens that displayed structural, design, and vegetative similarities to the 12 forest gardens explored in Papers I and II, all of which were inspired by the model described by Crawford (2010). The concept of affordances was also featured in a Frontiers in Psychology special issue, which further informed the analysis. The author’s experiential knowledge also extends to involvement in a forest garden at Stockholm University’s campus, which served as a site for a summer course in urban gardening between 2012 and 2019.

7.5 Study Areas

In total, 19 farms were included across the four papers as case studies. These farms are located in the central–southern regions of Sweden, specifically within the counties of Västra Götaland, Dalarna, Värmland, Örebro, Västmanland, Uppsala, Södermanland, Östergötland, and Skåne. From a biophysical perspective, four farms are situated in the boreal zone, ten in the boreal–nemoral zone (mixed forests), and five in the nemoral vegetation zone (deciduous forest). All farms fall within cultivation zones 1–5, according to the Swedish system for classifying plant hardiness (Sweden Plant Hardiness Zone Map, 2022).

The growing season across these farms ranges from 170 to 215 days, with a mean summer temperature of 15 °C and a mean winter temperature of −3 °C. Annual precipitation is approximately 700 mm (Sveriges Meteorologiska och Hydrologiska Institut, 2023). The soils consist of various types of clay and sand, with differing levels of soil organic matter.

Figure 2. Map of Sweden with county-level farm locations. Consolidated map from maps available in Papers I and II, with supplementary information in Paper III. Map by Sophie Trygger.

For this thesis, the classification of AFS developed by Mosquera-Losada et al. (2018a) was adopted. This framework identifies five primary AFS types: silvopasture, silvoarable, riparian buffer strips, forest farming, and homegardens (see Table 2). A more recent update includes six practices – silvopasture, silvoarable, woody linear landscape strips, forest farming, homegardens/kitchen gardens – and one temporal practice, woody perennial fallow (Mosquera-Losada et al., 2023).

The original aim of Mosquera-Losada et al. (2018a) was to make agroforestry practices more visible and useful for EU climate change strategies, while also simplifying the classification to facilitate integration with the Common Agricultural Policy (CAP), thereby promoting agroforestry adoption in Europe. While this was not the primary aim of the present thesis, the framework provides a valuable basis for understanding AFS in Sweden and assessing their broader ecological and socio-economic benefits, including contributions to climate change mitigation.

A key feature of Mosquera-Losada et al.'s (2018a) framework is its inclusion of forest farming, an AFS observed among Swedish agroforestry practitioners and central to the analyses in this thesis. To better reflect the Swedish context, certain adaptations were made. For example, the term "homegardens" was replaced with "forest gardens" (also referred to as "edible forest gardens" in Papers I, II, and IV), a term that aligns more closely with local practice and farmer understanding. Explanations of how the Mosquera-Losada et al. (2018) AFS categories were adapted for this thesis are provided in Table 2.

Table 2. Categories of AFS in Europe according to Mosquera-Losada et al. (2018) and their descriptions in the present thesis.

Agroforestry System (Mosquera-Losada et al., 2018)	Terms Used in This Thesis	Description in This Thesis
Silvopasture	Silvopasture / Forest grazing / Wood pasture	Combines woody vegetation with forage and livestock production (Papers II–III). Differentiated between dense forest grazing and wood pasture with less dense trees and more shrubs.
	Multipurpose silvopasture*	Multipurpose silvopasture includes systems with fruit trees and fodder/grazing, either traditional (>100 years) or recently planted (~5 years). Note: Multipurpose silvopasture was not included in Paper III
Silvoarable	Silvoarable	Widely spaced woody vegetation intercropped with annual or perennial crops.
	Alley cropping	Alley cropping and rows of woody polycultures (e.g., apples, hazelnut, berries) between crop fields.
	Multipurpose silvoarable	Multipurpose silvoarable includes fruit tree integration.
Forest Farming	Forest Farming	Forested areas used for cultivation of products within mixed forests. Examples include: (i) oyster mushrooms on logs, (ii) walnut trees in birch forests, (iii) shade-tolerant species such as herbs, berries, or nuts. Harvest of naturally growing/wild crops is excluded.
Homegardens / Kitchen gardens	Forest gardens / Edible forest gardens	Multi-layered polycultures of woody perennials with fruits, nuts, berries, vegetables, and herbs. May include small livestock (hens) or trees for timber/fibre. Range from small plots (60 m²) to larger areas (>0.5 ha) for commercial production.
		Food forest refers to larger forest gardens, while smaller plots are considered forest gardens.

Agroforestry System (Mosquera-Losada et al., 2018)	Terms Used in This Thesis	Description in This Thesis

Table 3. Overview of agroforestry farms in Papers I – III.

Type of AFS	N of Farms	Size of AFS	Size of Farms	Paper(s)
Silvopastoral systems	9	1.5–2,000 ha	7–2,000 ha	5 in Papers I & II (4 overlap with III); 4 unique in Paper III; Total: 9 farms
Silvoarable systems	2	a) 1 ha b) 8 ha	a) 230 ha b) 100–200 ha	1 in Paper II; 2 in Paper III (a) overlapping
Forest farming	3	~0.5–1.5 ha	2–33 ha	Paper III
Forest gardens	16	60 m²–7 ha	0.5–230 ha	12 in Papers I & II; 4 overlaps with Paper III; 2 farms overlap with I & II but other FG types are included. Total: 16 farms
Total farms:	19	–	–	–

The AFS listed below have been included in this thesis.

Silvopasture systems: Farms practising silvopasture integrate wooded elements with forage and livestock production (Mosquera-Losada et al., 2018a). A total of nine farms were included under this category. Subcategories comprised: (i) forest grazing, (ii) wood pasture, and (iii) integration of fruit trees with fodder/grazing. Forest grazing, observed on five farms in Paper III, covered areas ranging from 40 to 2,000 hectares and involved grazing sheep, cows, pigs, and horses within denser forest stands. Practices included clear-felling in spruce forests and designated pig-grazing areas. Two farms also employed continuous cover forestry alongside sheep and cow grazing in mixed forests. Wood pasture systems, characterised by lower tree density compared to forest grazing, were present on five farms and often overlapped with semi-natural grasslands. Integration of fruit trees with fodder/grazing, corresponding to multipurpose silvopasture in Mosquera-Losada et al. (2018a), was observed on two farms. Four farms from Paper II overlapped with those in Paper III, although Paper III incorporated new questions and additional data.

Silvoarable systems: Silvoarable agroforestry involves widely spaced woody vegetation intercropped with annual or perennial crops (Mosquera-Losada et al., 2018). This system was studied on two farms in Paper III. Alley cropping was the predominant practice, with rows of tree crops (e.g., apples) and shrubs (e.g., hazelnuts, berries) intercropped with annual crops such as cereals and sugar beet. Both farms fit the multipurpose silvoarable category, in which the woody component consists of fruit trees (Mosquera-Losada et al., 2018a).

Forest farming: This AFS involves the cultivation or harvest of natural standing crops for medicinal, ornamental, or culinary purposes (Mosquera-Losada et al., 2018a). Forest farming was observed on three farms (Paper III), including activities such as a) mushroom cultivation on logs and b) planting nut trees, shrubs, and herbs within existing forests c) planting of walnut trees into a birch forest. Continuous cover forestry practices were employed on all three farms. Forage forest was not included. In the Swedish context, forests are also commonly used for berry and mushroom picking as well as game management.

Forest gardens: Referred to as edible forest gardens in Papers I, II, and IV, these systems correspond at least partially to the homegarden category in Mosquera-Losada et al. (2018). To better align with terminology used by Swedish practitioners and to reflect the specific design and management approaches observed in the case studies, the term forest gardens is preferred. These systems are closely aligned with the concept of food forests as discussed in the literature (Park et al., 2018, 2019; Albrecht & Wiek, 2021). Forest gardens, as defined by Crawford (2010) and adopted by interviewed and participating farmers, forest gardens involve intercropped polycultures of edible woody perennials arranged in layers. Often, these gardens are designed to mimic young woodland, the forest edge zone, and the mosaic structure of such ecotones. In Paper III, three subcategories were identified:

1. Small forest gardens (60–200 m^2) featuring five layers and 30–100 species of fruits, nuts, berries, vegetables, herbs, and flowers. These primarily functioned as kitchen gardens for subsistence use.

2. Middle-sized fruit gardens with hens (200 m²–0.5 ha), featuring 2–3 layers, 10–20 species of trees and shrubs, with hens integrated into the system, replacing a planted ground layer. These gardens served both subsistence and commercial purposes.
3. Food forests (0.5–7 ha), with 2–5 layers and up to 400 edible perennial species. At one farm, the tree layer was also used for high-quality timber production for commercial purposes.

In Papers I and II, forest gardens of the same design were established at all 12 participating farms, using 60 m² plots with five layers of approximately 30 edible perennials. Four of these small forest gardens were also included in Paper III.

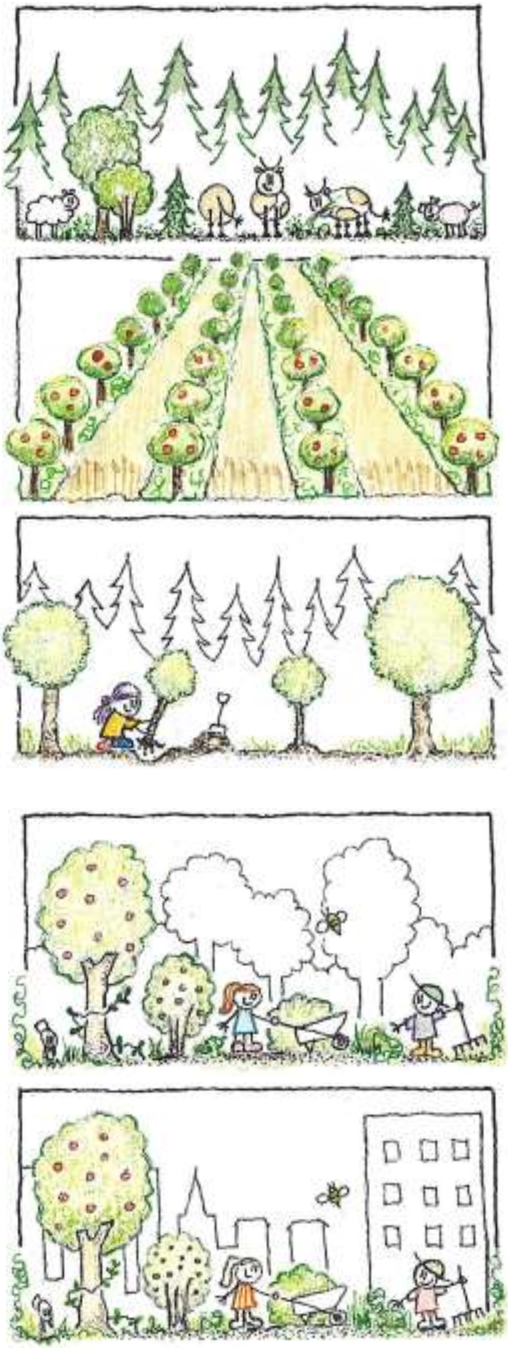
The land use of forest gardens in the empirical studies (Papers I–III) spans both agricultural and forested areas, whereas in the theoretical analysis of Paper IV, forest gardens for urban land use are examined.

Traditionally, perennials such as apples, gooseberries, and red and black currants have been important for food security and are part of kitchen gardens in Sweden. These are excluded from this thesis. The focus here is on agroforestry practices intentionally designed by farmers using multilayered polycultures of edible woody perennials on the same area unit, in line with the distinctions by Park et al. (2019). In the literature, the terms food forest and forest garden are often used interchangeably for multilayered systems (Park et al., 2018, 2019; Albrecht & Wiek, 2021; Moereels et al., 2024), and are distinguished from non-layered urban food forestry models (e.g., Clark & Nicholas, 2013).

The term forest garden and the multilayered model were consistently used by all participants in the PAR group in Papers I and II, and by all interviewees in Paper III. The model and terminology are inspired by handbooks and the work of Martin Crawford in the UK (Crawford, 2010) and Jacke & Toensmeier (2006). At the time of the investigations and the writing of Papers I, II, and IV, there were no published academic papers on the topic, so the term *edible* forest garden was adopted. In Paper IV, the terminology was simplified to forest garden, which is also used consistently in this thesis.

Riparian buffer strips: Another AFS category in Mosquera-Losada et al. (2018a) is riparian buffer strips, defined as perennial vegetation (trees/shrubs), natural or planted, between croplands or pastures and water sources (streams, lakes, wetlands, ponds) to protect water quality. These strips can be combined with arable lands (silvoarable) or grasslands (silvopasture) but are distinguished by their role in water protection. Although riparian buffer strips exist in Sweden, they were not present on the lands studied in this thesis and are therefore excluded.

In summary, the modifications done compared with Mosquera-Losada et al. (2018a) are the following (i) addition of subgroups for silvopastoral systems, (ii) exclusion of wild/natural crops (e.g., berries, mushrooms) in forest farming, (iii) the homegarden category is replaced with (edible) forest gardens, including defined subgroups.



a)

b)

c)

d)

e)

Figure 3: These types of agroforestry systems in Sweden are included in this thesis a) silvopastoral systems, b) silvoarable systems, c) forest farming, d) forest gardens e) urban forest gardens. Illustrations by Sophie Trygger.

8. Results

8.1 Ecosystem Services Attributed to Agroforestry Systems

8.1.1 Ecosystem Services Attributed to Silvopastoral Agroforestry Systems

Farmers attributed ecosystem services from all four categories – supporting, provisioning, regulating, and cultural - to their silvopastoral systems, identifying a total of 19 ecosystem services (Table 4).

Supporting ecosystem services included habitat provision and conservation of genetic resources. Traditional wood pastures were both maintained and restored through grazing, which farmers perceived as contributing to biodiversity conservation. One farmer noted:

> *"There are many insects; we see new species every day, and also the birdlife is valuable for us. In the future, we do not want to keep animals at the cost of wild biodiversity"*
>
> (Paper III).

Several farms practised continuous-cover forestry, viewed as beneficial for maintaining habitats and ecosystem functions. Genetic resource conservation was also supported through the maintenance of traditional livestock breeds, such as mountain-dwelling cows, and over 100 heritage apple tree varieties within wood pasture systems.

Provisioning ecosystem services included food, fibre, fuel, fodder, and fur. Farmers primarily produced meat from cows, sheep, and pigs, while milk was produced solely for household consumption (Paper III). Two silvopastoral systems, one traditional and one newly established, integrated apple trees with grazing animals, providing both apples and fodder. Many provisioning services were closely linked to supporting ES; for example, beef production was integrated with biodiversity conservation in mosaic landscapes comprising semi-natural grassland, dense and less dense forest, within a Natura 2000 area. One farmer explained:

"The government wants grazing animals to keep the landscape open. This is not primarily about meat production but about nature conservation, landscape management, and keeping the land open"

(Paper III)

He also referred to research showing improved tree growth in grazed areas compared with fenced, ungrazed sections. Fibre production included timber from birch, spruce, and pine, primarily for sale. Fuelwood was obtained from less dense wood pastures and mainly used for household consumption, although some farmers harvested coniferous and deciduous trees for sale during periods of high market prices. Fodder was sourced from tree leaves and branches, with pasture grasses remaining the primary feed. Sheep grazing also provided fur (Paper III).

Regulating ecosystem services included pollination, soil regeneration, climate mitigation, and climate adaptation. Pollinating insects were observed in wood pastures and valued by farmers. Soil regeneration was supported by no-ploughing and no-tilling practices, which farmers believed maintained plant diversity and soil health. One farmer noted:

"*The goal with our pastures is to find a production system without ploughing. Today, these fields maintain a diversity of plants that we want to support*"

(Paper III)

Climate mitigation was associated with the carbon-sequestering potential of woody perennials, whose extensive root systems store carbon. Farmers also viewed agroforestry as reducing reliance on fossil fuels. Climate adaptation benefits were linked to trees and shrubs providing shade and shelter for grazing animals, helping maintain fodder availability during droughts. Silvopastoral systems were perceived as enhancing resilience to climate change by creating more stable and self-sustaining landscapes (Papers II, III). Several farmers aimed to reduce input resources and dependence on fossil fuels, both for environmental reasons and to decrease reliance on imported resources. Silvopastoral systems were perceived as more circular and environmentally friendly, offering a sustainable alternative to conventional agriculture (Paper II).

Cultural ecosystem services included aesthetic qualities, human health and well-being, knowledge exploration, formal research and education, inspiration and informal learning, and biocultural heritage. Farmers emphasised that aesthetic qualities and personal well-being were central to maintaining silvopastoral landscapes. For example, restoring traditional pastures contributed to aesthetic qualities, inspiration, and the preservation of biocultural heritage. One farmer explained:

> "*We keep mountain-dwelling cows, sheep (for fur), and hens. We have had them for a long time because we want to open up and restore these pastures – just because we like them. They are nice, they are beautiful*."
> (Paper III)

Knowledge exploration occurred through continuous-cover forestry experiments, pig-assisted forest regeneration, and efforts to re-establish forests via grazing – considered one of the challenges of silvopastoral systems. One couple experimented with a multipurpose silvopastoral system by first integrating fruit trees with fodder crops and then introducing grazing animals.

Land stewardship was viewed as fulfilling, encompassing restoration of wood pastures, preservation of family-owned land, and creation of more open forests that accommodate both grazing and recreational activities such as horseback riding. Some farmers maintained livestock simply for enjoyment.

Formal research collaborations included university-led studies on tree growth in grazed versus ungrazed areas. Farms were used for student field visits, with two also incorporating silvopastoral systems into adult education programs, including six-month folk high school courses and weekend workshops. Beyond formal education, farms provided opportunities for inspiration and informal learning, hosting cafés, restaurants, rental cottages, workshops, and open events that offered visitors firsthand experiences of agroforestry practices. Farmers valued the cultural and ecological significance of wooded pastures, historically associated with traditional silvopastoral practices. One farmer described the landscape:

> "*In the wood pastures, there are roses, sloe, juniper, gooseberries, wild strawberries, chanterelles, oak, cherry, rowan, etc. – all of which*

historically must have been important for farm livelihoods. Birch for firewood is still harvested… Some visiting experts believe this landscape should be preserved, as it was intentionally created"

(Paper III)

Table 4. Ecosystem services attributed to silvopastoral systems in Sweden.

	ECOSYSTEM SERVICES (ES)	**Paper**
	Supporting ES	
Habitats for species	By keeping or restoring traditional wood pastures by grazing animals,	II, III
	By continuous cover forestry	III,
Genetic resources	Mountain-dwelling cows	II, III
	Varieties of apples in traditional wood pastures with more than 100 old apple trees.	III
	Provisioning ES	
Food products	a) Meat (beef, lamb, pork)	II, III
	b) Milk	II, III
	c) Fruits (apples) from silvopastoral systems in which the woody component are fruit trees.	III
Fiber	Timber (birch, spruce, pine).	II, III
Fuel	Firewood (mixed)	II, III
	Wood chips (mixed)	III
Fodder	From the woody components (e.g., leaves, branches) and from the ground (e.g., grass)	II, III
Fur	From sheep	III
	Regulating ES	
Pollination	Observations in wood pastures, forests	III
Regeneration of soils	By no ploughing/tilling	III
Climate mitigation	By carbon binding from large root systems of the woody perennials	III
Climate adaptation	By no-digging/tilling techniques	III
	Trees protected grazing animals and provided fodder during droughts	

	ECOSYSTEM SERVICES (ES)	**Paper**
	Supporting ES	
	Cultural ES	
Aesthetic qualities	Joy/appreciation of watching birds, insects etc.	III
Human health and well-being	Well-being for farmers from land stewardship such as restoration of wood pastures	III
	Recreational opportunities (horseback riding, hiking in wood pastures)	III
	Keeping of livestock for the joy of it	
Exploration of knowledge	Reforestation by pigs on boulder forest land	II,
	Continuous cover forestry	III,
	Experimentation with re-establishment of forest with grazing animals	III III
	Fruit trees combined with fodder (newly established) and grazing when established	III
Formal education	For adult education at two folk high schools (~six months courses) Shorter courses (~weekends) at several farms	II
	Study visits by university-students annually	
Academic research	Collaboration with Universities (e.g., investigations of tree growth with and without grazing animals)	III
Inspiration &informal learning	Inspirational environment for visitors to café, restaurant, rental cottages, workshops, and other on farm events.	III
Biocultural heritage	Traditional wood pastures with more than 100 old varieties of apple trees.	III

8.1.2 Ecosystem Services Attributed to Silvoarable Agroforestry Systems

Farmers attributed a range of ecosystem services from all four categories – supporting, provisioning, regulating, and cultural – to their silvoarable systems. 14 ecosystem services were identified across the two studied farms (Paper III) (Table 5).

Supporting ecosystem services included habitat provision, biodiversity conservation, and soil fertility enhancement. The presence of widely spaced trees and shrubs between arable crops provided microhabitats for insects, birds, and small mammals. Alley cropping systems created structural diversity in otherwise uniform arable fields, supporting pollinator populations and beneficial predators.

Provisioning ecosystem services included food, timber, and fodder. Fruit trees and shrubs intercropped with cereals or sugar beet provided both edible products (apples, hazelnuts, berries) and fodder for livestock. Farmers noted that combining crops and trees could diversify outputs while maintaining agricultural production.

Regulating ecosystem services encompassed soil protection, nutrient cycling, pollination, and microclimate regulation. Tree rows reduced wind erosion, improved soil structure, and supported pollinators and beneficial insects. Microclimatic benefits, such as shading and shelter for crops, contributed to drought resilience and moderated field temperatures. Carbon sequestration was also recognised as a potential benefit due to the presence of woody perennials integrated with annual crops.

Cultural ecosystem services included knowledge generation, inspiration, and aesthetic appreciation. Farmers viewed silvoarable systems as experimental platforms for testing novel cropping arrangements and for integrating agroforestry principles into conventional agriculture. Educational visits, workshops, and farm tours provided opportunities for knowledge sharing and engagement with the broader community. Aesthetic values of mixed tree-crop landscapes were also highlighted as contributing to farm identity and landscape heritage.

Table 5. Ecosystem services attributed to silvoarable agroforestry systems in Sweden.

	ECOSYSTEM SERVICES (ES)	**Paper**
Habitats for species	Woody alleys, in vast areas with annual cropping, beneficial for wildlife	III
	Supporting pollination insects	
Genetic resources	Testing 140 species /varieties of perennial crops suitable for arable lands	II, III
Nutrient cycling	Deep roots from perennials absorb the nutrients that the annual crops do not.	II, III
	Litter from the trees in the alleys are recycled.	
	Provisioning ES	
Food products	Annual crops cereals, sugar beets	III
	Fruits, berries, hazel nuts (some mixed) in woody rows	II, III
	Regulating ES	
Pollination	By woody rows supporting pollinating insects in the arable fields	III
Natural pest control	Predating birds, supported by poles, protects crops from voles	III
Regeneration of soils	No ploughing in the perennial rows	III
Climate mitigation	Carbon binding from large root systems of the woody perennials	III
Climate	No-digging/tilling techniques	III,
adaptation	Rows of trees and shrubs for increased resilience of arable lands from climate change effects	II

	ECOSYSTEM SERVICES (ES)	**Paper**
Control of water	Deep roots of woody components effects water retention	II
Control of eutroph-ication	Deep roots of woody components effect nutrient flows from the fields of annual crops	III
	Cultural ES	
Exploration of knowledge	Testing establishment of novel silvoarable systems	II, III
	Testing perennial crops for arable lands and of management models	II, III
Formal education	Used for student projects, BSc, MSc	III
Academic research	University test site, established for research (main purpose)	III,
	Testing of soils, nutrients, water	III
	Partners in research and development projects	II, III
Inspiration & informal learning	Demo site for other farmers and other agricultural actors	II
	Inspiration and learning study visits for students, officials and other groups.	

8.1.3 Ecosystem Services Attributed to Forest Farming

I identified 12 ecosystem services attributed by farmers to forest farming across all four categories: supporting, provisioning, regulating, and cultural (Table 6). Three systems of forest gardens were studied:

- **System a**: Oyster mushroom production on logs, where the surrounding mixed coniferous and deciduous forest provided moisture and shade beneficial for mushroom cultivation. The logs were arranged in small piles, each approximately 0.5 metres long, with an estimated optimal setup of up to 16 piles (Eksvärd et al. 2016).

- **System b**: Shade-tolerant edible perennial crops were planted in a mixed forest following the thinning of spruce and pine trees, creating favourable conditions for the production of food and medicinal plants. The site was typically visited once a year for harvesting and maintenance.
- **System c**: Walnut trees were planted within an existing birch forest. The forest environment was considered more suitable for tree establishment compared with arable land.

Supporting ES, such as habitat provision, were closely linked to the ways in which farmers intentionally modified their forest environments to establish forest farming systems. One farmer explained how they selectively thinned a mixed forest by removing all coniferous trees while retaining deciduous species, subsequently planting a mix of edible perennials. In doing so, both habitat structure and species composition were purposefully shaped.

Provisioning ES varied across the three forest farming systems (Paper III). System a involved oyster mushroom cultivation on logs in the forest. The primary products were oyster mushrooms, along with timber and firewood harvested from the surrounding mixed forest, which was managed using continuous cover forestry (CCF). System b involved thinning a mixed forest by removing coniferous trees and planting a variety of shade-tolerant edible perennials, including wild garlic (Allium ursinum), mini kiwi (Actinidia arguta), and various nut species, as well as medicinal plants such as five-flavour fruit (Schisandra chinensis) and devil's shrub (Eleutherococcus senticosus). Firewood was also an important product alongside food crops. System c focused on integrating walnut trees into an existing birch forest, with walnuts and firewood as the main products.

Regulating ES in forest farming differed somewhat from other AFS, as the surrounding forest played a crucial role in providing services such as climate regulation, moisture control, and natural pest management. Thus, the surrounding forest was considered an integral component of forest farming. Farmers viewed forest farming as a more resilient production system. Carbon sequestration was regarded as particularly significant, especially on farms with larger forested areas (approximately 20 ha), where CCF models were implemented to enhance long-term carbon storage. The farming couple behind System a emphasised that the surrounding forest maintained adequate moisture and provided essential shade for mushroom production, thereby increasing resilience and buffering against climate change effects. Similarly, the farmer managing System b described the forest as a suitable environment for low-input, low-maintenance forms of food production. The farmer practising System c explained that the birch forest provided a better environment for tree establishment than arable land, likely supported by mycorrhizal associations. Walnut establishment was more successful within the forest than in open fields, as the surrounding birch trees offered protection against frost, drought, and pests such as voles. The farmer further noted that young tree seedlings are often sensitive to extreme weather events.

Cultural ES attributed to forest farming included knowledge development, formal education, inspiration, and community engagement. A central element of knowledge development was the experimental and pioneering establishment of entire forest farming systems on each farm (Paper III). The farmers engaged in mushroom cultivation on logs described their work as an exploration of ways to enhance the profitability of CCF-managed forests, suggesting that larger-scale production could be particularly suitable along logging roads.

All three farmers were also engaged in adult education, each contributing to programmes at different folk high schools, where their farms and agroforestry sites served as vital platforms for experiential learning. Beyond formal education, the farms functioned as community hubs, hosting a variety of public events including festivals, workshops, and other gatherings, thereby attracting numerous visitors interested in forest-based agroforestry practices.

Table 6. Ecosystem services attributed to forest farming in Sweden.

	ECOSYSTEM SERVICES (ES)	**Paper**
	Supporting ES	
Habitats for species	Modification of a mixed forest by thinning of all coniferous trees and keeping the deciduous trees and planting edible crops into it.	III
	Provisioning ES	
Food products	Oyster mushrooms Fruits, berries, nuts, herbs, Walnuts	III
Medicine	Medical plants	III
Fiber	Timber	III
Fuel	Firewood	III
	Regulating ES	
Natural pest control	Less voles in walnut tree plantation from keeping the surrounding birch forest	III
Climate mitigation (global)	Carbon binding from large root systems and of the growing forest	III
Mitigation of microclimate	By the surrounding forest component in these systems which made the walnut trees less sensitive for frost and draught Better climatical conditions of moist and shade for mushroom cultivation	III
Control of moisture	The moist in the existing forest- beneficial for production.	III
	Cultural ES	
Exploration of knowledge	Testing of establishment of forest farming systems. Exploration of making CCF more profitable.	III
Formal education	Used within adult education on agroforestry. All three farms/ sites run folk high school programs	III
Inspiration, communi-cation	For visitors to festival, events, workshops etc. All three were vivid communities.	III

8.1.4 Ecosystem Services Attributed to Forest Garden Agroforestry Systems

Respondents attributed ecosystem services belonging to all four categories – supporting, provisioning, regulating, and cultural – to forest gardens (Table 7). In total, 19 ES were identified.

Supporting ES included habitat provision for species and the conservation of genetic resources (Papers I–III). Habitats were enhanced through the deliberate adoption of mixed vegetation, combining trees, shrubs, and other woody and predominantly edible perennials. Vegetables, herbs, and flowers formed the ground layer. This diverse habitat composition was among the main objectives in the establishment of 12 forest gardens (Paper I). After three years, farmers reported increases in floral diversity, as well as greater numbers of butterflies, bees, and birds (Paper II). In addition to supporting biodiversity, forest gardens also attracted wildlife such as moose, deer, and voles (Paper I), which in this context were considered pests (see Challenges section).

Forest gardens further contributed to the conservation and enhancement of genetic resources, as several farmers experimented with a wide range of species and varieties. Between 30 and 400 different edible perennials were cultivated across sites (Papers I, III).

Provisioning ES attributed to forest gardens included food, fibre, and fuel. Food production derived from a diverse range of trees, shrubs, vegetables, herbs, and flowers. Trees yielded fruits such as apples, pears, plums, and cherries, while shrubs provided hazelnuts and more than 15 species of berries. These included both commonly cultivated varieties – currants (Ribes spp.), raspberries (Rubus spp.) – and species relatively recently introduced to Sweden, such as saskatoon (Amelanchier alnifolia), honeyberry (Lonicera caerulea), sea buckthorn (Hippophae rhamnoides), silverberry (Elaeagnus commutata), dwarf/Japanese quince (Chaenomeles japonica), and aronia (Aronia melanocarpa) (Papers I, III).

Alongside cultivated crops, farmers integrated wild edible plants into their gardens (Papers I, III) and made use of naturally occurring plants in adjacent areas (Paper III). The planted ground layers included both edible and non-edible perennials, with remarkable species diversity ranging from 30 (Paper I) to 400 varieties (Paper III). The gardens extended the availability of fresh greens throughout a prolonged harvest season, an uncommon advantage in these climatic zones, and one which was recognised by farmers as highly valuable (Paper I).

In terms of nutrition, a 200 m² forest garden was estimated to provide sufficient food for one person for an entire year (Paper I). Certain crops were of particular importance: Good King Henry (Chenopodium bonus-henricus) emerged as the most promising perennial vegetable (Paper I). Other crops highlighted for their potential to expand production in Sweden included newly introduced berry species, alongside established crops such as apple (Malus domestica) and hazelnut (Corylus avellana) (Papers I, III). Consequently, 12 farms also established separate hazelnut groves (Paper II).

Egg production was observed in well-established, medium-sized forest gardens (200 m²–0.5 ha). Farmers noted that maintaining highly diverse ground layers was labour-intensive, and some instead allowed hens to graze beneath trees and shrubs (Paper III). One large-scale forest garden (7 ha) focused on cultivating high-quality timber species, including rowan (Sorbus torminalis), cherry (Prunus spp.), and walnut (Juglans spp.) for commercial purposes (Paper III). Timber from both coniferous and deciduous trees was also used for crafts and construction. In addition, pruned branches were repurposed for mulch and compost, while some timber was harvested for domestic use (Paper III). Forest gardens further provided fuel in the form of mixed-origin firewood for household consumption (Paper I).

Regulating ES included pollination, natural pest control, soil regeneration, and climate regulation (Papers I–III). Climate regulation was the most frequently cited service (Paper III). Farmers considered their systems to contribute to carbon sequestration due to the extensive root systems of woody perennials. Furthermore, the absence of tillage and the reliance on perennial crops were perceived to increase resilience to drought (Paper III). Pest control was enhanced by integrated practices, such as allowing hens to manage vole populations (Paper III). Soil regeneration was supported by herbaceous perennials and evergreen species (Paper I), the application of mulch, and the development of planted ground layers (Paper III).

Cultural ES encompassed aesthetic values, human health and well-being, knowledge exploration, formal research and education, inspiration and informal learning, social relations, and connection with nature. The visual appeal of flowering gardens attracted pollinators and birds (Papers I–II), which farmers associated with enhanced well-being. Some forest gardens also became important gathering spaces for visitors (Papers II, III). One site played a central role in a folk high school, providing educational programmes on agroforestry and related subjects. The gardens were also viewed as health-promoting environments for staff and students:

> "*The school has also focused on good outdoor environments and health – places for rest, calm spaces, and… well, environmental psychology. We want to develop a good outdoor environment for the health of everyone working and studying here.*"
>
> (Paper III)

Forest gardens facilitated knowledge exploration in multiple ways. Farmers experimented with species selection, crop productivity, flavours, establishment methods, land-use strategies, and the adaptation of entire systems to northern climatic conditions (Papers I–III). Extensive species and variety trials were carried out, with individual gardens hosting between 30 and 400 varieties (Papers I, III). One farmer explained:

> "*We test a wide variety of crops; they end up in our market garden. We do a lot of research and development work.*"
>
> (Paper III)

Many of these new species were considered to hold potential for income diversification, improved nutrition, and expanded flavour profiles, thereby contributing to increased domestic food production in Sweden (Papers I, III).

The pursuit of knowledge often originated from farmers' own curiosity (Paper III), but in some cases was driven by formal research initiatives, such as the silvoarable system trials (Paper III) and the (PAR) project (Papers I–II). Some farmers also carried out independent investigations, including species inventories and assessments of water and nitrogen balances (Paper III).

Forest gardens further played a role in formal education. They were integrated into adult education programmes at three folk high schools (lasting ~six months) and used for shorter courses (weekend formats) on several farms. They also functioned as sites for informal learning and inspiration, attracting visitors to cafés, restaurants, rental cottages, workshops, festivals, and other events, often with explicit educational purposes. As one farmer explained:

> "*We aim to create an educational environment for children and adults, where they can gain inspiration and learn about ecology, forest gardens, food production, and gardening.*"
>
> (F8, Paper III).

Through these activities, forest gardens also contributed to the strengthening of social relations within and beyond farming communities.

Table 7. Ecosystem services attributed to forest gardens in Sweden.

		Paper
	Supporting ES	
Habitat for biodiversity	Diversity of perennial vegetation (trees, shrubs, herbs, vegetables, flowers).	I, II, III, IV
Genetic resources	Genetic material from cultivated biodiversity, up to 400 varieties.	I, II, III
Nutrient cycling	Use of mulch, no tilling, intercropping of nitrogen-fixing plants.	I
	Provisioning ES	
Food products	a) Diversity of edible perennials (fruits, nuts, berries, herbs, vegetables, flowers), ranging from 30–400 species/varieties. b) Eggs. c) Wild food. d) Nutrient and energy self-sufficiency. e) Prolonged harvest season from perennial crops. f) Mix of edible perennials in urban areas.	
Fibers	a) Timber for household consumption. b) High-quality timber for sale (walnut, rowan, cherry). c) Wood for crafts, construction materials, mulch, compost.	
Fuel	Firewood (mixed sources).	
	Regulating ES	
Pollination	Observations of pollinating insects.	
Pest control	Use of hens for vole control.	
Soil regeneratio n	a) Use of herbaceous perennials and evergreen plants in layers. b) Application of mulch and planted ground layers. c) Use of nitrogen-fixing crops instead of fertilisers.	
Climate mitigation	a) Mitigation of GHG emissions through carbon sequestration. b) Carbon storage from large root systems of woody perennials. c) Minimised use of fossil fuels. d)	

	Increased domestic production reducing dependency on global markets.	
Climate adaptation	a) No-dig/tillage techniques and perennial crops increase resilience to drought. b) Greater vegetation diversity (trees and shrubs) compared to lawns.	
	Cultural ES	
Aesthetic qualities	Beauty associated with floral richness and the presence of butterflies, bees, and birds.	I, II
Health & well-being	a) Benefits for producers. b) Provision of a satisfying living environment. c) Healthy working environment for others (e.g. pupils, staff at folk high schools). d) Restoration from psycho-physiological stress and attention fatigue.	I, II I, III III IV
Knowledge exploration	a) Varieties of cultivated species, new crops for Sweden, productivity, new land use, and forest garden systems in northern climates. b) For producers. c) For other actors.	I, II, III I, II, III II, III
Formal education	a) Adult education at three folk high schools (~6 months). b) Short-term courses (~weekends).	III
Academic research	a) Collaboration with universities. b) Independent investigations and production of reports, including species inventories.	I, III
Inspiration & informal learning	Environments for visitors to cafés, restaurants, rental cottages, workshops, festivals, and other events.	III
Social relations	a) Social interactions via cafés, tourism, workshops, and events in rural areas. b) Social interaction in forest gardens organised as community gardens in urban areas.	III IV
Contact with nature	Provision of environments more similar to the "natural world" than lawns in urban settings.	IV

8.1.5 Ecosystem Services Attributed to Forest Gardens in Urban Areas

Ecosystem services provided by forest gardens in urban areas were, to some extent, similar to those in rural contexts, particularly in relation to biodiversity habitats, food provision, climate adaptation, health and well-being, inspiration and learning, and social relations. However, two key differences stood out: urban land availability was more constrained, and urban areas are characterised by higher population densities. In Paper IV, we analysed the potential of urban forest gardens, drawing on insights from Papers I and II, as well as findings from Schaffer (2016).

With respect to supporting ecosystem services, we argued that urban forest gardens could enhance biodiversity by providing habitats through their mixed vegetation structures (trees, shrubs, perennial herbs, vegetables, and flowers). This structural diversity was also identified as contributing to climate regulation and adaptation, particularly in comparison with the dominant land use of lawns in Swedish urban green spaces (Hedblom et al. 2017; Paper IV).

For instance, we estimated that the same combination of edible perennials observed in the 60 m² plots examined in Paper I could yield comparable food products – such as fruits, nuts, berries, vegetables, and herbs – if implemented in urban settings, albeit in smaller quantities than in rural areas. Such perennial vegetation could simultaneously contribute to climate adaptation.

A notable distinction between urban and rural forest gardens is their potential role in facilitating contact with nature for urban residents. The three-dimensional vegetation structures of urban forest gardens more closely resemble natural woodland ecosystems than lawns, thereby offering a more immersive and restorative nature experience (Paper IV). We therefore systematically examined the potential of forest gardens to serve as health-promoting environments, particularly for stress recovery and restoration from psycho-physiological fatigue, using the Perceived Sensory Dimensions (PSD) framework (Paper IV). Our findings indicate that urban forest gardens are highly multifunctional, supporting human well-being and sustainability in multiple ways.

When organised as community gardens, such as those established in Stockholm (Schaffer 2016), urban forest gardens contributed not only to healthy food production and climate resilience but also to social cohesion (Paper IV).

8.1.6 Multifunctionality of Agroforestry Systems

The results reported in Papers I–IV indicate that AFS contributed to all four categories of ecosystem services: supporting, provisioning, regulating, and cultural. Across the four types of AFS studied, 25 distinct ES were identified.

Six of these ecosystem services were common to all AFS types, including habitat provision for biodiversity, food production, climate adaptation, knowledge exploration, formal education, and informal learning and inspiration. Seven additional ES were shared by three out of the four AFS types, namely genetic resources, fibres, natural pest control, soil regeneration, climate mitigation, and formal research (Table 8).

Each type of AFS simultaneously generated multiple ecosystem services, which were highly interconnected rather than functioning as separate or discrete components. Further discussion of these interrelationships is provided in the Discussion section.

Table 8. Multifunctionality of agroforestry systems.

Category of ecosystem services	Silvo-pasture	Silvo arable	Forest farming	Forest gardens
Supporting ES				
Habitat for biodiversity	✓	✓	✓	✓
Genetic resources	✓	✓		✓
Nutrient cycling		✓		✓
Provisioning ES				
Food products	✓	✓	✓	✓
Medicinal plants			✓	
Fibres	✓		✓	✓
Fodder	✓			
Fuel	✓		✓	✓
Fur	✓			
Regulating ES				
Pollination	✓	✓		✓
Pest control		✓	✓	✓
Soil regeneration	✓	✓		✓
Climate mitigation	✓	✓		✓
Climate adaptation	✓	✓	✓	✓
Control of water flows		✓		
Control of eutrophication		✓		
Control of moisture			✓	
Cultural ES				
Aesthetic qualities	✓			✓
Health and well-being	✓			✓
Knowledge exploration	✓	✓	✓	✓
Formal education	✓	✓	✓	✓
Academic/formal research	✓	✓		✓
Informal learning and inspiration	✓	✓	✓	✓
Social relations				✓
Contact with nature				✓
Biocultural heritage	✓			

8.2 Motivations of Farmers to Practise Agroforestry

All farmers expressed multiple motivations, which were grouped into four broad categories: (1) sustaining the household economy, (2) supporting environmental sustainability, (3) mitigating and adapting to climate change, and (4) landscape stewardship (Paper III) and (5) methods that were less dependent on input resources (Paper II).

Sustaining the household economy was an important motivation for practising agroforestry, although it was always combined with other drivers. Producing good yields was central for farmers on the studied farms:

> "*The ambition with the farm is to contribute positively to the ecosystems and at the same time produce useful products. The aim is to go from producing more to how to produce and developing methods that can use the ecosystem services.*"
>
> (Paper III)

However, achieving substantial yields on newly established agroforestry farms required time. Consequently, some farmers relied on income from off-farm work:

> "*The aim is to generate income for us, to make a living from the harvest, the processed products and selling seedlings from the forest garden, and our eco-café, and educational activities such as courses, lectures and guided tours. We also do (consultancy) ecosystem-based management and nature conservation for other producers.*"
>
> (Paper III)

Farmers employed various business models and strategies to sustain their farm economy. Many integrated agroforestry with other production systems, such as annual crops and conventional forestry. Income was generated not only from product sales but also by "selling" the site and agroforestry knowledge through courses, events, tourism, and sales of seedlings and processed products. Some farmers relied on off-farm part-time work, consultancy, or teaching, leveraging their expertise in AFS.

Several respondents had only recently established their farms, recognising that tree planting takes time, and therefore adopted alternative strategies to maintain their livelihoods. For example, F1 compared prices for berries with cereals in an alley cropping system, noting that berries commanded ten times the price per areal unit. F7 focused on high-quality timber, which could command favourable prices in Germany. F2 highlighted the role of subsidies for forest grazing in sustaining farm income. F6 and F10 emphasised that selling products was not their primary goal; instead, income was generated through education and events on the farm. Conversely, F13 experienced challenges selling meat locally due to public-sector procurement issues. F9 transitioned from commercial to self-subsistence production for family reasons, intending to resume commercial fruit production in about ten years, noting that the trees would remain and likely be more productive with time. Additionally, two couples received pensions, one of whom initiated an agroforestry project post-retirement approximately 15 years ago; in two other couples, one partner received pension income.

Supporting environmental sustainability was explicitly mentioned by 11 of 13 farmers. They referred to multiple aspects of sustainability, including maintaining biodiversity, improving soil fertility, recycling organic matter, and enhancing animal welfare. None of the farms used pesticides or chemical fertilisers, and three were certified organic. Some farmers highlighted biodiversity as a central priority:

> "*To keep the richness of biodiversity is more important than to produce for selling; this is a shift in mindset that has happened since 2011 when we started.*"
>
> (Paper III)

Seven farmers emphasised the role of agroforestry in both **climate mitigation** (e.g., carbon storage) and **adaptation** to extreme weather events. One farmer explained:

> "*To establish a food-producing ecosystem that is beneficial for biodiversity and is adapted to climate change and that also stores relatively big amounts of carbon both in the ground and in the biomass.*"
>
> (Paper III)

Silvopastoral systems were perceived as particularly resilient to droughts, such as those experienced in 2018, as the vegetation provided better fodder and shade for livestock. Similarly, forest gardens retained soil moisture during dry periods due to planted ground layers and organic litter layers.

Landscape stewardship was another key motivation. Farmers sought to use traditional knowledge to restore and maintain historical agroforestry landscapes (F3, F4). One farmer who had recently initiated forest grazing explained:

> "*This piece of land (the birch forest grazed by sheep) makes our land coherent. It is located between our farm and the lake, making it accessible. It is also a place for us (humans) for hiking and horseback riding. This is good management of the landscape. It is also beautiful.*"
>
> (Paper III)

In Paper II, in addition these motivations, the PAR-group included environmental concerns related to the use of commercial fertilisers, pesticides, and fossil fuels. Additionally, they sought production methods that were **less dependent on such input resources** (Paper II).

Among the 12 farms a narrow focus on agricultural production alone was considered insufficient. Farmers sought models that placed equal value on generating ecosystem services. Consequently, forest gardens were designed to optimise multiple functions, including food and timber production, nitrogen fixation, nutrient accumulation, pollinator support, carbon sequestration, and the creation of a favourable microclimate. The design and plant selection for these 60 m² plots were developed collaboratively by participating farmers, with the aim of fostering habitat diversity.

The principles of agroecology guided the design of the forest gardens, incorporating functional design, intentional biodiversity use, multifunctionality, and efficient nutrient cycling. Farms implementing this approach aimed to produce food either for household consumption, for the market, or both (Paper I).

8.3 Challenges with Agroforestry in Practise

8.3.1 Perceived Challenges by Farmers and the PAR-group

Alongside the numerous benefits of AFS, farmers in (Paper III) and the PAR-group (Paper I&II) highlighted several challenges, regarding AFS which were grouped into five broad categories: (i) management challenges, (ii) lack of appropriate technologies, (iii) insufficient availability of plant materials, and (iv) limited knowledge of agroforestry and cultural expectations (v) lack of supportive institutional structures and subsidy systems

Management challenges were primarily associated with the complexity of AFS. For example, the high diversity of species in the ground layer of forest gardens was perceived as an obstacle to achieving consistent and sufficient yields. Farmers also faced practical difficulties, such as pest infestations, particularly from voles. Some farmers addressed these challenges by simplifying their systems, reducing the number of species, and incorporating hens for pest control:

"We have problems with voles, and therefore we keep hens in the garden. Instead of a planted ground layer, we maintain trees, shrubs, and hens."
(Paper III)

Similar concerns about the complexity of forest gardens were reported by farmers. Experiences from the establishment phase also highlighted the necessity of rigorous weed management and the use of high-quality mulching materials. Edible forest gardens were considered particularly suitable for specific environments, such as field boundaries, islets, and corridors, and for developing multi-strata alley cropping systems (Paper II).

Technological challenges were identified in Paper III as the lack of appropriate tools for small-scale agroforestry farms and the limited availability of necessary equipment. Similar concerns were raised in Paper I, where farmers suggested technological solutions such as drones to support agroforestry management.

Availability of plant materials represented another challenge. Several new species of edible perennials were gaining popularity, yet the limited availability of seedlings constrained the expansion of these systems. One farmer noted:

"The supply of plant varieties is a limitation in Sweden. For example, everyone agrees that Japanese quince is a fantastic, beautiful, and useful fruit - an excellent alternative to citrus - but it is nearly impossible to find seedlings here."

(Paper III)

Similar concerns were reported by the PAR, emphasising that selecting suitable species and high-quality varieties is critical to avoid delays during the establishment phase. The high cost of quality plant materials was also seen as a constraint on agroforestry development (Paper I).

Knowledge-related challenges were primarily associated with silvopastoral systems and concerned establishing and maintaining agroforestry on new land:

"We do experiments with grazing and forestry. The reforestation is a challenge."

(Paper III)

The PAR-group further highlighted challenges specific to multipurpose silvopastoral systems with fruit trees. For example, growing fruit trees on natural pastures with uneven terrain made it difficult to arrange them in orderly rows. Farmers also noted challenges in preventing fallen fruit from contamination and in implementing effective harvesting techniques. Although these systems have the potential to generate higher production, all stages of production were found to require more time compared with conventional grazing areas (Paper II).

Farmers emphasised that promoting silvopastoral practices requires a re-evaluation of existing trees in pastures. On one hand, they highlighted the importance of helping farmers recognise the potential of their current resources and management practices. On the other hand, they stressed the need to engage authorities and adapt Rural Development Program (RDP) support systems to better accommodate silvopastoral farming. Farmers also called for further research on the benefits of multifunctional pasture systems and best practices for their management. Financial revaluation of products such as cider apples and wood were another key concern. Prevailing societal norms and market systems were perceived as failing to assign adequate economic value to farm products and ecosystem services, including carbon sequestration (Paper II).

Establishing plant nurseries that provide information on edibility was also highly valued. Farmers emphasised the need for improved knowledge about intercropping, plant compatibility, and the nutritional value of different species (Paper I).

Regarding forest gardens, the PAR group concluded that they remain poorly understood in Sweden. To improve awareness and acceptance, the group called for the development of well-functioning prototypes across different growing zones, particularly for public spaces such as parks and campuses (Paper I).

For silvoarable systems particular challenges regarded planting woody crops required approval from both neighbouring landowners and county administrative boards, adding further complexity. Support from the RDP was minimal, and the application process proved highly cumbersome. Unresolved questions regarding harvesting techniques also posed a challenge (Paper II).

Cultural perceptions of landscape use also presented challenges. There was ongoing debate about whether trees should be planted on arable land. Among small-scale farmers in woody landscapes, planting trees on already limited crop fields - often surrounded by forests - was not considered desirable, as these fields had been cleared with considerable effort by previous generations and quickly revert to forest without active management. These farmers also prioritised preserving land for fodder production. Conversely, farmers with larger landholdings or marginal lands no longer productive for cereals showed greater interest in integrating cereals or pasture with fruit and berry production (Paper II).

One major challenge is institutional, particularly the lack of support from the Common Agricultural Policy (CAP) and misalignment with existing subsidy structures. For example, farmers expressed concerns about the financial viability of silvopastoral systems in Sweden, which depend heavily on funding from the RDP (Eksvärd & Marquardt, 2018). Since the RDP operates under specific production rules, its framework does not currently accommodate multifunctional production approaches, making development of such systems financially difficult (Paper II).

Another challenge identified by the PAR group was the limited agroforestry expertise within the agricultural extension service. Agroforestry requires integrated knowledge from horticulture, forestry, and agriculture, yet this interdisciplinary approach is not well supported within existing advisory structures (Paper II). Moreover, the concept of agroforestry remains largely unknown in Sweden among farmers, retailers, and consumers, although some practices, such as traditional wood pastures (*hagmark*), are more familiar (Paper II).

Based on four years of exploring modern AFS in Sweden, the PAR group identified several key challenges that must be addressed for these land-use models to expand and increase market-level production, rather than remaining primarily household-based (Paper II). In addition to the institutional support, several factors were identified as critical for scaling up (increasing plot size) and scaling out (expanding adoption) of AFS in Sweden. In conclusion, the PAR group argued that for agroforestry to grow and go from niche to mainstream in Sweden, several factors must align:

- Availability of new crop varieties,
- Innovations in production systems, tools, and methods,
- Shifts in consumption patterns and diets,
- Improved market access,
- Evolving cultural expectations of landscapes,
- Enhanced knowledge of agroforestry design, species interactions, and nutrient composition.

….Additionally, the group emphasised the need for further research, establishment of demonstration plots, long-term monitoring and evaluation, greater support from authorities, and policy adjustments to better align subsidies and regulations with agroforestry practices (Paper II).

8.4 Niche Innovations in Agroforestry Systems

This section presents the results for Research Objective 3, which analyses transitions from conventional land-use practices to multifunctional and sustainable AFS. The focus is on real-world examples of agroforestry niche innovations identified in Papers I, II, and III.

8.4.1 Silvopastoral systems

Silvopastoral systems, which have a long historical presence in Sweden, constitute a key area of agroforestry innovation. These systems combine forestry with livestock grazing, offering an alternative to traditional monocultural forestry. Historically, silvopastoral practices date back centuries and currently represent the largest portion of AFS in Sweden, covering approximately 99 % of AFS land (den Herder et al., 2017).

In this study (Papers II and III), niche innovations were identified in which these systems were adapted to address specific challenges. For example, Farm 1 combined pig farming with forestry on land dominated by boulders that were inaccessible to machinery. This innovation not only enabled productive use of otherwise difficult land but also provided both timber and pork, thereby reducing reliance on machinery and fossil fuels.

Several farms experimented with Continuous Cover Forestry (CCF), integrating forest cover with grazing animals while maintaining ecological balance and biodiversity. This approach offers a potential solution to the vulnerabilities of large-scale monocultures, which are susceptible to pests, diseases, and extreme weather events.

A particularly illustrative case is Farm 10, where fruit trees were combined with fodder crops and grazing sheep in a silvopastoral system. Compared with conventional apple orchards, this approach is more environmentally sustainable and allows for the production of hay and fodder during the early years while the fruit trees mature. Over time, the system can generate additional outputs, including meat and manure, thereby enhancing overall farm productivity.

8.4.2 Silvoarable systems / Alley cropping

In 2019, two Swedish farms established the first novel, multipurpose silvoarable systems by integrating annual crops with rows of woody plants such as apple trees, hazelnuts, and berries, and sometimes mixed within the same row. This niche innovation contrasts with traditional monoculture farming and addresses multiple challenges, including biodiversity loss, water quality degradation, and climate change impacts. More often timber trees are grown within the crop rows, but instead planting tree crops and shrubs in alley cropping systems is considered innovative (Wolz et al., 2018). To add timber trees on arable land in a forested country as Sweden is less suitable, according to farmers in Paper II. In addition, berry and hazel shrubs would comparably faster contribute to an extra income compared to timber trees (Wolz et al., 2018).

Farm 1 combined its alley cropping system with the cultivation of 140 varieties of edible perennials in an adjacent area. Additionally, perennial cereals were tested in collaboration with a nearby university. At Farm 11, 7–8 hectares were allocated as a research site for investigating below-ground factors such as soil health, water, and nutrient management. This site also hosted researchers and BSc/MSc students conducting field studies. Farm 1 and 11 refers to Paper III.

These farms serve as knowledge hubs for innovative agroforestry practices. Farm 1, in particular, was designed as a demonstration site for other farmers. Both farms illustrate how integrating woody elements into arable land can diversify farm income while simultaneously contributing ecosystem services, including pollination, natural pest control, and soil regeneration.

8.4.3 Forest farming

Three Swedish farms explored forest farming systems, representing another form of niche innovation in agroforestry. These systems utilise forested environments for food production, leveraging surrounding ecosystem services to enhance productivity.

- **System a)** involved oyster mushroom cultivation on logs within a mixed forest. Natural moisture and shade provided by the forest created optimal conditions for mushroom growth.
- **System b)** focused on planting edible, shade-tolerant perennial crops in a mixed forest after thinning spruce and pine trees, creating a more favourable environment for these crops.

- **System c)** involved planting walnut trees within an existing birch forest. The forest's natural conditions offered protection against frost and voles, while mycorrhizal networks enhanced tree establishment.

These forest farming systems represent niche innovations in forested landscapes for food production and contribute to the multifunctionality of forests. When integrated with CCF, forest farming provides alternative income sources for farmers while maintaining the ecological functions and values of the forest. Furthermore, these farms serve as important sites for spreading awareness and knowledge, hosting formal adult education programmes, events, festivals, and study visits that promote the adoption of forest farming practices.

8.4.4 Forest gardens

The establishment and exploration of forest garden systems in Sweden represents a significant niche innovation within agroforestry. Forest gardens Through a collaborative effort between farmers and researchers, this project aimed to develop and test agroforestry practices adapted to northern climates (Paper I). The model employed a multi-strata, layered system of intercropped edible perennials, designed for a 60 m² plot. This system, co-developed by researchers and farmers, represented a novel agroforestry practice, positioning forest gardens as an innovation within Swedish agriculture (Paper II). This would be in line with niches as critical spaces for experimentation, learning, and momentum-building for alternative practices (Schot and Geels 2008), and niches as enabling new actor configurations (Darnhofer, 2015).

Forest gardens contrast sharply with conventional monocultural agriculture, which typically focuses on single-purpose systems. By diversifying production, forest gardens provide multiple ecological and economic benefits. These gardens integrate a variety of vegetation types, including trees, shrubs, vegetables, and herbs, contributing to biodiversity, soil conservation, carbon sequestration, and pollination. Their potential to provide nutritious food products while maintaining and enhancing ecosystem services makes them a viable model for multifunctional land use.

The model was inspired by larger-scale forest gardens in Devon, UK, as documented by Crawford (2010). Despite initial challenges related to the lack of suitable plant species for Sweden, forest gardens have demonstrated adaptability across different land types, including arable fields, forests, pastures, and lawn-based kitchen gardens, without significant differences in productivity (Paper I).

One of the primary aims of these forest gardens was to integrate ecological functions, such as nitrogen fixation and carbon sequestration, while enhancing local microclimates. The emphasis on native and perennial species has proven beneficial for promoting these ecological functions and ensuring long-term sustainability. Early challenges included managing the high biodiversity within these systems; some farmers employed innovative strategies, such as using hens to control pests like voles that threatened fruit trees.

The largest forest garden which combine seven hectares of high-quality timber species with 25 species of edible perennials (farmers' own investigation), further emphasise the multifunctionality of agroforestry. This niche innovation demonstrates the potential for integrating forest-based food production into existing forestry systems, which traditionally focus on monocultures and clear-cutting – practices that often have negative impacts on biodiversity, climate resilience, and socio-cultural functions.

In summary, AF can be understood as a niche innovation system situated between the agricultural and forestry regimes. It offers a space for co-developing alternative, multifunctional land-use models that challenge conventional sectoral boundaries. Within this system, the following niche innovations were identified in Sweden

1. Novel silvopastoral arrangements, such as integrating forestry with pig keeping;
2. Development of multipurpose silvoarable alley-cropping systems with multi-cropped tree and shrub rows;
3. Exploration of three models of forest farming;
4. Establishment of twelve forest gardens within the PAR project; and
5. Forest gardens combining high-quality timber production with edible perennial crops.

Niche innovations in agroforestry, demonstrated through silvopastoral systems, silvoarable systems, forest farming, and forest gardens, highlight the growing potential of these practices in Sweden. Each system presents unique approaches to land use that integrate food production with ecological and socio-cultural benefits. The combination of practical implementation, knowledge exploration, and knowledge sharing positions these farms as key actors in transforming Swedish agriculture into a more sustainable and multifunctional system. Integrating agroforestry into various land types – including forested lands, arable lands, and urban green spaces – offers a model for multifunctional land use that can contribute to sustainability, biodiversity, and climate resilience across diverse landscapes.

9. Discussion

9.1 Agroforestry Systems as Providers of Multifunctionality (linked to Objective 1)

This thesis set out to explore AFS in Sweden as a means of creating multifunctional landscapes – those that simultaneously support biodiversity, human well-being, and productive land use. In relation to Research Objective 1, I examined the tangible and intangible benefits of silvopastoral systems, silvoarable systems, forest farming, and forest gardens. Despite their marginal status within the Swedish land-use regime, all four systems demonstrated high multifunctional potential, providing new empirically based insights on agroforestry in the Nordic region and advancing theoretical discussions on ecosystem services and landscape multifunctionality.

Across the systems studied, the findings consistently demonstrate the simultaneous provision of multiple ecosystem services spanning all categories (Table 8). Silvopastoral systems stood out for fodder provision and animal welfare, while also contributing to climate change mitigation and adaptation. Silvoarable systems effectively combined food production with regulating services, including soil regeneration and the control of nutrients and water flows. Forest farming uniquely integrated the production of food and medicinal plants with regulating, cultural, and educational benefits derived from forestry. Forest gardens provided the broadest suite of services, encompassing biodiversity habitat, genetic resources, nutrient cycling, multiple provisioning and regulating functions, and the widest range of cultural benefits, including biocultural heritage and strengthened social relations.

Beyond these system-specific strengths, a further and significant finding is that AFS enhance several dimensions of resilience in food production systems – at the local farm level, across multifunctional landscapes, and potentially at the national level for food security. Farmers diversify outputs, reduce dependence on external inputs, lower costs, and require comparatively little machinery and labour. Importantly, farmers in this study were not merely recipients of ecosystem services; they actively shaped them through deliberate design and management. Intercropping with trees, shrubs, and other perennials was central to enabling these systems to function as multifunctional landscapes. This key finding directly addresses Knowledge

Gap 1, AFS in the Nordic region, while also addressing Knowledge Gap 4 by illustrating the potential of under-researched novel AFS, such as forest gardens and forest farming, to contribute to both ecological and socio-economic resilience.

This thesis also broadens the understanding of agroforestry on forested land, which has traditionally focused on various forms of forest grazing (Öllerer et al., 2019). My study on AFS in Sweden also includes other practices on such land: small-scale forest gardens (measured in square metres) functioning as kitchen gardens established on forest land; relatively larger plots (hectares) focusing on high-quality timber production; and novel models of forest farming. Taken together, these systems could function as new models for multipurpose forestry in reforested areas in the Nordic region. Kumm and Hessle (2023) emphasise the role of grazing animals in enhancing biodiversity by maintaining mosaic pasture–forest landscapes in Sweden, which can simultaneously contribute to domestic meat production and national climate change strategies.

The diversity of functions highlights the value of combining different AFS within a landscape to enhance functional complementarity, ensuring that key ecosystem services are maintained under changing environmental and socio-economic conditions. In this sense, AFS represent a form of land sharing, reconciling biodiversity conservation with productive land use. Their contributions to regulating services, particularly climate mitigation and adaptation, further underscore their relevance as land-use models that prepare for the uncertainties associated with global warming.

These results resonate with prior findings on silvopastoral and silvoarable systems (e.g., Jose, 2009; Wilson & Lovell, 2016; Torralba et al., 2016; Garcia de Jalón et al., 2018; Sollen-Norrlin et al., 2020), but provide unique empirical validation for temperate and boreal regions, thereby addressing Knowledge Gap 1. Importantly, this thesis extends the empirical base by including forest gardens and forest farming, filling Knowledge Gap 4 and broadening the scope of agroforestry research in Europe.

Furthermore, the evolution of agroforestry concepts provides a broader interpretive frame. Initially defined as the integration of agriculture and forestry for productivity, agroforestry has progressively expanded into a paradigm of multifunctional landscapes that combine production with ecological and cultural values. In its most recent articulation, this integration represents not only a practical approach but also a broader domain for policy and regulation (van Noordwijk et al., 2018). My findings situate Swedish AFS within this trajectory, illustrating their potential to simultaneously contribute to conservation, production, and climate resilience, and highlighting their relevance for future land-use policy in Northern Europe.

This thesis also emphasises the often-overlooked cultural and health-related dimensions of AFS. Paper IV, which focused on urban forest gardens, employed the concept of salutogenic affordances – environments that promote human health, well-being, and in some cases social cohesion (Antonovsky, 1996; Grahn & Stigsdotter, 2010). Analysis revealed that forest gardens supported all eight Perceived Sensory Dimensions (PSDs). Four of these – Serenity, Nature, Space, and Rich in Species – are closely linked to more “natural” ecosystems, while the remaining four – Prospect, Refuge, Culture, and Social – relate to cultural landscapes. Importantly, the rural forest gardens studied were perceived by farmers as inclusive, interactive, and restorative environments, supporting multiple dimensions of well-being and social cohesion. Additionally, aesthetic quality emerged as a recurring cultural ecosystem service, consistent with earlier findings on more traditional forms of AFS (Fagerholm et al., 2016a). Taken together this widen the health-dimensions beyond the positively nutritious health effects of nuts and berries documented by Lovell et al., (2023). However, this research demonstrates that novel AFS, particularly forest gardens, generate a broadened spectrum of cultural ecosystem services, including health promotion, learning opportunities, and enhanced social relations. These findings contribute to Knowledge Gap 2 (limited understanding of socio-cultural dimensions of AFS) and Knowledge Gap 5 (scarcity of research on urban agroforestry) as highlighted by other scholars (Fagerholm et al., 2016a; Castle et al., 2022; Taylor & Lovell, 2021).

Another significant finding is the integration of multiple AFS within single farms. In this study, two farms combined silvopasture, silvoarable, and forest gardens; one farm combined silvopasture, forest farming, and a forest garden; and five farms integrated two AFS types alongside other cultivation practices. This demonstrates that farmers are not merely adopting single models of AFS but are creatively combining them to optimise land use and enhance multifunctionality. Each system contributes distinct benefits – silvopasture integrates livestock and trees while supporting animal welfare; silvoarable (alley cropping) links annual crops with fruit and berry production; forest gardens foster edible perennial diversity; and forest farming diversifies income through non-timber forest products. By combining these systems, farmers can make efficient use of space and resources, enhance overall productivity, and strengthen the resilience of the farm economy.

From an economic perspective, diversification across AFS types can provide multiple income streams, as products such as timber, fruits, nuts, perennial vegetables, and non-timber forest products are harvested at different times of the year. This approach not only reduces vulnerability to market fluctuations but also creates more stable and predictable income flows, aligning with findings from earlier studies (e.g., Wilson & Lovell, 2016; Smith et al., 2022). Moreover, the deliberate blending of AFS types reflects the adaptability and innovative capacity of farmers, highlighting agroforestry's potential to create dynamic, multifunctional landscapes that simultaneously support ecological, social, cultural, and economic sustainability.

In addition, recent crises underscore the urgency of increased domestic food production and by more resilient ways of production. (e.g Eriksson 2018). The 2018 heatwave and fires, the 2020–21 pandemic, and the ongoing war against Ukraine exposed vulnerabilities in global supply chains and highlighted the importance of nearby green spaces for human well-being. In this context, agroforestry could strengthen Sweden's domestic food production by its resilient, sustainable methods, provided rural communities, especially farmers and foresters, receive coherent support.

9.2 Motivations Behind Farmer-driven Multifunctionality and Challenges to Agroforestry Adoption (Linked to Objective 2)

In relation to Research Objective 2, this thesis investigated the motivations and challenges underlying farmers' adoption of AFS in Sweden. While farmers attributed numerous benefits to agroforestry, they also perceived significant challenges. The multifunctionality of all studied AFS was closely linked to farmers' deliberate design of landscapes that intentionally combined food and material production with the provision of multiple ecosystem services.

Five primary motivational factors were identified: (i) sustaining household economy, (ii) supporting environmental sustainability, (iii) climate change mitigation and adaptation, (iv) landscape stewardship, and (v) reducing dependence on external inputs. Farmers expressed strong environmental concern and sought production models less reliant on imported fertilisers, pesticides, and fossil fuels. Their objective was to balance economic, ecological, and cultural goals rather than maximise short-term profitability. Biodiversity conservation, carbon storage, soil quality improvement, and resilience to extreme weather were repeatedly highlighted as key environmental aims. In parallel, cultural ecosystem services – including social relations, education, recreation, and tourism – were viewed as essential for sustaining provisioning services.

Farmers operationalised these motivations through diversified intercropping systems that generated bundles of provisioning, regulating, supporting, and cultural services. Silvopasture integrated livestock with trees; alley cropping combined annual and perennial food production; forest farming linked non-timber forest products with continuous-cover forestry; and forest gardens intercropped a high diversity of woody perennials. These strategies promoted synergies among ecosystem services, though farmers also recognised trade-offs – for instance, reduced yields when prioritising regulating functions or biodiversity habitats. To manage such trade-offs, farmers employed low-input, low-maintenance models, reducing labour and resource dependency. This aligns with wider literature on diversified farming systems, which demonstrates that while short-term costs may constrain adoption, diversified systems often deliver higher and more stable yields, enhanced biodiversity, and reduced long-term risks (Rosa-Schleich et al., 2019).

These findings also resonate with earlier research on ecosystem service bundles (Rodriguez et al., 2006; Raudsepp-Hearne et al., 2010; Plieninger et al., 2015; Saidi & Spray, 2018), highlighting the importance of managing synergies and trade-offs at the landscape scale. My results confirm that, from farmers' perspectives, AFS generate synergies across all ES categories, while trade-offs are actively managed through adaptive practices. Importantly, benefits accrued at the farm level – such as soil fertility, carbon storage, and biodiversity – also provide societal-level advantages (Jose, 2009, Hardaker et al., 2021), yet these contributions remain insufficiently acknowledged and inadequately compensated, for example via Payments for Ecosystem Services. Farmers, therefore, contribute to public goods without proportionate institutional support.

Despite the broad range of benefits, farmers faced several challenges that constrained the establishment, management, and wider adoption of agroforestry in Sweden. A common difficulty was the management complexity of species-rich systems, particularly forest gardens, where high biodiversity made yields inconsistent and increased vulnerability to pests, such as voles. Farmers responded adaptively by reducing plant diversity or integrating hens for pest control, though weed management and access to high-quality mulching materials remained critical concerns. Based on their experience, farmers identified potential roles for simplified forest gardens – for example, on marginal land, as linear elements along forest–field edges, or, as suggested by Jose (2012), near larger natural habitat areas or between forest patches.

Across all AFS types, farmers reported shortages of suitable technologies and materials. The lack of appropriate small-scale machinery and limited availability of seedlings – particularly high-quality edible perennials and nut varieties adapted to northern climates – posed significant barriers. High costs of planting material further constrained expansion. Knowledge gaps compounded these difficulties, especially in silvopastoral and silvoarable systems, where farmers struggled with integrating trees into pastures and crop fields, managing reforestation, and resolving practical challenges such as fruit contamination, uneven terrain, and complex harvesting requirements in multipurpose systems.

Institutional and socio-cultural barriers further constrained the adoption of agroforestry in Sweden. Subsidy schemes under the Common Agricultural Policy (CAP) and the Rural Development Program (RDP) were poorly aligned with multifunctional production systems, while agroforestry expertise was largely absent from agricultural extension services. Awareness of agroforestry practices among farmers and consumers were perceived low, except for more traditional wood pasture systems. Cultural perceptions also influenced adoption: larger farms or those with marginal land were often receptive to integrating trees, whereas small-scale farmers in densely wooded areas were reluctant to plant trees on their limited arable land.

Taken together, these challenges resonate with earlier studies (e.g., Graves et al., 2009; García de Jalón et al., 2017; Rios-Diaz et al., 2018). However, the Swedish context presents distinctive features. Different from these earlier studies farmers did not primarily perceive financial constraints as a personal barrier, although the PAR group recognised that the lack of financial support remains a key limitation for the wider expansion of agroforestry. Notably, the farmers in Paper III did not view the limited awareness of AFS among other actors as a major obstacle.

Importantly, this thesis underscores that AFS benefits emerge from co-created people–nature interactions, in which multiple human interventions actively shape ecosystems. These benefits can be conceptualised as social-ecological services (Huntsinger & Oviedo, 2014; Elbakidze et al., 2021), many of which are only fully visible at the landscape scale, where diverse land-cover mosaics interact. This aligns with calls to adopt the broader concept of landscape services for planning and managing multifunctional, culturally embedded agroecosystems (Termorshuizen & Opdam, 2009). In an agroforestry context, Van Noordwijk et al. (2018) propose the Land Equivalent Ratio for Multifunctionality (LERM) as an advanced metric extending the more traditional LER, which typically measures total production from a single AFS area. LERM considers the degree to which various land uses – natural forest, planted forest, agroforestry, open-field agriculture, and industrial areas – contribute to human needs within a continuous landscape mosaic. Additionally, LERM could guide the management of synergies and trade-offs across SDG portfolios.

9.3 Agroforestry as Niche Innovation in Sustainability Transitions (linked to Objective 3)

This thesis demonstrates that Swedish farmers experimenting with AFS are not merely adopting existing models but actively shaping and diversifying them through extensive innovation. Across the studied cases, multiple niche-innovations reconfigured conventional land-use practices into multifunctional systems. These included: (i) novel silvopastoral arrangements, such as integrating forestry with pig keeping; (ii) the development of multipurpose silvoarable alley-cropping systems; (iii) the exploration of three models of forest farming; (iv) the establishment of twelve forest gardens within the PAR-project; and (v) forest gardens combining high-quality timber production with edible perennial crops.

Taken together, these findings show that AFS in Sweden function as dynamic experimental arenas in which farmers generate context-specific solutions aligned with their own aspirations. From the perspective of transition theory and the socio-technical approach (Loorbach et al., 2017;

Geels, 2002), these examples represent early phases of niche-innovation within regimes dominated by conventional monocultural land use. Niche-innovations emerged through three interrelated mechanisms. First, the agency of pioneering farmers – their willingness to experiment, take risks, and invest in unconventional practices – was central. Second, collaboration with academic research lent legitimacy, resources, and technical input, reinforcing farmers' innovations. Third, participation in transdisciplinary initiatives, particularly the PAR-project, fostered collaborative experimentation and the co-production of knowledge across farmer and researcher communities. These mechanisms sometimes overlapped, generating synergies between practice, research, and education, while at other times operating independently. The result was a diversity of innovations that served as "real-life laboratories" (cf. Luedreitz et al., 2017) for sustainable farming and forestry.

Farmers did not only innovate practices but also created platforms for knowledge sharing. Demonstration plots, workshops, and open events – such as farm tours, festivals, and training courses – diffused agroforestry practices beyond individual holdings. Such initiatives resonate with the concept of "living labs" in sustainability transitions, where experimentation is embedded in real-world contexts and linked to wider stakeholder networks. This illustrates that agroforestry in Sweden is not a static practice but an evolving system generating new forms of collaboration, community engagement, and learning.

Yet, while niche-innovations offer promising pathways, the multi-level perspective (MLP) highlights dynamics that constrain scaling beyond the niche level. At the farm scale, challenges include the complexity of managing multifunctional systems, limited technical knowledge, and balancing short-term economic returns with long-term ecological benefits. At the regime level, the lack of supportive policy frameworks, subsidy structures, and institutional incentives constrains wider adoption. As Potters et al. (2014) argue, scaling novel agricultural approaches requires not only technical refinement but also major changes in organisational arrangements, actor networks, and institutional support. Both their findings and mine emphasise that transitions depend less on universal "recipes" and more on societal conditions on the regime- and landscape levels (Grin et al., 2010) that allow novelty to flourish.

This thesis addresses Knowledge Gaps 6 and 7 by providing empirical evidence of agroforestry niche-innovation in Sweden and documenting the participatory processes underpinning it. The PAR-project exemplifies how transdisciplinary collaboration generates both tangible outputs – such as forest gardens, reference data on silvopastoral systems, nutritional assessments of underutilised crops, and demonstration plots featuring nearly 140 perennial varieties – and intangible outcomes, including enhanced farmer capacities, strengthened farmer–researcher networks, and wider dissemination through media, grassroots movements, and educational activities. Such co-production of knowledge responds directly to calls for more participatory agroforestry research (Lovell et al., 2018; Quandt et al., 2023) and demonstrates how collaborative models enrich both science and practice.

The transdisciplinary design of the PAR-project was particularly significant. Nine workshops over four years created continuity in exchange and learning, while rotating locations between farms deepened mutual understanding across contexts. Neither farmers nor researchers were positioned as sole “experts”; rather, each contributed complementary knowledge, generating actionable insights. Farmers co-authored reports and participated in publications, while researchers engaged directly in practical tasks, including adopting and maintaining forest gardens on their own farms. This flattened hierarchy exemplifies co-creation of actionable knowledge (Sörlin, 2019), where academic and practical expertise are valued equally.

These participatory processes also intersected with broader educational infrastructures. Folk high schools – historically rooted in social movements and increasingly oriented toward sustainability transitions (Lövgren & Nordvall, 2017; Sörlin, 2019) – emerged as promising partners for expanding agroforestry learning. Recent studies (Focacci et al., 2025) suggest that urban forest gardens and folk high schools function as important knowledge hubs in Sweden. Linking agroforestry niche-innovators with such institutions could reinforce transitions by embedding knowledge in both formal and informal learning contexts.

Overall, the findings suggest that agroforestry niche-innovations in Sweden are not isolated experiments but part of broader societal dynamics. They highlight the importance of farmer agency, research collaboration, and participatory processes as drivers of innovation, while also underscoring structural barriers that limit scaling. The Swedish experience illustrates that transitions toward multifunctional land-use systems require more than local experimentation – they demand supportive policies, institutional flexibility, and social infrastructures that create space for novelty. By documenting these dynamics, this thesis contributes to a deeper understanding of how agroforestry can evolve from niche innovation to a mainstream land-use strategy in Sweden and beyond.

My thesis demonstrates, through analysis of past shifts and transitions, the niche innovations that have already occurred within Swedish agroforestry. Taking a more forward-looking perspective, these insights highlight the transformative potential of agroforestry in Sweden. Scholars argue that such a transformation is needed, for instance, shifting from annual cropping systems toward perennial systems, such as polycultural alley-cropping (Wolz et al., 2017), from annual to perennial vegetables (Toensmeier et al., 2022), and adopting tree crops that encourage a “thinking beyond grain” approach (Lovell et al., 2018). These perspectives emphasise the capacity of agroforestry to restructure production systems in ways that are more ecologically, socially, and economically sustainable.

10. Methodological Reflections

10.1 Ecosystem Services Framework

The ecosystem services concept provided a clear framework for communicating otherwise invisible ecological processes, such as soil formation, climate regulation, and pollination. In the context of this thesis, however, the framework had three key limitations. First, it separates ecological and socio-cultural benefits, thereby underrepresenting the relational human–nature interactions that are central to agroforestry as a social–ecological system (SES). Second, the canonical ecosystem service definition – “the benefits people obtain from ecosystems” – does not fully capture the co-production of values and functions by humans and nature within AFS. Third, critiques of ES as anthropocentric intersect with debates over intrinsic versus instrumental value of nature. Himes and Muraca (2018), states relational values as anthropocentric yet non-instrumental, reflecting how several farmers described their relationships with their AFS.

The ecosystem services framework also tends to obscure the role of farmers as landscape stewards (Plieninger & Bieling, 2017; Angelstam et al., 2019). Adopting a landscape perspective helps bridge ecological and socio-cultural dimensions, supporting the focus on multifunctional landscapes pursued in this thesis. Alternative framings can address some limitations of ES. For example, IPBES’s Nature’s Contributions to People (NCP) broadens the scope of cultural benefits (Díaz et al., 2018), and Van Noordwijk et al. (2018) propose metrics to assess the multifunctionality of AFS and other systems along a spectrum from natural to man-made to technological.

Despite its shortcomings, the ecosystem services framework proved useful for structuring the presentation of results and discussing multifunctional benefits of agroforestry coherently. Its widespread adoption in agroforestry research made it a convenient and comparable framework, while the use of complementary concepts remains important for capturing the full complexity of AFS.

10.2 Participatory Action Research and Transdisciplinary Approaches

Participatory Action Research (PAR) was applied as a transdisciplinary approach engaging participants in jointly diagnosing problems and co-producing solutions, rather than implementing researcher-defined interventions (Bryman, 2008; Lang et al., 2012). Workshops were hosted on each farm, anchoring learning in context while allowing cross-site reflection. A trained facilitator from the research team ensured inclusive sessions with up to 20 participants. Participants were invited to contribute to conferences and co-author reports and papers. Importantly, both researchers and farmers established forest gardens on their own land during the project. Beginning as novices together fostered a sense of shared endeavour, while responsiveness to farmers' emerging ideas nurtured trust. Without this trust, the transdisciplinary process would have been far less productive.

Common critiques of PAR relate to rigour and potential bias (Bryman, 2008). The project mitigated these risks through documented facilitation protocols, transparent decision rules, and iterative cycles. Nevertheless, ultimate judgements of rigour remain with readers and reviewers. PAR remains comparatively uncommon in Europe, though its use in agroecology is increasing (Méndez et al., 2018; Fernández-González et al., 2021). Transdisciplinary research (TDR) in this thesis is understood as a reflexive, integrative, and method-driven principle for addressing complex sustainability challenges by combining knowledge from scientific and societal sources (Lang et al., 2012; Wiek et al., 2012; Miller et al., 2014; Leemans, 2017).

Practical constraints were non-trivial. Farmer travel and time required funding, nine workshops were scheduled outside the growing season, and sustained facilitation was necessary. In terms of representativeness, the process likely favoured well-resourced, highly motivated actors within established networks, limiting inclusivity and generalisability.

10.3 Focus Group and Semi-Structured Interviews

The qualitative design combined a 2019 focus group with former PAR participants and subsequent semi-structured interviews identified via snowball sampling. Trees establish slowly; therefore, the focus group was conducted three years after the PAR project to elicit longer-term reflections.

Telephone interviews with previously unknown respondents were generally shorter, reducing depth and comparability. Economic variables, such as labour, transaction costs, and profitability, were not consistently measured. The study did not systematically triangulate with quantitative biodiversity inventories or spatial analyses, and perspectives from public authorities and non-AFS farmers were outside the study's scope.

Nevertheless, the sample represents pioneering Swedish agroforestry practitioners with more than five years' experience and objectives beyond self-provisioning. Many silvopastoral producers in Sweden were not included; a focused study on that group would be valuable.

10.4 Conceptual Analysis

Paper IV presents a conceptual analysis of urban agroforestry, chosen partly for time reasons and partly due to limited prior literature. Park et al. (2018) later addressed both rural and urban systems, using the term "food forests." The analysis was informed by empirical and practice-based insights, including a 2016 conference paper on community forest gardens in Stockholm (Schaffer, 2016) and the small-scale forest garden experiment reported in Paper I (~60 m^2), a size well suited to urban settings. More recently, Focacci et al. (2025) investigated 30 urban forest gardens in Sweden and corroborated the multifunctionality posited in Paper IV.

Paper IV focused on health and well-being, using the Perceived Sensory Dimensions (PSD) framework's eight features to assess correspondence with urban forest-garden environments. This conceptual mapping could be tested empirically in future work, for example by combining PSD-based surveys with behavioural observation and ecological measurements in urban AFS.

Finally, while the findings of this thesis are based on a rigorous methodological approach, the qualitative nature of the studies and the limited number of respondents mean that the results cannot be generalised beyond the contexts investigated. Therefore, the findings are presented as indicative, highlighting patterns, insights, and potential trends rather than providing universally generalisable evidence.

11. Contributions to Practice and Policy

The results of this thesis provide several entry points for strengthening agroforestry systems in Sweden through policy development and practical interventions:

1. Recognising AFS as multifunctional land-use systems

The research demonstrates that AFS deliver a broad suite of ecosystem services – provisioning, regulating, supporting, and cultural – while enhancing farmer resilience through diversified, low-input, low-maintenance management. Policy frameworks should therefore recognise AFS not merely as agricultural practices but as multifunctional land-use systems relevant to biodiversity conservation, climate mitigation and adaptation, and rural development. Policy instruments should move beyond narrow productivity metrics and integrate ecosystem service accounting into subsidy design, rewarding farmers for public goods such as carbon storage, soil fertility, and landscape biodiversity.

2. Supporting farmer motivations and addressing adoption challenges

Farmers pursued AFS to sustain household economies, enhance sustainability, adapt to climate change, and reduce reliance on external inputs. They also faced significant barriers: management complexity, limited access to adapted plant material and machinery, gaps in technical knowledge, and misaligned institutions. Addressing these challenges requires targeted, practice-oriented interventions, including:

- Extension services with agroforestry expertise to provide ongoing technical advice
- Investment in plant breeding and nurseries to expand edible perennials such as berries and nuts suited to northern climates.
- Machinery innovation programmes to develop small-scale technologies compatible with tree-integrated, multifunctional systems.

- Policy realignment to ensure that CAP and RDP instruments support multifunctionality and reward diversification rather than penalising departures from monocultural models.
- Payments for Ecosystem Services (PES) schemes to acknowledge and compensate farmers for societal benefits they generate.

3. Strengthening agroforestry as a niche-innovation pathway
The Swedish cases illustrate farmers acting as pioneers, experimenting with novel AFS and co-producing knowledge through collaborations such as the PAR project. Policy and practice can support these "living laboratories" by:

- Supporting transdisciplinary research platforms that embed farmers as co-researchers, ensuring innovations remain grounded in practical needs.
- Investing in knowledge-sharing infrastructures, such as demonstration farms, farmer networks, and living labs, to accelerate diffusion.
- Collaborating with adult education institutions, such as folk high schools and universities, to integrate agroforestry into formal curricula and informal adult learning programmes.

4. Embedding AFS in broader climate and rural-development strategies
Given their multifunctionality and adaptability, AFS are highly relevant to Sweden's climate and rural development goals. Policy could explicitly integrate agroforestry into national climate-adaptation and biodiversity strategies, framing it as a land-sharing approach that reconciles production with conservation. In practice, this implies supporting farmers not only as food producers but as stewards of multifunctional landscapes that generate long-term ecological resilience and social benefits.

5. Shifting focus from consumers to producers
Debates on sustainable food systems often prioritise the consumer end – what appears on the plate. A complementary focus is needed on production: the role of farmers, the methods employed, land-use configurations, and the additional benefits or losses these configurations entail.

6. Payments for shrubs

From 2024, Swedish support for agroforestry on arable land covers tree planting, while shrubs remain ineligible (Jordbruksverket). This study shows that hazelnut and berry shrubs are widely used and valued by farmers, offering comparable ecosystem services to trees, diversifying income, and supplying both traditional and novel berries. Expanding support to include shrubs would align policy with on-the-ground practices and multifunctionality.

7. Food security

Sweden imports roughly half of its food by value, including the vast majority of its berries. According to the Swedish Civil Contingencies Agency (MSB), domestic food production remains dependent on external inputs such as fossil fuels, pesticides, fertilisers, machinery, and seeds (Eriksson, 2018). Low-input, low-maintenance agroforestry can reduce such dependencies. Expanding domestic production via diverse perennial systems – ranging from small household forest gardens to larger silvoarable and silvopastoral systems for market production – can diversify farm incomes and strengthen national preparedness.

8. Urban green infrastructure planning

The multifunctionality of urban AFS positions them as promising nature-based solutions for health, well-being, climate adaptation, and local food production. Accessibility is crucial; prioritising forest gardens in street-level public green spaces maximises use and equity. Once established, perennials require lower maintenance than annual beds, while providing shade, storm-water regulation, habitat connectivity, and seasonal foods. Given the potential of green-space affordances to mitigate socio-economic health disparities, placing urban forest gardens in disadvantaged areas is particularly pertinent.

9. Cross-fertilsation with other initiatives

There is an increased attention and interest in AFS in Sweden from Swedish board of Agriculture, and for example also by single county-level educational initiatives, active work by the NGO Agroforestry Sweden, collaborations through EURAF and international partners. There is also an untapped potentiality in cross-fertilisation with to some extent AF-related initiatives such as, organic farming, regenerative agriculture, agroecology, permaculture, multiple use of forest, community supported agriculture, smallholders, urban agriculture and similar.

12. Conclusions

This study has for the first time documented the perceived benefits, challenges and motivations attributed by farmers to diverse agroforestry practices within silvopasture, silvoarable, forest farming, and forest gardens in Sweden.

AFS deliver multiple benefits for biodiversity and human well-being, yet Northern Europe, including Sweden, remains under-studied. This thesis helps fill that gap. The results show that AFS multifunctionality is farmer-driven. Farmers pursue agroforestry to earn income, advance environmental sustainability, mitigate and adapt to climate change, steward landscapes, and reduce dependence on external inputs. They intentionally organise practices to produce bundles of ecosystem services - provisioning, regulating, supporting, and cultural – while sustaining household economies through diversification and practical innovation.

AFS also create land-use and landscape benefits. On forest land, practices such as forest grazing, integrated timber-and-food forest gardens, and forest farming can diversify incomes alongside continuous-cover forestry and may inspire more sustainable approaches in conventional forestry. In urban settings, forest gardens and related AFS act as salutogenic environments that support stress recovery, attention restoration, nature connectedness, and food literacy, while contributing to biodiversity and climate adaptation and also to edible green infrastructure.

From a production perspective, edible perennials extend the harvest window – early via perennial herbaceous plants and vegetables and late via fruits, nuts, and berries – offering nutrient-rich foods that can substitute for imports. However, species-rich, multi-layer forest gardens are management-intensive; high species numbers and structural complexity increase labour and knowledge demands.

AFS are not without challenges. Key challenges include management complexity (especially in silvopasture and species-rich forest gardens), technological and material shortages, knowledge gaps across actors, and institutional barriers, notably the misalignment of CAP/RDP instruments with multifunctional systems. In urban contexts, competition for land is an additional barrier.

Change nevertheless emerges from niche innovation and co-production of knowledge. Pioneering farmers experiment, produce high-quality products, and generate context-adapted knowledge; their farms function as platforms for peer learning and applied research. Transdisciplinary co-production (e.g., PAR) yields relevant, context-specific insights, and long-term studies are needed in temperate regions given slow establishment dynamics.

The thesis found that to move AFS from pioneer niche-innovation project to a recognised agricultural approach, education and extension services must be strengthened; profitability and legislative issues addressed; and practical production challenges solved. Flexible payments that reward public goods and multifunctionality are required, alongside solutions that are viable in the field and manageable in offices.

In conclusion, agroforestry systems in Sweden already deliver diverse ecosystem services and social benefits while facing solvable constraints. With aligned policy instruments, robust extension, practice-oriented innovation, and long-term co-production of knowledge, AFS can move from niche to mainstream, and contribute meaningfully effectively to biodiversity management, climate mitigation and adaptation, rural livelihoods, and enhanced public health.

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Popular science summary

Land use in agriculture, forestry, and urban areas is often designed with a one-sided focus on the production of a single crop or for a single purpose. Such systems need to be transformed into approaches that adopt a broader perspective and generate multiple benefits. One promising model is agroforestry, defined as the integration of trees, crops, and/or livestock on the same land area. Agroforestry combines agriculture and forestry to deliver a range of environmental, economic, and social benefits at both farm and community levels.

This thesis examines agroforestry systems (AFS) in Sweden in light of the need for multifunctionality and sustainability during the transition from monocultural to multifunctional land use. The overall aim is to enhance knowledge and understanding of AFS by:
(i) documenting and analysing their benefits in agricultural, forestry, and urban contexts using an ecosystem services framework;
(ii) investigating farmers' perspectives, motivations, and challenges related to agroforestry; and
(iii) analysing transitions from conventional land use to multifunctional agroforestry through the lens of niche innovations based on existing examples of AFS.

The study is based on empirical material from 19 case studies of farms in central and southern Sweden. Methods used to study agricultural agroforestry include participatory approaches, focus groups, and semi-structured interviews, while studies of urban agroforestry were conducted through conceptual analysis.

The four main types of agroforestry in Sweden included: (1) Silvopastoral systems – integration of grazing animals in forests and pastures. (2) Silvoarable systems – integration of trees and shrubs with annual crops on arable land, often as alley cropping. (3) Forest farming – production of food and other products in managed forests alongside forestry. (4) Forest gardening – intercropping of edible perennials such as fruit and nut trees, berry shrubs, herbs, vegetables, and flowers.

The study shows that farmers attributed a wide variety of benefits to their AFS, which were categorised as different types of ecosystem services - supporting, provisioning, regulating, and cultural. Each AFS generated ecosystem services in diverse combinations, demonstrating a high degree of multifunctionality.

Production from AFS provides farm-level benefits such as diversified outputs, opportunities for experimentation, aesthetic values, and enhanced well-being for both humans and animals. Many of these benefits also extend to the landscape and community levels, contributing to increased biodiversity, reduced monocultural areas, lower greenhouse gas emissions, greater climate adaptation, and strengthened rural livelihoods.

The diversity of benefits reflects farmers' conscious choices to combine food production and forestry with nature conservation. Five key motivational factors were identified behind the adoption of agroforestry practices: (i) maintaining household finances, (ii) promoting environmental sustainability, (iii) contributing to climate change mitigation and adaptation, (iv) acting as landscape stewards, and (v) reducing dependence on external inputs.

However, several challenges were also identified, including the complexity of management and maintenance, limited access to suitable technology, knowledge, and plant material, and insufficient institutional and policy support. Despite these obstacles, farmers demonstrated extensive experimentation, leading to the emergence of niche innovations within all four types of AFS.

Across all four types of AFS, niche innovations were demonstrated, each reflecting a distinct approach to land use that integrates food production with the delivery of multiple ecosystem services. These niche practices represent experimental spaces where farmers test and adapt multifunctional solutions, thereby contributing to sustainability transitions in agriculture. Through the combination of practical implementation, knowledge co-production, and horizontal knowledge exchange, these farms act as frontrunners in transforming Swedish agriculture toward more resilient and multifunctional systems. The integration of agroforestry into diverse land types—forested land, and arable land—illustrates how niche innovations can challenge existing land-use regimes and provide tangible models for system-level change. Such multifunctional land-use systems not only enhance biodiversity and the generation of ecosystem services but also strengthen climate resilience and social-ecological sustainability across landscapes.

Overall, the thesis contributes to a deeper understanding of agroforestry as a multifunctional land-use strategy in Sweden. It highlights its potential to foster resilience, diversify production, and support the transition toward more sustainable urban and rural landscapes. With coordinated policy instruments, effective advisory systems, visible examples, and long-term co-production of knowledge, agroforestry can evolve from a niche practice into a mainstream model contributing substantially to biodiversity conservation, climate mitigation and adaptation, rural livelihoods, and public health.

Populärvetenskaplig sammanfattning

Markanvändningen i jord- och skogsbruk samt i städer är oftast utformad med ett ensidigt fokus på produktion av en gröda eller för ett syfte. Dessa behöver ställas om till metoder som har ett bredare fokus och som kan generera fler nyttor. En sådan modell är agroforestry, vilket kan definieras som integreringen av träd, grödor och/eller boskap på samma yta. Agroforestry är en praktik som i princip förenar jord- och skogsbruk för att dessa ska bidra till en rad miljörelaterade, ekonomiska och sociala nyttor på gårds- och samhällsnivå.

Den här avhandling undersöker agroforestry-system (AFS) i Sverige utifrån behoven av mångfunktionalitet och hållbarhet i omställningen från monokulturell till mångfunktionell markanvändning. Det övergripande syftet med studien var att öka kunskapen och förståelsen för AFS genom att (i) dokumentera och analysera deras nyttor inom jordbruk, skogsbruk och stadsmiljöer med hjälp av ett ekosystemtjänstramverk, (ii) undersöka lantbrukares perspektiv på, motivation till, och utmaningar med agroforestry, samt (iii) att undersöka omställning från konventionell markanvändning till mångfunktionell agroforestry genom att analysera nischinnovationer utifrån redan existerande exempel på AFS.

Undersökningen bygger på empiriskt material som samlats in från 19 fallstudier av gårdar i mellersta och södra Sverige. Metoder som använts för att studera agroforestry på lantbruk inbegriper en deltagardriven forskningsansats samt fokusgrupper, semistrukturerade intervjuer. Studierna av agroforestry i urbana områden analyserades konceptuellt.
Avhandlingen omfattar fyra huvudtyper av agroforestry i Sverige; silvopastorala system (kombinationer av betande djur på skogs- och i hagmark), silvoarabla system (träd och buskar kombinerad med odling av ettåriga grödor på åkermark, i form av alléodling), skogsodling (produktion av livsmedel i modifierad skog tillsammans med skogsbruk) samt skogsträdgårdsodling (samodling av ätbara perenner såsom frukt- och nötträd, bärbuskar, örter, grönsaker, blommor).

Studien visar att lantbrukarna tillskrev sina AFS en mångfald av olika nyttor vilka därefter kategoriserades som olika ekosystemtjäntser såsom stödjande, produktiva, reglerande och kulturella. Var och en de fyra AFS genererade ekosystemtjänster i en rad olika kombinationer, och alla kunde således tillskrivas en hög grad mångfunktionalitet.

Produktion från AFS genererar nyttor på gårdsnivå- som till exempel diversifierad produktion, experimenterande med AFS, estetiska värden och ökat välbefinnande för både människor och djur. Många av dessa nyttor är samtidigt viktiga på landskaps- och samhällsnivå som ökad biologisk mångfald och minskade monokulturer, för både minskad påverkan på klimatet och ökad klimatanpassning och för försörjningsmöjligheter på landsbygden. Mångfalden av nyttor härrör ur lantbrukarna medvetna val att kombinerade matproduktion och skogsbruk med naturvårdande landskapsskötsel.

De värden och funktioner som är speciellt viktiga för urbana områden är skogsträdgårdars roll för hälsa och välbefinnande, framför allt då de kan utgöra miljöer för stressåterhämtning. Därtill kan den ”lund-lika” miljön erbjuda ökad kontakt med naturen för urbana människor. De är dessutom artrika och kan bidra till ökad biologisk mångfald, samt även till ökad klimatanpassning.

Studien visar att det fanns fem typer av motivationsfaktorer bakom lantbrukarnas val att använda agroforestry-praktiker (i) att upprätthålla hushållsekonomi, (ii) att främja miljömässig hållbarhet, (iii) att bidra till begränsning av och anpassning till klimatförändringar, och (iv) landskapsförvaltning och (v) att minska beroende av externa insatsvaror. Det fanns även uppenbara utmaningar såsom att AFS inbegriper en mer komplex skötsel, att tillgång till lämplig teknik, kunskap och växtmaterial är begränsad, samt att stödjande institutionella strukturer och subventionssystem saknas.

Lantbrukarnas eget experimenterande med AFS var omfattande och studien identifierar en rad nichinnovationer inom de fyra typerna av AFS, som tillexempel nya former av silvopastorala system i vilket grisar användes i skogsbruket, nya alléodlingssystem med rader av bärbuskar, frukt-och nötträd, tre modeller av skogsodling, etablering av 12 nya skogsträdgårdar i tempererade områden samt en annan skogsträdgård med fokus på högkvalitativ timmerproduktion samodlat med en rad ätbara perenna grödor. Avhandlingen bidrar till att öka kunskapen om agroforestry som mångfunktionell markanvändning i Sverige och ger insikter om dess potential att öka resiliensen, diversifiera produktionen och stödja omställningen mot ökad hållbarhet i stad och land.

Sammanfattningsvis pekar studien på att AFS i Sverige levererar olika miljömässiga och sociala nyttor samtidigt som de finns en rad begränsningar, till vilka det finns lösningar. Med samordnade politiska instrument, robust rådgivning, praktiskt inriktad innovation, tillgängliga gårdsexempel efter de olika geografiska förhållandena i Sverige och långsiktig samproduktion av kunskap kan AFS gå från att vara en nisch till att bli mainstream och bidra effektivt till biologisk mångfald, klimatbegränsning och klimatanpassning, försörjning på landsbygden och förbättrad folkhälsa.

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To those who sing ‘There is a crack in everything, that's where the light gets in’ – remember that cracks can also burst and shatter your existence, your heart and your trust in other people.

For faithfulness – Sigge

In dark times, it is hopeful to see younger generations, such as gardening activists and students, when exposed to AFS in practice and theory, are engaging renewed hope and agency.

So thank you, agroforestry for inspiration!

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Exploring the potential of edible forest gardens: experiences from a participatory action research project in Sweden

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Abstract To meet the environmental challenges that are presently confronting society, the narrow focus on agricultural production needs to be altered to one that places equal value on the generation of crucial ecosystem services. Current research shows that perennial intercropping systems such as agroforestry may be a feasible alternative. Based on studies during the establishment of edible forest gardens in 12 participating farms in Sweden, this paper explores the potential of utilizing multi-strata designs for food production in temperate, high-income countries. Design and species composition of such gardens, types of food they provide, and how they would best fit into the present landscape are discussed. Factors for success and major problems related to the establishment are shared. Potential benefits were found to be closely related to a thorough analysis of the social and ecological contexts before establishment. Characteristics of the site and goals of the garden need to guide species and design choices. If forest garden approaches to food production should contribute to more than local self-sufficiency, the gardens need to increase in scale. Marginal lands and transitions areas between different land uses may be appropriate. Large knowledge gaps concerning potential production, social and economic benefits, and agronomic issues were identified.

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Introduction

The global food system significantly contributes to the complex and widespread environmental challenges that we face. At present, agriculture plays a serious part by transcending the identified ecological "*planetary boundaries*" (Steffen et al. 2015), including the four boundaries that are already thought to be exceeded or at high risk of being exceeded: global warming, disruption of the nitrogen cycle, land use changes and extinction of species (Foley 2011). The perpetuating dependency on non-renewable resources, such as phosphorous and fossil fuels, also plays a critical role in planetary health and future food production.

This implies a fundamental renegotiation of the aims of agriculture. The narrow focus on production needs to be altered to one that places equal value on the generation of crucial ecosystem services (De Schütter and Vanloqueren 2011). Radical changes in both diets and the modes of production are necessary (Foley 2011). Agroforestry may be a feasible option. Current research shows that such systems are both productive and generate more ecosystem services than conventional land use in tropical and temperate areas (Pretty et al. 2006; Jose 2009; Torralba et al. 2016; Wilson and Lovell 2016).

Agroforestry is defined as "…the integration of woody vegetation, crops and/or livestock on the same area of land" (EURAF 2015) and has also been proposed as a management option for agriculture to meet the challenges related to the planetary boundaries (McIntyre et al. 2009; DeSchütter and Vanloqueren 2011; European Commission 2016). Most of the systems are deliberately designed to use symbiotic interactions within the agroecosystem (Jose 2012). Such systems may involve high levels of planned diversity or intercropping of only two crops (Nair 1993). These designs aim to maximize the benefits by increasing the efficiency of capturing light, water and nutrients (Lorenz and Lal, 2014). The systems can be developed on arable land, in pastures or forests (Nair 1993).

Most experience and knowledge about modern agroforestry has originated from tropical areas (Torralba et al. 2016), where it is a way to increase the production of necessary products when land is a scarce resource (Smith et al. 2012a). However, agroforestry in temperate areas has been a tradition since ancient times. The main agroforestry approach has been silvopastoral systems with livestock grazing in forests or on agricultural land (Herzog 1998; Montagnini and Nair 2004), however, different kinds of silvoarable systems, including nuts, fruits or berries with or without animals, as well as trees and bushes in alleys (e.g., hedgerows and wind breaks), were also common (Herzog 1998; Nerlich et al. 2012). Traditional systems were lost because of competition when low oil prices led to mechanization and intensification (Smith et al. 2012a). Policies based on a division between agriculture and forestry have also not been beneficial (Dupraz et al. 2005). Still, in Europe today, agroforestry is practiced in almost 9% of the agricultural areas (den Herder et al. 2016).

Meta-analyses from temperate areas present compelling evidence that an increase in the complexity in the agricultural landscape through agroforestry systems delivers more supporting and regulating ecosystem services, such as carbon sequestration, maintenance of biodiversity, water quality, nutrient recycling, soil fertility and erosion, than conventional land use (Tsonkova et al. 2012; Kim et al. 2016; Torralba et al. 2016; Wilson and Lovell 2016).

However, for the systems to be efficient carbon sinks, they must be composed mainly of perennial crops, while this potential is substantially less when perennials are intercropped in systems dominated by annuals (Alam et al. 2014; Torralba et al. 2016). Moreover, the key design components for high conservational values in agroforestry have been found to be the inclusion of multiple species and vegetative strata, minimal management intensity and long rotation periods (Jose 2012).

Edible forest gardens are complex multi-strata agroforests that are characterized by astonishing diversity, including perennial plants at all structural levels, from high trees to low trees, bushes, herbs, soil covers, tubers and climbers (Jacke and Toensmeier 2006). Edible forest gardens have a long tradition among owners of small farms in the southern hemisphere, so called *"homegardens",* and have been clearly recognized to have social and ecological benefits in tropical areas on all continents (Landreth and Saito 2014; Pulido et al. 2008; Bardhan et al. 2012; Matsson et al. 2015; Willeman et al. 2013). In Europe, these gardens are commonly small-scale systems that contribute to the self-sufficiency of urban or suburban households, with the highest presence in central and eastern Europe (Mosquera-Losada et al. 2009).

This paper explores the potential of the multi-strata design used in edible forest gardens based on studies during the establishment of edible forest gardens (the first four years) in the agricultural settings of a group of participating farms in Sweden. The design and species composition of such gardens, the kind of food they may provide, and how they would best fit into the present landscape are discussed. The factors for success, major problems in the establishment, working requirements in relation to productive outcome and what the participants valued as the most important benefits from the gardens are shared. Finally, knowledge gaps in the development of the multi-strata approach in agriculture are identified.

Materials and methods

The research presented is based on the knowledge produced and experiences developed within a facilitated participatory action research (PAR) group focusing on the development of modern agroforestry systems in Sweden, 2012–2016. The core of the group comprised farmers from 12 farms, including two researchers and one PhD student with expertise in environmental science, agroecology and participatory methodologies (Eksvärd et al. 2016). Although all farms are located in the southern parts of Sweden, the climates are notably different (Fig. 1 and Table 1). The sizes of the farms range between 3 and 200 ha. Approximately half of the farmers had experience in agroforestry as silvopastures at the start of the project. The participants consisted of both full- and part-time farmers, and production was for subsistence, commercial reasons or both.

To study the management and use of multi-strata systems, edible forest gardens of 60 m^2 with common species compositions and planting schemes were planted in 2013 by the farmers on their farms. The collaboratively developed design contained plants in all structural layers, with species that could exploit the different ecological niches and contribute to a diverse composition of habitats. A theoretical framework of agroecological principles, such as functional design, intentional use of biodiversity, multifunctionality, adapted scale, awareness of ecosystem services, and circulation and effective use of plant nutrients (Gliessman 2014), was used.

During 9 workshops, 15 telephone conferences, and individual work on and in forest gardens, the acquired knowledge and experiences were collectively analyzed and decided upon. Permanent sampling points inside and outside the research site were established during the year of planting. Initial vegetation and basic soil parameters were documented as well as the inputs, outputs and working hours (Tables 1 and 2). Photographic documentation at permanent points on set dates and a diary with notations on important observations were also included. Only seven of the 12 places are included in the summary table (Table 2), as five farmers did not provide enough observations from their sites for inclusion.

Results

Design and establishment

The desired functions from the systems were agreed to be the provision of nutritious and tasty food products, nitrogen fixation, nutrient accumulation, the provision of quality food for pollinators, carbon sequestration, contribution to a benign microclimate and the provision of timber. The design and species composition were planned to optimize these functions (Fig. 2).

The research gardens were established at different places in the landscape, from farmer fields and permanent pastures to forest slopes and home gardens (Table 2). Some gardens were established in swards, and others on black soil after cultivation with machinery or pigs. In the places with establishment in swards, pits were dug for the plants, and the rest of the area was covered with paper or plastic weave, or, left with the swards. Soil improvements as manure or compost were also added to some of the sites to improve plant establishment. The soil improvements were optional. Some of the farmers chose not to do this to study the potential for self-generation of fertility at these sites.

Experiences on plant composition, development and use

All layers in the three-dimensional structure of the edible forest gardens established on each of the participating farms were dominated by perennial domestic species, with the inclusion of some wild species (e.g., garlic mustard (*Alliaria petiolata*), fat-hen (*Chenopodium album*)). To analyze how the different plants became established and interacted in the design, the Crawford (2010) division of different vertical layers was used:

Medium to large canopy trees (> 10 m)

Experiences from the group suggest that in small or dense and narrow gardens in temperate climates, the first layer of high trees, which provides desirable

Fig. 1 Map of Sweden showing geographical positions of the edible forest gardens in the study

shade in hot and sunny climates, might not be useful when sunlight is a critical factor in intercropping systems. Especially in locations as Sweden, where the majority of the landscape is used to produce timber. It might be better for the tree layer to be lower, including smaller or coppiced trees that provide edible fruits, berries, leaves and possible nitrogen fixation. In these systems, large trees likely appropriate too much sunlight and space in relation to the services they provide.

Table 1 Precipitation and temperature during establishment, basic soil parameters before planting and former land use types at the sites

Farm number	Average precipitation[a] (mm year^{-1})	Average annual temperature[a] (°C)	Soil	C (%)	pH	Former land use
1	600	7.0	Cl	1.79	7.8	Tilled soil
2	475	7.0	hu Cl	3.65	4.7	Pasture
3	800	6.5	ClTi	4.61	5.2	Pasture
4	680	6.5	cl Sa	3.91	5.6	Lawn
5	665	7.5	hu cl SaTi	3.45	5.3	Pasture
6	665	7.5	hu Cl	5.21	7.4	Pasture
7	640	7.5	hu Sa	18.28	4.0	Forest
8	705	9.0	hu cl SaTi	9.69	4.8	Forest
9	765	9.0	hu cl Sa	6.20	7.2	Lawn
10	650	9.0	cl Ti/cl Sa	1.75	n.a	Lawn
11	650	9.0	hu cl Ti/hu cl Sa	6.76	4.8	Pasture
12	650	9.0	hu cl Ti	3.95	n.a	Impediment

Cl clay, *cl* clayey, *hu* humus-bearing, *Ti* till, *Sa* sand, *SaTi* sand till, *ClTi* clay till

[a] Average 2013–2015 from the nearest Swedish Meteorological and Hydrological Institute (*SMHI*) weather station

Small trees and large shrubs (4–9 m)

This second layer included three types of apple trees (*Malus domestica*) to provide fruit over a long period. Hazel (*Corylus avellana*), a winter-hardy, energy-dense crop that is traditionally grown, was a self-evident choice. The critical aspects identified by the PAR-group were the selection of large nuts and means for efficient harvest. The sites also included the nitrogen-fixing Siberian pea tree (*Caragana arborescens*) as a protein source, a common ornamental plant in Sweden. To use the seeds, substantial improvements of the common varieties to obtain larger seeds are necessary. The nutritious value also needs to be further examined.

Shrubs (< 3 m)

This level consisted of silverberry (*Elaeagnus commutata*) (or autumn olive (*Elaeagnus umbellata*) in the southern sites), the nitrogen-fixing sea buckthorn (*Hippophae rhamnoides*), saskatoon (*Amelanchier alnifolia*) and dwarf quince (*Chaenomeles japonica*). Saskatoon is a common ornamental plant in Swedish urban gardens and was fast growing at most sites while producing tasty berries with high nutritional value (Mazza and Cottrell 2008) that were easy to pick. Furthermore, sea buckthorn exhibited substantial yields only two years after establishment, and dwarf quince was of special interest to the group as a potential substitute for imported citrus.

Herbaceous perennials and evergreen plants (0–3 m)

This layer contained different kinds of mint (*Mentha* spp.), mallow (*Malva* spp.), used in salads or tea, and comfrey (*Symphytum uplandica)* for its role as a “nutrient pump” from deep layers in the soil because of its extensive root system. Daylilies (*Hemerocallis* spp.), anise hyssop (*Agastache foeniculum*), sweet cicely (*Myrrhis odorata*) and oregano (*Origanum vulgare*) provided tasty leaves and flowers that could be used in substantial amounts in salads during a large part of the growing season. The PAR group found the fourth layer to be especially important for attracting beneficial insects, birds, and butterflies, acting as soil builders in the early stages, which was verified in master’s thesis research performed at five of the research sites (Lagerquist 2016).

Among the herbaceous perennials, good king Henry (*Chenopodium bonus-henricus*) was perceived to be of special interest. The plant developed fast and provided both leaves to be used in salads and seeds that could be cooked to provide fat and protein. A

Table 2 Farmer observations of the establishment phase (2013-2016)

Farm	Labor hours, establishment of tree and shrub layers	Labor hours, management and harvest	Preparation before planting trees and shrubs	Preparation before planting herbal and ground cover layer	Manure	Irrigation, occasions, yr^{-1}	Inclusion of annuals during establishment phase	Main harvested plants	General observations
1	25	10	Tilling	Tilling	None	4–6	No	*Amelanchier anifolia*, Malus domestica, *Hippophae rhamnoides*, *Chenopodium bonus henricus*	Satisfactory growth of trees and shrubs, promising growth of *chenopodium bonus-henricus*
2	22	22	None, planting in the sward	Plastic weave	None	None	Yes	*Fragaria* × *ananassa*, *Amelanchier anifolia*, *Hippophae rhamnoides*, *Rubus lacinatus*	Slow growth when planting in sward, invasive *Rubus lacinatus, Malus domestica* disfavored due to high groundwater
3	26	5	Tilling	Cardboard, litter	Well composted sheep manure	Few	No	*Amelanchier anifolia*, *Malus domestica*, *Rubus lacinatus*	Tree and shrubs growth retarded due to competition with the herbaceous layer
4	28	n.a.	None, planting in the sward	Cardboard, litter, cultivation of annuals	Cut grass, composted manure	Yes	Yes	*Fragaria vesca, Amelanchier anifolia, Malus domestica, Hippophae rhamnoides, Agastache foeniculum, Hablitzia tamnoides*	*Symphytum upplandica* invasive to *Malus domestica*, less work and more harvest required each year for leaves and flowers for salads
5	24	18	None, planting in the sward	Cardboard, newspaper and litter	Fresh sheep manure	Few	No	*Amelanchier anifolia, Hippophae rhamnoides, Rubus lacinatus, Chenopodium bonus henricus, Agastache foeniculum*, *Hablitzia tamnoides, Mentha* spp., *Origanum vulgare*	*Vinis vinifera* and *Malus domestic*us suffer from low pH, invasive *Mentha* spp., *Alliaria petiolata* and Chenopodium bonus-henricus
6	24	6	Cultivation by pigs	Cardboard	Cut grass, composted horse and sheep manure	Few	Yes	*Fragaria vesca, Agastache foeniculum, Chenopodium bonus henricus*	Invasive *Symphytum upplandicum*, fences required for roe deer, larger contribution to the household each year
7	28	n.a.	Cultivation by pigs	Newspaper, litter	None	None	Yes	*Hippophae rhamnoides, Rubus lacinatus*	Tree and shrub growth retarded due to competition with the herbaceous layer

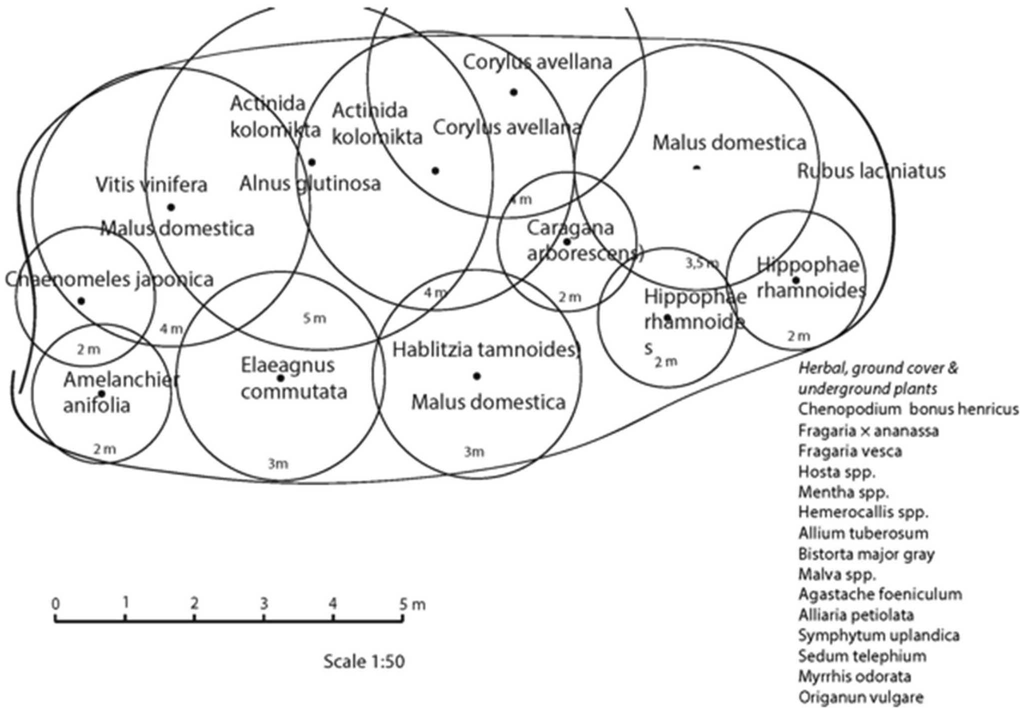

Fig. 2 Edible forest garden designed by the PAR group to study such systems as an approach for food production. Trees, shrubs and climbers are included in the scheme. All intended herbal, ground cover and underground plants are listed to the right

nutrient analysis of the seeds from good king Henry indicated that when cooked and the water was poured off, the content of bad-tasting oleanolic acid was low ($< 0.03\%$). If the seeds of good king Henry are shown to have edible value, the group stressed that it might also be appropriate to grow in monoculture in larger areas, facilitating harvest and contributing to turning agricultural production toward perennial crops.

Ground cover plants and creepers

At some sites where this layer did not develop well, it lacked space in terms of soil and light due to the strength of the herbaceous layer. The careful selection of plants for both layers was emphasized to ensure adequate interactions among species and an optimal combination of required edible products. However, at the edges, plants such as strawberry (*Fragaria* × *ananassa*) and wild strawberry (*Fragaria vesca*) thrived.

Climbers

Blackberries (e.g., *Rubus laciniatus* and *Rubus fruticosus*) and vines (*Vitis vinifera*) were included at the research sites. Both plants required support on which to climb before the trees were well established, and the blackberries required intensive pruning in some gardens. Caucasian spinach (*Hablitzia tamnoides*) was a climber that caught interest. This climber was found to grow fast and provide tasty leaves for salads throughout the growing season. Another climber that was included was the tasty and vitamin C-rich arctic kiwi (*Actinidia kolomikta*). However, the establishment of the plants was found to be somewhat difficult at most sites.

Underground layer

In the layer with perennial edible roots and tubers, the possible choices were found to be restricted. The wild alpine bistort (*Bistorta vivipara* Gray), which is known to have been used as flour during the famine because of its high carbohydrate content (Fält and Källman 1988), was included, but tubers were not used as plants were too small. The culinary values are largely unproven, and breeding efforts might be important for extensive use. The more widely used Jerusalem artichoke (*Helianthus tuberosus*), which some growers added at the back edge to act as a "wall" and windbreaker, quickly provided acceptable produce where it thrived.

Management regimes, development of the gardens and working requirements in relation to outcomes

The gardens developed differently not only because of different groundwater table, nutrient levels and differences in climate conditions but also because of accessibility and time allocation differences. The differences range from fully developed gardens to those heavily affected by wildlife, as well as changes in the herbal composition to less-diverse solutions. The more frequent the visits and the greater the time spent, the more complex the development and the higher the increase in insects, such as butterflies. A reason for this was that visits nearly always included caretaking, such as pruning, weeding and watering.

The labor hours required for planting the tree and shrub level in the gardens were similar irrespective of the methods used (Table 2), while the hours required for management and harvest differed substantially between the participants. The more hours spent on weeding, manuring and watering, the faster the establishment of the plants. The hours spent in the gardens also reflected their uses. The gardens rapidly yielded leaves and berries; however, harvesting required substantial amounts of time, and the participants tended to harvest at different degrees due to factors such as life situations and distances to the garden.

Factors for success and major problems in the establishment phase

The success in the establishment of an edible forest garden was found to be largely dependent on the management regime, e.g., the distance between the garden and the residence as well as the labor hours available. The initial soil properties were also important. Low pH and fluctuating water levels affected the establishment of fruit trees and vines. The initial amounts of organic matter and nutrient levels also affected the growth. At some gardens where additional green and composted manure were applied, this successfully accelerated the establishment and increased the harvests. The landscape attributes, e.g., the presence of vole and other wildlife such as moose and roe deer, heavily affected the plant composition of some gardens. Fences may be used, but the design needs to be adjusted to crops that are less appetizing for wild animals in such areas. One experience shared by the majority of the group was the importance of establishing the tree and shrub layer well before planting the herbaceous layer, which would otherwise hinder the growth of the trees and shrubs. At all gardens, some of the domestic plants, e.g., blackberries, comfrey and mint, became invasive and needed to be suppressed or removed.

Experiences of eating

To understand the potential of producing food through a forest garden, both food production and consumption experiences were documented. As the gardens are still in the establishment phase, the quantities have not yet been properly assessed, but the benefits provided by the gardens so far were justified by the participants.

The edible forest gardens produced energy, proteins and carbohydrates from the edible leaves, seeds, flowers, berries, fruits and nuts. The participants stated that obtaining fresh and tasty salads from the garden from the early spring to late autumn, a very extended season for these climate zones, was an easy task. It simply required broadening the definition of a salad to include leaves, herbs and flowers. Obtaining the major part of required vitamins and minerals was also perceived to be easy as a result of the diversity of fruits and berries grown.

Hazel was identified as a key species because of the fat content and high energy density in the nuts. Because nuts were of such interest, group members have tried to create areas with benign microclimates to establish uncommon species in the region, such as northern pecan (*Carya illinoinensis*), heartnut

(*Juglans ailanthifolia*), walnut (*Juglans regia*) and chestnut (*Castanea sativa*).

Major benefits

A general conclusion from the PAR group was that the benefits from an edible forest garden are closely related to a thorough analysis of the social and ecological context before the establishment. The relations among the location, what is grown and the beneficiaries are crucial, and there is not a universal design. For example, forest gardens far from the residence of people, as well as gardens that cover larger areas, need to have simpler crop compositions with coherent harvests than ones situated in a home garden. The objectives for creating an edible forest garden will determine the design and crop choices. A garden with the aim of delivering a daily harvest for cooking may contain a diverse design with multiple species, while a forest garden used to produce a commercial harvest needs to focus on fewer high-value products that are easily managed and harvested.

The major benefits from the complex composition and design of an edible forest garden that were identified in the PAR project were the delivery of a variety of tasty leaves and flowers for salads and tea throughout the cropping season as well as mineral and vitamin-rich berries. The literature reviews also indicate that a 200 m^2 edible forest garden with the design of the present project would produce minerals and vitamins in sufficient quantities to cover the needs of one man-year with the exception of vitamin B12 (Bodö 2013). However, the PAR group was reluctant to support the idea that an edible forest garden approach to production would provide the bulk of the energy necessary in human diets in northern temperate climates. Leafy salads, which would constitute a large part of such a diet, contain a high percentage indigestible fiber. Eating the volume that would provide enough energy might, therefore, be a problem. The group concludes that such a diet would be rather tedious.

Furthermore, the gardens were developed as beautiful places that attracted both humans and beneficial insects.

Discussion

Scaling up edible forest gardens in the present food landscape

There is a rapidly growing interest in edible forest gardens in temperate industrialized countries [e.g., see the review on food forest projects in (Clark and Nicholas 2013)]. Mainly urban and suburban dwellers establish edible forest gardens in their home gardens or on community-owned land.

However, if an edible forest garden system is intended to contribute to the production of more food rather than to self-sufficiency, the scale of the garden needs to increase. Based on the experiences from the sites of the research gardens in the project, the PAR group detailed where and how such systems could be managed and argued that there are locations that are appropriate for edible forest gardens systems in different shapes also on larger farms. Marginal lands and areas as edges between forest, pasture and arable land, were identified as appropriate. Field islets and point or linear elements in pastures or arable lands, were also suggested locations for such systems. The group stated that in such areas, edible forest gardens would favorably combine food production and carbon sequestration as well as harbor the biodiversity crucial for food production in other areas. This approach provides the possibility of increasing the diversity of products and the total production of a farm without reducing the yields of other crops.

Dixon (1994) argued that degraded, substandard soils and marginal lands, which occupy a significant proportion of the land use in temperate areas, may contribute to substantial long-term carbon sequestration if these areas are used for agroforestry. Smith et al. (2012b) also stated that such land use is especially valuable in marginal areas where the intensification of crop production is not a viable option due to the topography, soil or climate. A strategic location in the landscape near a large area of natural habitat or between remnants of forest patches is emphasized by Jose (2012) to be important for the ecological value of the overall agricultural landscape.

Molnar et al. (2013) point at that the characteristics that make marginal land "marginal" can make the land suitable for agroforestry, which, for example, may help improve the soils. However, the experiences in the PAR group show that these characteristics also need to guide the plant choices. Common reasons for abandonment, such as low pH or high groundwater tables, may otherwise negatively affect the establishment if plants that are sensitive to these conditions are included. The group also emphasized that sites require protection from wild animals or a design that comprises species that can tolerate visits from wildlife such as moose, deer and vole.

Challenges, knowledge gaps and development

High diversity and complexity, which are advantageous for the generation of most ecosystem services, were ultimately found to be the main drawbacks for the management of a production system driven by fossil fuel-based technologies. Sixty square meters can be tended by hand; but, the lack of appropriate technology for management was evident at larger scales. However, it is easy to get stuck in the current technology, but the PAR group proposed solutions such as drones and different types of robots that already exist. Still, the group perceived that the main activities had to be done on one's own, by a hired labor force or by customer self-picking, which reduces the competitiveness compared to monocultural land uses in areas where labor costs are high.

The productivity of an agroforestry system depends on the interactions among and within species and with the abiotic environment (Smith et al. 2012a). Theoretically, the three-dimensional vegetation, both above and below ground, of an edible forest garden, as well as plant interactions with the biotic communities in the soil, facilitate the efficient exploration of available niches, which may lead to high productivity (Cannell et al. 1996). On the other hand, an overlap in the resource use of different species could counteract this benefit (Smith et al. 2012b). In northern temperate regions, light, for example, could be a critical resource, and Malézieux (2012) therefore questions whether this form of land use is optimal in temperate climates. Torralba et al. (2016) also observed a general trend of diminishing positive effects of agroforestry with increased precipitation and decreased temperature. Field studies in the PAR group, together with experiences from other practitioners, indicate that designs with shade-tolerant plants, good spacing, and the placement of plants with increasing heights from the south toward the north, as is possible in edge zones, were important means of reducing light competition.

Experiences from the PAR project, which were supported by the findings by Lowell et al. (2017), point to the crucial knowledge gaps concerning potential production as well as the ecological value of edible forest gardens in temperate areas. There is a lack of data on the yields of specific species when they are grown in monoculture as well as regarding the yields of species in intercropping conditions. The possible design combinations are numerous, and the slow establishment makes this research challenging (Ibid). The PAR group anticipated that access to the varieties of plant materials that have high edible values and can be easily harvested is crucial for the development and expansion of edible forest gardens. The group called for structured breeding work to be organized on a regional basis. Lowell et al. (2017) also anticipated that improved tree crop varieties might "boost the overall performance of the system", and Clark and Nicholas (2013) started this work by identifying species that may be suitable due to cold hardiness, drought tolerance and edibility. The group further identified the need for research on the interactions between the forest garden plants and the above and below ground wild biotic community, e.g., biological regulation due to predation, parasitism, symbiosis and allelopathy.

Conclusions

The group concluded that the forest garden produces abundant fresh products for consumption throughout the growing season and provides minerals and vitamins that are currently imported, including a vast amount and variety of berries rich in minerals and vitamins. Moreover, the group indicated that the forest gardens had become beautiful, harmonious and pedagogic places that they highly appreciated being in. These experiences call for further efforts to identify the possibilities for producing immense amounts of both common and new forms of fruits, nuts, fat-rich seeds and berries from such systems. There is an urgent need to identify species and combinations that work in different types of sites as well as to evaluate the contributions to the generation of ecosystem services from different designs.

For edible forest garden approaches to play a serious part in the sustainable development of food production in the future, efforts to develop technologies appropriate for managing such diverse and complex systems, as well as for breeding species for high and harvestable yields, have to be substantially expanded.

We can also conclude that for scaling the multi-strata production, adaptation of the edible forest garden design is needed to fit the local context and location.

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Article

Can Agroforestry Grow beyond Its Niche and Contribute to a Transition towards Sustainable Agriculture in Sweden?

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Abstract: Agroforestry is thought to be an approach that could support agriculture in the transition from a system with sustainability problems to one containing regenerative activities contributing to viable ecosystems and, therefore, sustainability solutions. A transdisciplinary and participatory action research (PAR) group that included farmers approached the development of temperate agroforestry systems in the modern agricultural setting of Sweden through practical experience on 12 farms for collective analysis. The objective was to research potential systems such as edible forest gardens, silvopasture and silvoarable systems to discuss their use and effects as well as scaling possibilities. Knowledge and experiences of challenges and solutions related to the development of agroforestry were identified at both niche and regime levels.

Keywords: agroforestry; temperate; agroecology; participatory action research; transition; niche innovation

1. Introduction

Modern agriculture has contributed to an increase in yields at the expense of a decrease in other ecosystem services that are important for human wellbeing [1]. The use of non-renewable resources such as fossil fuels and phosphorus is extensive. Almost all of the ten planetary boundaries are related to food production [2], and four of them (biodiversity, biogeochemical flows, land use change, and climate change) have exceeded "the safe zone boundaries" into uncertain zones [3]. In accordance with Agenda 2030 and the UN Sustainability Goals (SDG), the FAO has addressed the need to transform food and agricultural systems and agroecological initiatives could contribute to this effort [4]. From a global assessment identifying redesign approaches that could contribute to a transition in agriculture and agroforestry practices, "trees in agriculture" are one of the seven listed [5].

1.1. Temperate Agroforestry

One agroecological practice, agroforestry, is defined by the European Agroforestry Federation (EURAF) as "the integration of woody vegetation, crops and/or livestock on the same area of land". Temperate regions have a long tradition of agroforestry system adoption (e.g., animal grazing in natural woodlands, alleycropping, orchard intercropping, and home gardens/edible forest gardens). Some practices have been re-introduced due to the influence of tropical regions, where more research has been conducted than in temperate regions.

Through the AGFORWARD research project, which involved 40 stakeholder groups and roughly 820 stakeholders across 13 European countries, agroforestry innovations were field tested and developed through participatory research to understand how agroforestry can support European agriculture and rural development [6]. Agroforestry land, which constitutes 9% of the agricultural land in the EU, is encouraged by working with farmers at the farm or landscape level rather than per hectare square [6].

Compared to conventional agriculture, the integration of trees and other perennials with the landscape increases biodiversity and supports both wildlife (habitats) and domestic animals (health) while extending ecosystem regulation services by reducing fire risks, enhancing carbon sequestration, reducing soil erosion and nutrient leaching and increasing levels of soil organic carbon. Stakeholders in Europe also perceive aesthetic qualities and other cultural benefits that could attract tourists and other visitors [6–8]. The limitations of agroforestry relate to increased labour needs, more complex work (e.g., working with trees and harvests), and management and administrative costs [7,9]. Furthermore, the establishment of woody perennials takes time as well the evaluation of effects of planting certain trees, which may be possible after 20–80 years [6,10]. This could constitute one of the factors behind why research on agroforestry in temperate regions is limited [11,12].

1.2. Agroforestry in Sweden

Depending on what is included on the concept of agroforestry, different account emerge. Land Use and Land Cover Survey (LUCSUS) data show that in Sweden, arable agroforestry, livestock agroforestry and high value tree agroforestry (e.g., fruit and nuts orchards) represent 1.1% of territorial areas, reflecting 15.2% of all utilized arable area [13]. Livestock agroforestry constitutes 99% of the total area designated for agroforestry in Sweden [13]. At the farm level, an assessment of ecosystem services of woody pastures of at least one Swedish farm has been included in a European project [14].

Historical and contemporary examples of agroforestry in Sweden show that extensive forests have traditionally been used for cattle, sheep and goat grazing in silvopastoral systems and by the system of summer farms [15]. In northern parts of Sweden and in Finland and Norway, the Sami people have traditionally maintained and still maintain large herds of semi-domesticated reindeer grazing freely in mountainous and forested areas. In terms of area, Valinger et al. (2018) claim this to represent one of the largest agroforestry systems in Europe (i.e., reindeer husbandry alongside forestry, hunting and tourism) [16]. Field experiments addressing agroforestry with a focus on the intercropping of perennials are under development at the Swedish University of Agricultural Sciences (SLU). One project is developing and testing how edible forest gardens installed at pre-schools could function as pedagogic tools for children [17]. There has also been an emerging interest in different agroecological approaches in sometimes overlapping grassroot movements related to permaculture, urban gardening and Transition town movements [18–20].

1.3. The Need for Transition

A shift to modern agriculture that contributes to a sustainable planet will involve not only an adjustment or change to the maintained production system but also a transition [21,22]. New methods of agricultural performance based on agroecological principles could allow for such a transition as shown by Nicholls, Altieri, and Vazquez (2016) [23]. Such agricultural production approaches, which are considered not only sustainable but also regenerative, involve different agroforestry systems [24,25].

To address global food security, Tittonell et al. (2016) [26] point to a need for local agricultural innovation worldwide. Their suggestions include using perennial crops and encouraging functional diversity at the plant, field and regional scales. They also show that in the Global North, reducing agricultural impacts on the environment will require a greatly reduced use of external inputs. Additionally, in Sweden, increased production of fruit, berries and greens could reduce the use of inputs abroad, as dependence on imported fruit and vegetables to provide vitamins and minerals is high [27].

To explore and learn more about agroforestry in temperate regions, a group of researchers and Swedish agricultural producers has conducted a pilot project on agroforestry in Sweden through a participatory action research (PAR) project and has tested and analysed different forms of agroforestry across 12 farms. The joint work and the process of establishment applied at each farm are presented in detail in an online report written in Swedish [28], and outputs of the PAR project are published in Björklund et al. (2018) [29]. In this paper, we will investigate the need for agroforestry to expand beyond its niche and through this transition become an acknowledged facet of Swedish sustainable agriculture.

2. Materials and Methods

This initiative, a case study of a participatory action research (PAR) project conducted from 2012–2016 as a pilot project to investigate the establishment of agroforestry in Sweden, will be described in depth. This agroforestry innovation system, i.e., a collaborative platform created by participants and their practices, is explored as an example of an agricultural transition and in reference to the need to scale transitions [30] depending on practices, prerequisites and contexts.

The PAR project on agroforestry was based on cross-organizational collaboration fostering transformational change towards sustainability through work in "real-world laboratories" as described by Luederitz et al. (2017) [31] in adherence with principles of agroecology [32]. It was carried out through a participatory action research (PAR) group of producers from 12 different areas: 9 were small holders of farms of different sizes (3–200 ha) often with a combination of different forms of food production and other activities (e.g., visitors as tourists or participants in learning events), 2 were community projects inspired by transition town movement, one was a part of an ecovillage, and one managed a demo/learning site involving a large number of volunteers and a formal educational programme where agroforestry practices have been implemented since the start of 2004. Despite their heterogeneity, we refer to them hereafter as 12 *farms*. Two researchers, both with a background in agronomy and one with facilitating skills initiated the project. Through the workshops, which each involved 1 or 2 people from each farm, 18 people participated over 4 years. On several occasions, experts on subjects such as soils, pasture and leaf protein were invited to the workshops. The goal of the work was to develop modern agroforestry systems and to learn about their effects, practices, use and scaling opportunities. Potential farmer participants were identified before the actual research project started through a pre-workshop held by people with agroforestry experience in southern Sweden to explore interest in an investigation of applied agroforestry in Sweden. Anyone with such an interest was invited to participate in the research project. None of the participants used commercial fertilizers or pesticides, and all were interested in reducing the amount of oil used in agriculture. Their management approaches focused on resource effective production with limited external inputs. Agroforestry was seen as a way to achieve less dependence on such inputs.

The group met for 9 workshops over 4.5 years and held 14 telephone meetings. The facilitated workshops were conducted at the different farms. To facilitate learning on new and unexperienced practices, three activities were engaged in: i) collectively determining the scope and intentions of the group; ii) on an iterative basis, "exploring impacts through situation analysis defined through the analysis of questions and by deciding which to explore" [33]; and iii) creating a space for creativity, sharing and feedback.

The farming systems research project was driven by all of the participants, and the facilitating researchers were also practitioners who also took part in the research. The research questions were formulated jointly by the researchers and farmers. All participants were invited during the project to attend national meetings and international agroforestry conferences and were also consulted during the production of public written materials. All farms contributed to the report in Swedish with detailed descriptions of case studies and of methods employed on the 12 farms. The approach used in this study builds on experiential [34] and social learning [35] for all participants to gain competence. The process was designed to enable learning about individual farm conditions through our collective learning and vice versa.

To facilitate discussions on scaling and transitions, transition theory and multilevel perspective (MLP) theory [36] adapted to agriculture [37] were used as heuristic tools in group discussions. This approach was adopted to facilitate coverage of societal impacts on systems, including aspects observed at the niche, regime and landscape levels and their complex connections. The niche reflects the micro level from which new innovations or local projects are developed and are regarded as "seeds for change" [38], while the regime or meso level considers areas such as policy, science, market or technology. The landscape level reflects a less dynamic environment (e.g., economic growth or oil prices) [38]. A transition involves societal change as the outcome of interactions between niches, which could also involve places or communities and the regime or landscape levels [38].

3. Results

Here, we provide an overview of the *processes*, *outputs* and *outcomes* of the project. Practical experience and means of scaling possibilities and limitations are presented in reference to each form of agroforestry. When using the term "group" or "PAR group" below, we refer to points raised through group discussions held at several workshops.

3.1. Process Overview

During the first workshop (April 2012), the PAR group decided to use agroecological principles of functional design, biodiversity, multifunctionality, adapted scales, ecosystem services, circulation and plant nutrients as a basis for collective work on the design and development of agroforestry systems to be studied. In this way, quantitative goals were set, and an agreement was made to work in teams. In April 2016 (workshop 9), the group summarized the outputs and outcomes of the project.

Through the PAR project, the group decided to plan for and apply three forms of agroforestry: edible forest gardens at all 12 farms where 3 of the farms also planned for silvopastures and five planned silvoarable systems. The edible forest garden design (compositions of plants and sizes) presented in Björklund et al. 2018 was adopted by the group [29]. Locations, the preparation of land and the addition of plants were individually determined at different farms (see Figure 1 and Table 1). Experiences with introducing and managing these systems were shared through facilitated discussions with the group and were well documented. The materials produced were analysed and re-discussed by the group and conclusions were agreed upon.

Figure 1. Map of Sweden showing the geographic positions of edible forest gardens studied, reprinted from Björklund et al. 2018.

Table 1. Farmers' observations of the establishment phase (2013–2016) of the edible forest gardens. The table pertains to project described here and is published in Björklund et al. 2018.

Farm	Labour Hours, Establishment of Tree and Shrub Layers	Labour Hours, Management and Harvesting	Preparation before Planting Trees and Shrubs	Preparation before Planting Herbal and Ground Cover Layers	Manure	Irrigation, Occasions, yr	Inclusion of Annuals during Establishment	Main Harvested Plants	General Observations
1	25	10	Tilling	Tilling	None	4–6	No	*Amelanchier anifolia, Malus domestica, Hippophae rhamnoides, Chenopodium bonus henricus*	Satisfactory growth of trees and shrubs, promising *Chenopodium bonus henricus* growth
2	22	22	None, sward planting	Plastic weave	None	None	Yes	*Fragaria x ananassa, Amelanchier anifolia, Hippophae rhamnoides, Rubus lacinatus*	Slow growth when planting in swards, invasive *Rubus lacinatus, Malus domestica* disfavoured due to high levels of groundwater
3	26	5	Tilling	Cardboard, litter	Well composted sheep manure	Few	No	*Amelanchier anifolia, Malus domestica, Rubus lacinatus*	Tree and shrub growth is retarded due to competition with the herbaceous layer
4	28	n.a.	None, sward planting	Cardboard, litter, cultivation of annuals	Grass cuttings, composted manure	Yes	Yes	*Fragaria vesca, Amelanchier anifolia, Malus domestica, Hippophae rhamnoides, Agastache foeniculum, Hablitzia tamnoides*	Symphytum upplandica is invasive to *Malus domestica*, less work and more harvesting, leaves and flowers for salads are produced each year
5	24	18	None, sward planting	Cardboard, newspaper and litter	Fresh sheep manure	Few	No	*Amelanchier anifolia, Hippophae rhamnoides, Rubus lacinatus, Chenopodium bonus henricus, Agastache foeniculum, Hablitzia tamnoides, Mentha* spp., *Origanum vulgare*	*Vinis vinifera* and *Malus domesticus* suffer from low pH *Mentha* spp., *Alliaria petiolata* and invasive *Chenopodium bonus henricus*
6	24	6	Cultivation by pigs	Cardboard	Grass cuttings, composted horse and sheep manure	Few	Yes	*Fragaria vesca, Agastache foeniculum, Chenopodium bonus henricus*	*Symphytum upplandicum* is invasive, fences for roe deer are needed, greater contributions to households each year
7	28	n.a.	Cultivation by pigs	Newspaper, litter	None	None	Yes	*Hippophae rhamnoides, Rubus lacinatus*	Tree and shrub growth is retarded due to competition with the herbaceous layer

3.2. Outputs

As outputs of this project, 12 edible gardens and one silvoarable system were established as well as reference data for future research, extensive nutritional data on two unmapped crops, additional nut gardens created on 12 farms, demonstration plots with nearly 140 varieties, a conference article and poster, and a report describing the 12 cases and group outcomes published online in Swedish [28,29].

3.3. Edible Forest Garden Experiences

All of the farms established edible forest gardens of the same size (60 m^2) and with the same woody plants across southern Sweden [28,29]. As shown by Bodö (2013) [39], these gardens work well as a production unit on a household scale and are able to adequately support human needs for vitamins and minerals. Establishment was performed by hand, and production took 3 years to initiate. These first years were time intensive, but the need for attention declined as planting continued. Identifying the right plant species and good quality varieties is critical to not prolonging establishment, but this is difficult to achieve. Good plant material is quite expensive. Weeds must be extensively tended to during establishment, and good mulching materials must be used. The household edible gardens were perceived as conferring multifunctional benefits in producing new products for *human consumption* and in offering aesthetic qualities from an enhanced richness of species such as flowers, butterflies, bees and birds.

Factors identified for the establishment of edible forest gardens in terms of scaling out (increasing quantities) and scaling up (increasing the size) were numerous. In practical terms, the improved availability of plants, seeds and seedlings and plant schools providing information on edibility were greatly appreciated, especially in reference to different types of nuts capable of producing in the northern climate. Knowledge of ways to determine which plants grow together (intercropping) and of the nutritional value of different plants was also desired.

As such gardens are still not well understood in Sweden, more well-functioning prototypes used in different growing zones were called for, especially for application in official contexts such as parks and campuses. For farming purposes, edible forest gardens were discussed as suitable for field boundaries, islets and corridors and as means to develop multi-strata alleys. To enhance the self-sufficiency of gardens under current circumstances, a shift in norms and values, a reduction in wage labor hours and cultural acceptability are likely needed. The report by Eksvärd et al. 2016 is accessible online and provides detailed information in Swedish on different modes of establishment applied in different farms and households with or without animals and based on different climatic zones [28].

3.4. Agroforestry with Animals: Silvopasture Experiences

In the group, five farmers were especially interested in silvopasture. Prior to the PAR project, all of the participants had started small-scale animal productions (less than 15 livestock units on a yearly basis) based on natural and field-based pastures. Natural pastures that had developed over time served as multifunctional systems producing apples, berries, fodder, timber and firewood. Modern forms of animal keeping were also integrated with crop rotation and forest re-establishment by pigs. Such multifunctional pasture systems were identified suited to their local contexts.

Pasture profitability in Sweden is very financially dependent on the Rural Development Program (RDP) [40] and is therefore bound by different production rules. As an approach to multifunctional production is not outlined under the Swedish RDP, developing such systems is financially difficult in practice. For those attempting this task, the group concluded that the regeneration of trees presents as a problem to solve: how do you plant new trees in an area where animals graze without many resources and with high labour costs? Additionally, when fruit trees are grown in a natural pasture with uneven ground, they are difficult to arrange in rows. Preventing fallen fruit from becoming contaminated on the ground was also discussed, as were harvesting techniques. All production steps were concluded to take more time than when applied to plain grazing areas, though sites may generate more production.

The farmers claimed that for silvopasture to be encouraged, a re-evaluation of trees already existing in pastures is needed. For farmers to better appreciate and see the potential in what they already have and are doing is one thing, while garnering the interest of different authorities and adjusting RDP support systems is another. More research on the contributions of multifunctional pasture systems and on ways to tend them was requested. The need for financially re-valuing products such as cider apples and wood were discussed. Again, the norms and values of our society and market system were concluded to not assign adequate economic value to farm products and ecosystem services such as carbon binding.

3.5. Agroforestry in the Field, Silvoarable Experience

As three farmers planned for and one had initiated agroforestry systems with fruit bearing trees and bushes in agricultural fields, discussions of this issue were at times intense. Among the participating small-scale farmers of woody landscapes, adding trees to their most small crop fields surrounded by forests was not of interest. Fields that have been cleared in such landscapes by earlier generations with much toil quickly return to forest when not tended to, and acreage is needed for fodder products. However, farmers with more acreage and marginal land that today is not productive enough for cereals were interested in the combined production of cereals or pasture with fruit and berries.

For the couple of farmers with comparably large-scale farms with flat fields, a focus on crop production and a desire to expand and improve farm ecosystem services and field agroforestry was noted. The farmers had planted demonstration patches of 140 different varieties of perennials in windy locations. This was done to determine how such varieties perform in the environment, their potential yields and potential financial outcomes as well as to determine which crops must be bred to survive in the Swedish environment. Plots were arranged and labelled for other agricultural actors to study with fellow farmers in mind. In addition, 1 ha of alley crops with rows of fruit, nut and berry crops was introduced, which was financed and set up by Organic Farmers Countering Climate Change [41]. To plant woody crops in their fields, the farmers needed to seek permission from their neighbours and county administrative boards. Support from the RDP was limited and the application process proved very complicated. Additionally, questions surrounding harvesting remained a challenge for the farmers.

Other questions that emerged from the group discussions focused on ways to secure as many services from a multi-strata design as possible in adopting edible forest gardens in the field. How much of the 7-layer structure of symbiosis can be maintained? Should one plant in alleys or islets, and how should boundaries be designed? How do different approaches to agroforestry correspond with landscapes, soils, points of the compass, farm machinery, labour capacities, etc.?

For agroforestry to proliferate, the group concluded that more trials and demonstrations are needed to further knowledge and management experience with different approaches and crop varieties. The use and development of technologies for harvesting and the use of labour spurred varied discussions. Another issue raised concerned the capacity to sell smaller amounts of diversified products. Questions regarding the value chain from storage approaches to selling products with added value on a market were also discussed.

To conclude, the group argued that the development of agroforestry as an agricultural approach in Sweden will be shaped by the availability of new crop varieties; changes in production systems, tools and methods; changes in consumption patterns and diets; access to markets; cultural expectations of landscapes; knowledge regarding design, symbiosis and other effects; and nutrient analysis. Additionally, further research, demonstration plots, monitoring and evaluation, more understanding from authorities, and adjusted rules and subsidies were called for.

3.6. Outcomes of the Agroforestry Project

In addition to establishing plantations as learning sites and supporting the PAR project as a learning platform, the group contributed to the arrangement of the first national conferences on agroforestry held in Sweden (Stjärnsund in 2014, Gothenburg in 2015, and Alnarp in 2017) as well as contributing to the establishment of the Swedish Agroforestry Association. Networking activities involving other research and development projects have been extensive. The group's work was covered in at least 8 magazine articles and in a scientific programme broadcast on public radio. The sites were visited by well over 2000 people from transition groups, local growers' organizations, students, the Federation of Swedish Farmers, universities, the Swedish Society for Nature Conservation, and others. The researchers also participated in higher education courses and lectures. One of the participants decided to start a Ph.D. project on agroforestry. One high school paper, two Bachelor's theses and one Master's thesis related to the group's work were also written [39,42–44]. Some participants helped established the European Agroforestry Federation (EURAF) and participated in its conferences in Montpeiller, France in 2016 and in Nijmegen, the Netherlands in 2018. Two research articles were also drafted.

4. Discussion

What is needed to establish agroforestry as an acknowledged approach of Swedish agriculture and national food self-sovereignty? How can this transition in agriculture proceed, what would it take for agroforestry in Sweden to expand beyond its niche, and what would it take for such a transition to expand further?

4.1. Farm-Level Management

In the PAR group, agroforestry was seen as a way to ensure less dependence on external inputs. This can be accomplished by adopting nitrogen fixating crops, crops with deep roots, well-established mycorrhiza and self-regulative processes. Agroforestry systems and multi-strata in particular are more complex systems requiring different management approaches such as harvesting from different layers. Such management necessitates new forms of competence that, according to García de Jalón et al. (2017), together with added administrative burdens, are perceived as principal constraints by European farmers when asked about their views regarding the adoption of agroforestry.

4.2. Financial Situations and Contexts

Whether the agroforestry systems studied were designed for subsistence or commercial purposes, they needed to generate a net profit of some kind. This was found to depend on many aspects and took the discussions to "higher than farm" levels of institutional change, as described in [45].

As a financial strength of an established and well-functioning agroforestry system, it can produce more harvests per acreage than mono-cultural systems [9,46]. However, as today's agricultural policies and food prices force farmers to rely on sources of income other than production amounts and their pricing, this aspect cannot ensure agroforestry production profitability. Additionally, for perennial woody crops, symbiotic interactions take time to establish, and productivity levels are low during the establishment phase. This raised questions regarding ways to increase productivity throughout the transition. How can production in, for example, a field be established to generate as much produce as possible during a transition? What crops can be grown in the meantime? As ways to generate income to cover extra costs and a lack of income, the farmers discussed two possibilities: increasing prices for added value, which would involve branding and developing value chains, and adapting support systems that would give credit to agroforestry systems.

Other questions posed on the importance of financial concerns were as follows. Is there a need to invest in machinery and to develop new machinery? Should high-tech solutions be adopted? Alternatively, can less resource-intensive low-tech solutions be adopted by hiring more labour? Hiring personnel at set Swedish salaries is expensive and is often unfeasible for smaller farmers. The farmers studied already use cheap labour through organized volunteering or internships. In a society where labour time is an expensive asset, access to appropriate technology is critical.

While voluntary labour that lowers monetary income and increases one's own labour load may be an option when seeking self-subsistence, for most farmers, this is not an option. Creating opportunities to enhance farm labour is closely connected to solutions at the regime level.

4.3. Competence Building

As agroforestry is very complex, support from research and extension services must offer advice that combine agriculture, horticulture and forestry in a systemic setting. This calls for collaboration and the development of competence in all actors.

Through our PAR project, the transition, however small, was not initiated with a research- or regime-level "push"; rather multiple actors "pulled" the process forward as described by [47]. An openness to connect with "multi-actor colleagues" proved essential in supporting creativity and processing inputs. Sharing from different actors, the co-creation of practical farm work (where the change actually happens), and research (where facts get analysed, validated and put into print) helped clarify the required inputs from different professions. The importance of such transdisciplinary approaches for sustainable development is illustrated by [32,48,49] among many others.

The experiences of the studied group point to a need for "knowledge and innovation brokering" [47] rather than for traditional extension and education according to the transfer of knowledge. As systems must be developed according to specific contexts at the local level, one cannot "copy and paste" systems or management approaches. Therefore, extension and education or brokering must promote creativity and innovation for transitions to occur. As an example, "hybrid forums" serve as spaces between the niche and regime levels where niche innovators can scale innovations up and out, as described by López-Garcia et al. 2018 in reference to a training programme provided at a Spanish university [50].

4.4. Bridges and Barriers

When defining biodiversity as a "necessary ecological structure to support agricultural production" [26] that varies in each location as observed through this PAR study, this definition clashes with EU policies on biodiversity. The identification of well-suited local systems does not adhere well to prefabricated, generalized and quantified indicators of control as today's formal systems postulate. When rules are top-down, as under the RDP, they may work as lock-in systems hindering creativity, biodiversity and development [40]. For agroforestry to become a more widespread approach, changes must also be made to forms of authority, as claimed by [37], and policies [51]. Several barriers to the spread of agroforestry were identified. The need to convince farmers emerged as an underlying theme. We argue that interest in agroforestry in Sweden has occurred the other way around in parallel with and in synergetic relationship with an agroecological movement that has emerged over the same period.

While there are problems to solve at the niche level, barriers to agroforestry have also been identified at the regime level. The management of multiple service systems must be supported through policy and institutional innovation for public education to offer the required incentives to support a reduction in agriculture's environmental footprint [52,53].

Potters et al. (2014) [30] showed that the scaling of a novel approach to agriculture may involve an increase in transactions at the local level, the emergence of technical and organizational changes and the involvement of different actors. Their study as well as ours revealed the importance of contextual factors of scaling. Rather than determining how a novel practice can be scaled, the question concerns how a society can provide room for novelty.

Thus, the notion of principles is brought into context. Midgley (2016) provides a condensed description of principles and methodological processes required for the co-creation of knowledge to be fruitful. These include taking account of multiple possibilities and allowing new and emerging properties be generated to enhance systemic awareness and create a generative context [54].

For society to contribute to agroforestry systems, new knowledge and skills must be acquired. Nicholls, Altieri, and Vazquez (2016) [23] describe such a systemic change that can re-design the needs of farming systems by applying agroecological principles.

5. Conclusions

We can conclude that systemic and symbiotic thinking and actions used by the studied PAR group serve as foundations for work exploring the introduction of modern agroforestry systems in Sweden, supporting not only the outputs presented in [29] but also the outcomes provided here.

A viable and strong agroecological movement with an interest in agroforestry in Sweden continues to grow. However, to increase acreage and develop agroforestry into an agricultural approach rather than an interest of enthusiasts, there is plenty yet to do. As shown in our discussion, education and extension services must be developed, profitability and legislative issues must be addressed, and practical production issues must also be addressed. In theory, agroforestry offers great benefits in regard to productivity, ecosystem services, regenerative processes, etc. In practice, while such benefits remain, a wide range of challenges were identified by the PAR group in terms of finding plant materials and adequate extension services and ensuring (sufficient) profitability.

To facilitate an agricultural transition that is not only sustainable but also regenerative, societal actors must learn to work with agricultural systems based on open system goals: improvements to each farm and principles (e.g., agroecological principles) and equality (e.g., PAR) at a regime level as shown in this article. The scaling of agroforestry to improve food self-sovereignty and to offer ecosystem services involves acknowledging local knowledge, multifunctionality in systems, flexible payment systems, and the interconnectedness of scales, creating opportunities for these systems to become profitable enough to live off of and easy enough to manage from the field and office.

Our PAR project based on 12 farms involved a unique collaboration of farmers and researchers in Sweden focused on agroforestry and may support more long-term studies on temperate regions, as the establishment of agroforestry systems takes time [10,12].

High temperatures experienced in the summer of 2018 that affected access to fodder for grazing animals in Sweden drew attention to farmer issues and to potential vulnerabilities to climate change. It may thus be necessary to monitor and evaluate existing practices to identify ways of improving agroforestry techniques and ways that authorities can adapt regulations to not further delay the ongoing process. Regime-level actors can work based on principles of equality, shared goals and transdisciplinarity to facilitate transitions within agriculture not only to ensure sustainability but also to allow for re-generative solutions such as agroforestry systems.

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III

Agroforest Syst
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Motivation and perception of farmers on the benefits and challenges of agroforestry in Sweden (Northern Europe)

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Abstract Agroforestry systems provide multiple benefits for human wellbeing and biodiversity; however, their diversity and spatial distribution has sharply declined across Europe. This study focuses on agroforestry farms in Sweden. The aim of the study was to explore farmers' motivations to start agroforestry, what benefits farmers attributed to their agroforestry farms and perceived challenges to practising agroforestry in Sweden. In total, 13 farms that practise various agroforestry forms were selected as case studies. A focus group, semi-structured interviews and field observations were used for data collection. We identified four types of agroforestry systems such as silvopasture, silvoarable, forest farming and forest gardens established on different land such as forested or agricultural land. All studied agroforestry farms were small but had complex spatial and temporal arrangements of crops, trees and animals, which were crucial to generating multiple benefits. Our results show that the multifunctionality of agroforestry systems resulted from farmers' desire to design such systems. Farmers' intentions to get foods and materials from their farms were always intentionally unified with multiple ecosystem services. We argue that agroforestry farmers are designers of multifunctional landscapes, as they deliberately organised their farming activities to get a bundle of ecosystem services belonging to all four categories—provisioning, regulating, supporting and cultural. However, the complexity of agroforestry management, lack of technologies suitable for small-scale agroforestry farms, limited plant materials (including seedlings) and limited knowledge about how to do agroforestry challenged the scaling up of agroforestry practices.

Keywords Agroforestry · Ecosystem services · Farmers' perspective · Multifunctional landscapes

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Introduction

Agroforestry denotes the multifunctional land-use system that deliberately integrates woody vegetation with crops and animal production through diverse and simultaneous land-management activities, resulting in the provision of multiple tangible and intangible benefits (Mosquera-Losada et al. 2009; Plieninger et al. 2015; Fagerholm et al. 2016; Torralba et al.

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2018; Elbakidze et al. 2021). Agroforestry practices often overlap with each other temporally or/and spatially, creating multifunctional cultural landscapes in Europe. Traditionally, agroforestry systems have been the key elements in the European cultural landscapes for centuries (Eichhorn et al. 2006; Nerlich et al. 2013; Plieninger et al. 2015).

In the EU, agroforestry systems currently occupy 15.4 million hectares, or 3.6% of the union's total territorial area (den Herder et al. 2017), 98% of which are organised under different forms of livestock agroforestry and 2% under arable agroforestry. Many studies confirm that agroforestry systems simultaneously provide multiple benefits for human wellbeing and biodiversity (Jose 2009; Smith et al. 2012, 2022; Tsonkova et al 2012; Torralba et al. 2016; Abbas et al. 2017; Bentrup et al. 2019; Sollen-Norrlin et al. 2020). The IPCC reports (2019, 2022) claim that agroforestry has the potential to combine production with less adverse effects on the environment than conventional agriculture and forestry, as well as provide multiple benefits such as mitigation and adaptation to climate change, reduced land degradation and desertification as well as improved food security. However, the diversity and spatial distribution of agroforestry systems have been in sharp decline across Europe (Eichhorn et al. 2006; Plieninger et al. 2015; Almeida et al. 2016; Godinho et al. 2016), a trend caused mainly by intensification of conventional agriculture and forestry, abandonment of agricultural land and encroachment due to urban sprawl (Mosquera-Losada et al. 2009; Plieninger et al. 2015; Garrido et al. 2017a, b; Barthel et al. 2019). There are also multiple internal challenges in maintaining agroforestry systems, such as higher labour input due to the high complexity of these land-use systems and higher costs for investment, maintenance and administration in association with holistic management decisions (Graves et al. 2009; Garcia de Jalón et al. 2018), compared with conventional agriculture and forestry (Sereke et al. 2015; Garcia de Jalon et al. 2018). Often contradictory public policy measures (e.g., CAP) fail to address the multifunctionality of agroforestry landscapes and have been considered unfavourable towards agroforestry practices (Fragoso et al. 2011; Almeida et al. 2016; Pinto-Correia and Azeda 2017; Santiago-Freijanes et al. 2021). Serious concerns are expressed by multiple actors and stakeholders, including decision-makers and academics, that under current policies and trends in land use, agroforestry practices will continue to decline in the EU (Godinho et al. 2014; Almeida et al. 2016; Fischer et al. 2018).

This paper explores the motivations of farmers to start practising agroforestry, the benefits they attribute to their agroforestry systems and the challenges they experienced to practise agroforestry in Sweden. This study is particularly important within the context of new policy demands at multiple levels related to diversification of approaches to land management (e.g., UN Environment 2019; IPBES 2019). Conventional approaches to land management, including agriculture and forestry, are often characterised by a predominant bias towards the provision of products and services with market value (Reid et al. 2005; McAdam et al. 2009). Other benefits with no market value, i.e. biodiversity and traditional knowledge, are usually given less priority. By contrast, numerous policy documents have pointed out the need for a balanced development approach that embraces all dimensions of sustainability, including both material and immaterial values, and the full range of ecological, economic and socio-cultural benefits to accommodate economic development and human wellbeing (see e.g. UNEP 2019; IPBES 2019). Agricultural policy in the EU has gradually refocused from supporting large-scale conventional agriculture toward restoration of multifunctional agricultural landscapes, and the contribution of agroforestry to achieving high-level environmental and societal goals is reflected in several policy documents within different sectors (Agroforestry network 2018; Fischer et al. 2018). Agroforestry primarily receives support through the CAP, although the significant ecological and social value of agroforestry was acknowledged at the EU level only in 2005. For the period 2020–2027, the European Green Deal will guide the CAP, alongside the Farm to Fork Strategy (EU 2020a) and the Biodiversity Strategy for 2030 (EU 2020b), both of which address agroforestry and its multifunctional potential. According to the Biodiversity Strategy, "the uptake of agroforestry support measures under rural development should be increased, as it has great potential to provide multiple benefits for biodiversity, people, and the climate" (EU 2020b).

Given the impending EU policies, it is imperative to explore the diversity of agroforestry systems in Sweden and comprehend the potential benefits they may offer. During the last decade, there has been growing interest in agroforestry on the part of different stakeholders in Sweden, while in-depth studies on agroforestry systems, mainly newly established ones, are still scarce in Sweden and Europe's North in general. A systematic review by Fagerholm et al. (2016) indicates that current agroforestry research hotspots are concentrated in the Mediterranean region, the UK, and France, with a notable dearth of studies from Northern Europe. In high-income countries, the majority of studies have been conducted in the US (Castle et al. 2022), with only six out of 290 studies conducted in the Nordic countries. Studies on agroforestry in Sweden have predominantly focused on various forms of traditional silvopastoral systems, such as wood pastures (Sandberg and Jakobsson 2018), reindeer husbandry (Valinger et al. 2018), and the system of summer farms, based on animal husbandry on outlying fields covered by boreal forests since arable land is often scarce (Eriksson 2011; Axelsson Linkowski 2017). Furthermore, Garrido et al. (2017a) identified multiple benefits attributable to traditional oak wood pastures in Sweden by diverse stakeholders from the civil, private, and public sectors at the local and regional levels. They demonstrated that provisioning and cultural ecosystem services were perceived as the most important from the perspectives of different stakeholder groups. Kumm and Hessle (2020) conducted a comparison of profitability between spruce plantations, natural afforestation through planting birch trees, and beef production on mosaic forest-pasture land. With larger herds of animals (more than 20), the beef production alternative proved to be the most profitable, with the exception of spruce plantation in southern Sweden.

A few studies have analysed newly established and modern forms of agroforestry such as forest gardens in Europe's North. For example, Almers et al. (2018) focused on the benefits of such gardens for outdoor pedagogy for children, and concluded that forest gardens were more accessible and provided more opportunities for children's creativity compared to forest excursions. In Vlasov et al. (2018), forest gardens were understood as grassroots innovations and the initiators of forest gardens as grassroot "ecopreneurs" in Sweden. Björklund et al. (2018) explored the establishment of forest gardens and Schaffer et al. (2019) investigated three types of modern agroforestry systems and what would be needed for such systems to grow beyond the niche level. Both studies comprised participatory action research (PAR) in which farmers at 12 farms in Sweden were included (Björklund et al. 2018; Schaffer et al. 2019).

Using agroforestry farms as case studies in Sweden, this study focuses on the following research questions: Why do farmers practise agroforestry? What benefits do they attribute to their agroforestry farms? What challenges are associated with establishment of agroforestry farms?

Methodology

Key concepts

In our exploration of benefits attributed to agroforestry systems, we used a multifunctional landscape concept. Conceptually, an agroforestry landscape as a cultural landscape can be understood as a geographical unit that holds significance for local communities and various stakeholders, encompassing dimensions ranging from biophysical and socio-cultural to perceived aspects (Antrop 2004). The biophysical components involve all natural elements, while socio-cultural components encompass cultural legacies, heritage, and the people interacting with the natural elements (Angelstam et al. 2013). Multifunctional landscapes are defined diversely. We adhere to the definition put forth by Lovell and Johnston (2009), who characterise these landscapes as providers of a diverse array of environmental, social, and economic functions. Human activities often alter natural landscapes to serve single functions, leading to landscape homogenisation (Jongman 2002; Fischer and Lindenmayer 2007; Garcia-Martin et al. 2021). In contrast, multifunctional landscapes, as opposed to monofunctional ones, integrate human production with ecological functions, maintaining critical ecosystem services and biodiversity (O'Farell and Andersson 2010).

To comprehensively map all benefits attributable to agroforestry systems, we employed the ecosystem service concept. The ecosystems approach, particularly the cornerstone concept of ecosystem services, has emerged as the prevailing paradigm in research on people-nature relationships since its initiation by the Millennium Ecosystem Assessment (Reid et al. 2005). Numerous studies have empirically assessed ecosystem services provided by agroforestry systems, confirming their multifunctionality and relevance for both biodiversity and human well-being (Jose 2009; McAdam et al. 2009; Garrido et al. 2017a, b; Hartel et al. 2017; Torralba et al. 2018; Kay et al. 2019; Castle et al. 2022). Ecosystem services, defined as the benefits people obtain directly or indirectly from ecosystems, encompass provisioning, regulating, cultural, and supporting services (MA 2005). Ecosystem services research traditionally emphasises the supply side, employing spatial analyses of different land covers and other spatially explicit data to quantify ecological characteristics for the provision of a specific ecosystem service. However, recent studies underscore the importance of addressing the demand side of ecosystem services (Bagstad et al. 2014; Fagerholm et al. 2019; Plieninger et al. 2019), considering diverse stakeholder perspectives and interests regarding ecosystem services (Garrido et al. 2017a, b).

Despite its widespread use, there is substantial critique arguing that the ecosystem services framework oversimplifies the complexity of people-nature interactions inherent in agroforestry systems (Lele et al. 2013; Norgaard 2010; Elbakidze et al. 2021). Some scholars propose alternative terms, such as "social-ecological services" (Huntsinger and Oviedo 2014) or "landscape services", to better capture the multiple tangible and intangible benefits provided by agroforestry systems. Moreover, these discussions underscore the crucial roles of farmers and land managers in generating services (Garrido et al. 2017a, b). Being aware of such discussions, we have paid particular attention to how farmers explained benefits provided by their agroforestry farms and how they perceived their role in generating these benefits.

Finally, we employed the concept of a multifunctional landscape to explore farmers' motivations for practising agroforestry. The motivation to support environmental sustainability through agroforestry was evident when farmers referred to maintaining biodiversity, improving soil quality, or implementing measures to adapt to or mitigate climate change. Sustaining the economic functions of agroforestry farms was considered when farmers organised their practices to support their household economies. Lastly, when farmers aimed to preserve landscape values and traditional knowledge associated with agroforestry practices, this activity was categorised as landscape stewardship to sustain the socio-cultural functions of agroforestry systems.

Agroforesrty in a Swedish context

Historically in Sweden, silvopastoral systems have been practised for at least 2 500 years BP (before the present). During this period, people cleared forests to create fields for grazing domesticated animals in the outlands (Dahlström et al. 2006; Kumm and Hessle 2023). Beyond grazing, forests were utilised for hunting, collecting firewood, and sourcing construction materials. Currently, agroforestry occupies 1.1% of the territorial area, or 15.2% of all utilised arable land (den Herder et al. 2017) in Sweden, and 99% of the agroforestry systems are categorised as silvopastoral systems. However, recently there are growing numbers of pioniers developing new forms of agroforestry, among them systems of alley cropping, mixing fruit trees with cereals or pasture, and edible forest gardens. The number of farms with this type of production, its scope and financial contribution to the farms' economy is still relatively small. Since 2016 there is an active NGO (Agroforestry Sverige) comprisning farmers, agricultural advisors, reserachers and other actors aming at promoting agroforestry in Sweden (Agroforestry Sverige 2023).

In the Swedish rural development support system for 2023–2027, within to the EU common agricultural policy there is currently no support for establisment of agroforestry systems at farms. Niether is agroforestry eligble for CAP direct payments (Jordbruksverket 2022; EU CAP Network 2023).

Agroforestry farms as case studies

To address our research questions, we employed three criteria for the careful selection of agroforestry farms for in-depth study. The first criterion involved choosing the most experienced agroforestry farmers in Sweden, with a minimum of five years of hands-on agroforestry experience. This criterion was established in recognition of the need for a substantial time frame to draw meaningful conclusions, especially in the context of tree planting within newly established agroforestry systems. The second criterion aimed to ensure a representative sample by selecting agroforestry farms that collectively showcase the diversity of agroforestry systems in Sweden. This approach allows us to pursue a comprehensive understanding of various agroforestry practices within the country. The third criterion focused on selecting farms where revenue extends beyond the household level, addressing the broader food security dimensions of agroforestry in Sweden. Considering that approximately 50% of all food in Sweden is imported and distributed primarily through stores and the broader value chain, it is crucial for agroforestry production to contribute beyond individual households to make a substantial impact on the country's food security.

We applied a snowballing method to select agroforestry farms, through contacts established during agroforestry conferences and other events in Sweden, and with the help of experts from the Swedish University of Agricultural Sciences who have studied agroforestry systems in Sweden.

In total, we selected 13 farms (F1–F13) which are located in 13 municipalities in the central-southern part of Sweden. From a biophysical perspective, two farms are located in the boreal zone, eight in the boreal-nemoral zone (mixed forests), and three in the nemoral vegetation zone (deciduous forest). All farms are located in cultivation zones 1–5, which refer to the Swedish system for classifying the hardiness of plants (Sweden Plant Hardiness Zone Map 2022, www.plantmap/). The growing season is 170–215 days long; the summer mean temperature is 15 °C, and the winter mean is − 3 °C. The yearly precipitation is ~ 700 mm (Sveriges meteorologiska och hydrologiska institut 2023, www.smhi.se/). The soils are constituted by various types of clay and sand with different soil organic matter content.

The selected farms practised agroforestry which belonged to four categories—silvopasture, silvoarable, forest farming and forest gardens (Mosquera-Losada et al. 2018a, b), and ten farms (out of 13) combined several of these agroforestry systems (see Appendix 1).

Farms employing *silvopasture* agroforestry system integrated wooded elements with forage and animal production, as outlined by Mosquera-Losada et al. (2018a, b). Our identification revealed various forms of silvopasture, including *forest grazing, wood pasture,* and *fruit trees integrated with fodder/grazing*. In the forest grazing system, denser forests were utilised for grazing various animals, such as sheep, cows, pigs, and horses. This practice was observed on five farms (F1, F2, F4, F12, F13), each ranging from 40 to 2 000 hectares in size. Clear-felling forest management, particularly in spruce forests, was employed, and certain areas were designated for pig grazing. Additionally, two farms (F2, F4) implemented continuous cover forestry along with sheep and cow grazing in mixed forests. *Wood pasture agroforestry*, characterised by grazing sheep and cows in pastures with a lower tree density compared to forest grazing, was identified on five farms (F2, F3, F4, F9, F13). Pastures in this system often overlapped with patches of semi-natural grassland.

The *silvoarable* agroforestry system incorporated widely spaced woody vegetation that was intercropped with annual or perennial crops, as outlined by Mosquera-Losada et al. (2018a, b). Among the selected farms, *alley cropping* was the predominant practice within this system.

Alley cropping involved the cultivation of rows of tree crops (such as apples) and shrubs (including hazelnuts and a mix of berries) or mixed polycultures of trees and shrubs. These were strategically placed between fields of annual crops. The identified alley cropping systems in our study, each at least five years old, represent a unique presence in Sweden. The practice of alley cropping was observed on two farms (F1, F11). Farm F1 dedicated 1 hectare to alley cropping, while farm F11 allocated a more extensive area of 7–8 hectares to this agroforestry system.

Forest farming occurs in forested areas, integrating forest and agricultural lands for the production or harvest of natural standing specialty crops with medicinal, ornamental, or culinary uses (Mosquera-Losada et al. 2018a, b). In our study, forest farming encompassed practices utilised alongside forestry, intentionally producing various products on forest land. Such practices included the cultivation of mushrooms on logs, as well as planting walnut trees, fruit trees, shrubs and herbs into existing forests. While Mosquera-Losada et al. (2018a, b) highlight the significant potential of forest farming as an agroforestry practice, to our knowledge, our study represents the first documentation of forest farming in Sweden. Forest farming was practiced on three farms (F2, F6, F10), ranging in size from 2 to 40 hectares. On F2, oyster mushrooms were cultivated on logs within a mixed forest. F6 planted walnut trees in a birch forest, and F10 implemented forest farming by planting shade-tolerant species such as herbs, vegetables, berries, and nuts in a mixed forest. Continuous-cover forestry practices were observed in all three farms.

Forest gardens, aligning with the homegarden/kitchen garden (Mosquera-Losada et al. 2018a, b) or food forest category (Sharma et al. 2022; Park et al. 2018; Albrecht and Wiek 2021), represent an agroforestry system that integrates trees/shrubs with vegetable production, typically in urban and peri-urban areas. The term "forest garden", as used by the interviewed farmers in our study, aligns with the concept presented by Crawford (2010). Within our investigation, forest gardens were recognised as intercropped polycultures of edible woody perennials, incorporating a diverse array of elements such as fruits, nuts, berries, vegetables, herbs, flowers, and occasionally, components like hens and trees intended for timber, fiber, or fuel production. These gardens were thoughtfully designed as two- to five-layered systems, often mirroring the characteristics of the forest edge zone and the mosaic structure found in such ecotopes. Our study identified three distinct sub-categories of forest gardens. The first sub-category, termed "small forest gardens", ranged from 60 to 200 m^2 in size. These gardens featured five layers of perennials and boasted a rich species diversity of 30–100 species of edible woody perennials, including fruits, nuts, berries, vegetables, herbs and flowers. The second sub-category, known as "middle-size fruit gardens with hens", ranged from 200 m^2 to 0.5 hectares in size. These gardens featured 2–3 layers with 10–20 species of trees and shrubs. In place of a cultivated ground layer, hens were integrated into the system. The third sub-category, termed "food forest", varied in size from 0.5 to 7 hectares. These extensive gardens featured 2–5 layers of woody perennials, with one layer often focused on high-quality timber production. Intercropped with 25–400 edible species, these food forests served various purposes, functioning either as kitchen gardens for household needs, for commercial purposes, or as a combination of both. *Forest garden agroforestry system* was practised on ten farms (F1–F10), ranging between 2 to 230 hectares in size.

In total, 26 individuals were engaged in agroforestry practices on the studied farms, and for the purposes of this study, they are referred to as "farmers" since all of them were involved in food production. The distribution of farmers across age groups and living situations is as follows: fourteen farmers were in the age range of 30–45 years, eight farmers were between 55 and 65 years, and four farmers were in the 70–80-year age group. Among the farmers, five had families with small children, five (aged 50+) lived without children on the farm, and three farmers did not reside on the farm at all. Regarding land ownership and management structures, ten farmers (F1–F5, F7–F10) owned the land they utilised, two farmers (F11, F12) leased the land, and one farmer (F6) operated on land owned by a foundation. Additionally, three farms had specific characteristics within the study context: F13 utilised 2 000 hectares within a vast nature reserve where silvopasture was integrated into land management; F11 served as a university test site for silvoarable systems, and F6 functioned as a learning site for folk high school programs. Furthermore, F10 was managed by a group residing in the same village, collaboratively working on various agroforestry projects.

Data collection and analysis

In a first step, a focus group session was conducted in November of 2019 with five farmers, three men and two women, representing three farms (F1–F3). The focus group's purpose was to discuss the purpose, experiences, challenges and potential for scaling up of agroforestry systems that these farmers have practised. The focus group session lasted for two hours. The discussions were recorded and later transcribed.

In a second step, semi-structured interviews were conducted with nine men and seven women, representing ten farms (F4–F13) between November 2019 and February 2020. The interview manual contained questions related to agroforestry systems that respondents conducted; farm products; varieties of trees and plants, farm productivity, motivations for doing agroforestry, possibilities for scaling up production; and the main constraints and opportunities for practising agroforestry (see the interview manual in Appendix 2). The interviews took from 30 to 60 min. All interviews were conducted by telephone, recorded and transcribed, except one which was conducted by e-mail (F8).

Finally, field observations were conducted on studied farms to learn more from each farmer's own experience about their agroforestry systems and to get an overview of the whole farm, not only the agroforestry system. Example of issues discussed during observation were the establishment of various perennial crops and trees, what land and location in the landscape could be most suitable for various agroforestry systems, what design regarding intercropping would be the best, challenges with the harvest, pests (voles) and so on. The field visits were guided by farmers and lasted up to four hours each.

All interviews, notes from field observations, and the focus group discussion were analysed using qualitative content analysis (Bryman 2008). All collected data were fully transcribed, and all transcripts were imported into the NVivo data analysis software. Using NVivo, we first grouped the data into six nodes organised after the content of the respondents' answers. After the initial analysis, we consolidated the findings into three nodes corresponding to the three research questions: motivations for practising agroforestry, perceived benefits attributed to different agroforestry systems, and perceived challenges associated with agroforestry. We did not have direct questions employing concepts such as ecosystem services, nor did we provide examples of challenges related to climate change or financial constraints. These themes were spontaneously addressed by the respondents. Additionally, each node was further divided into sub-nodes organised on the basis of the respondents' answer content. For instance, the node "Motivations" included four sub-nodes: (1) sustaining the household economy, (2) supporting environmental sustainability, (3) mitigating and adapting to climate change, and (4) landscape stewardship. All relevant data from each interview were extracted and organised within these nodes and sub-nodes.

The qualitative data related to the perceived benefits from agroforestry farms was converted into different categories of ecosystem services. We applied the Ecosystem Service Coding Protocol (CP) proposed by Wilkinson et al. (2013), which allowed for coding consistency of ecosystem services among all analysed interviews. The CP included four categories of ecosystem services: supporting (coded A), provisioning (B), regulating (C) and cultural services (D) (Reid et al. 2005). Appendix 3 illustrates the transformation of respondents' responses into various ecosystem services, grouped into four distinct categories.

Results

Motivations of farmers

All farmers expressed multiple motivations for practising agroforestry, among which we identified four broad groups: (1) to sustain the household economy, (2) to support environmental sustainability, (3) mitigation and adaptation to climate change, and (4) landscape stewardship.

Sustaining a household economy was an important motivation to practise agroforestry, but it was always combined with other motivations. Producing good yields was at the core for farmers in the studied farms: "*The ambition with the farm is to contribute positively to the ecosystems and at the same time produce useful products. The aim is to go from producing more to how to produce and developing methods that can use the ecosystem services*" (F1). However, getting good yields from recently established agroforestry farms took time. Therefore, generating income from off-farm jobs was necessary as well for some farmers: *"The aim is to generate income for us, to make a living from the harvest, the processed products and selling seedlings from the forest garden, and our eco-café, and educational activities such as courses, lectures and guided tours. We also do (consultancy) ecosystem-based management and nature conservation for other producers"* (F8).

Farmers employed various business models or strategies to sustain their farm economy. Many farms integrated agroforestry with other types of production, such as annual crops and forestry. Some generated income not only through selling products but by utilising the farm as a site, indirectly "selling" the site and agroforestry knowledge through activities like courses, events, tourism, and selling seedlings and products in their own cafés or restaurants. Others engaged in off-farm part-time jobs, consultancy, or teaching, leveraging their knowledge of agroforestry systems. Some respondents had only recently founded their farms, acknowledging that planting trees takes time, and thus employed alternative strategies for maintaining their livelihood. For instance, F1 conducted a rough estimation, comparing prices for berries with cereals in their alley cropping system, noting that berry prices were ten times better per kilo than cereals. F7 focused on high-quality timber, recognising that favourable prices could be charged in Germany. F2 highlighted the importance of subsidies for forest grazing in sustaining the farm economy. F6 and F10 emphasised that their primary goal was not to sell products; instead, they generated income through education and events on the farm. However, F13 faced challenges in selling meat locally to the public sector due to procurement contract issues. F9 transitioned from commercial to self-subsistence production due to family circumstances but planed to return to commercial fruit production in about ten years. This farmer explained that the trees would still be there and that they would likely be more productive after an additional decade. Additionally, two couples were in receipt of pensions, with one couple initiating their agroforestry project post-retirement some 15 years ago. Among two other couples, one of the persons in the couple respectively received pension income.

To support environmental sustainability was a motivation expressed explicitly by 11 out of 13 farmers. Farmers referred to multiple aspects of environmental sustainability, such as maintaining biodiversity, improvement of soil fertility, recycling organic matter and furthering animal welfare. None of these farms used pesticides or chemical fertilizers, and three farms were certified as organic farms. For example, some farmers explained that supporting biodiversity was one of their core priorities in practising agroforestry: *"To keep the richness of biodiversity is more important than to produce for selling; this is a shift in mindset that has happened since 2011 when we started"* (F9).

Seven farmers expressed the importance of agroforestry for both climate mitigation (e.g., carbon storage) and adaptation to extreme weather conditions. As one farmer said: *"To establish a food-producing ecosystem that is beneficial for biodiversity and is adapted to climate change and that also stores relatively big amounts of carbon both in the ground and in the biomass"* (F8).

Farmers also explained that silvopastoral systems were adapted to exceptional droughts, such as in 2018, since the vegetation in these agroforestry systems provided better fodder and shade for the animals than grazing systems without trees. Likewise, in forest gardens, due to a planted ground layer and a layer for organic litter, moisture was kept in the soils during droughts.

Landscape stewardship was another motivation for some farmers. The farmers wanted to use traditional knowledge to restore and maintain past agroforestry landscapes (F3, F4). One farmer who had recently initiated forest grazing said, *"This piece of land (the birch forest grazed by sheep) makes our land coherent. It is located between our farm and the lake, making it accessible. It is also a place for us (humans) for hiking and horseback riding. This is good management of the landscape. It is also beautiful"* (F12).

Ecosystem services attributed by farmers to agroforestry systems

Supporting ecosystem services – In this category, the perceived ecosystem services were nutrient cycling and supporting biodiversity (see Fig. 1). Farmers believed that the large roots of the trees recirculated nutrients in the alley cropping system. Many farmers also believed that fodder production simultaneously contributed to biodiversity: *"The goal with our pastures is to find a production system without ploughing. Today, these fields keep a diversity of plants which we want to support"* (F4). Several farms (F2, F4, F10) applied continuous-cover forestry to manage their forests. As one farmer explained, this forest management helped maintain habitats for numerous species and many other functions. The farmer also expressed their appreciation of biodiversity: *"There are many insects; we see new species every day, and also the birdlife is valuable for us, in the future we do not want to keep animals at the cost of wild biodiversity*" (F9).

Provisioning ecosystem services – This category of ecosystem services captured the most diverse set of ecosystem services compared to other categories that farmers attributed to their agroforestry systems (Fig. 1). In total, 12 provisioning services were acknowledged. Various products were produced in the studied agroforestry farms, both for sale and household consumption. Among those products were meat, cereals, eggs, dairy products, fruits and nuts, herbs, mushrooms, fodder, vegetables, wild food, and different assortments of wood and fur. The food products were the most diverse. For example, farms with forest gardens produced a high diversity of perennial crops such as nuts, fruits, berries, perennial vegetables, herbs, flowers and seedlings. The number of species and varieties ranged from 30 to 400. The

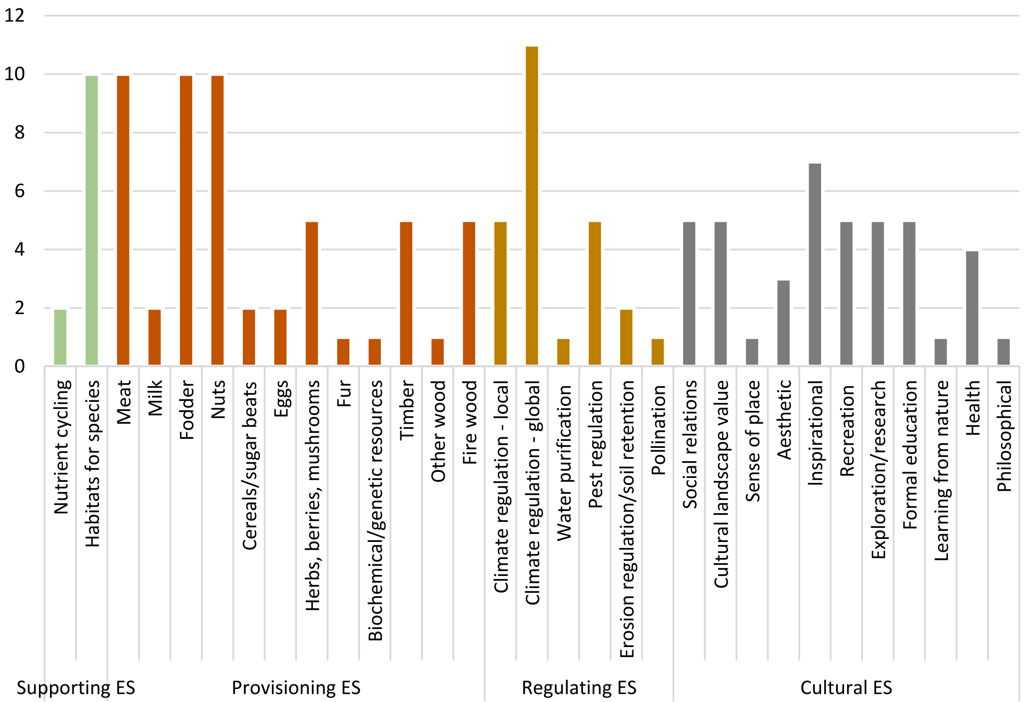

Fig. 1 Ecosystem services attributed by farmers to their agroforestry systems. Numbers show how many farms attributed specific ecosystem service to their agroforestry systems

best-performing crops from farmers' perspectives were hazel nuts (*Corylus avellana*), apples (*Malus Domestica*), and new species of berries for a Swedish context such as sea buckthorn (*Hippophae rhamnoides*), saskatoon (*Amelanchier alnifolia*), aronia (*Aronia melanocarpa*) and Japonese quince (*Chaenomeles japonica*), as well as perennial vegetables. Among the wood products, several farmers produced firewood and one timber from walnut, rowan and cherry.

The supply of many provisioning services was perceived by farmers in combination with the delivery of supporting services. For example, beef production was integrated with the maintenance of biodiversity in the Natura 2000 area (F13). The farmer explained that they kept extensive grazing to maintain patches of semi-natural grassland, wood pasture and forest grazing areas: "The government wants grazing animals to keep the landscape open. This is not about the production of meat primarily, but for nature conservation, landscape care, keep it open" (F13). He also referred to research conducted in the nature reserve, which showed that the growth of trees was better in areas with grazing cows compared to a fenced, non-grazed area on the same land.

Other farmers explained that all agroforestry systems provided food but also contributed to keeping the natural environment which is necessary for health and wellbeing, including physical and psychological experiences (cultural ecosystem services). One farm (F6) provided farm products for lunches for staff and pupils, taught about agroforestry and used their agroforestry farm for wellbeing: *"The school has also focused on good outdoor environments and health, places for rest, calm places and to create…well, environmental psychology. We want to develop a good outdoor environment for the health of everyone working and studying here"* (F6).

Regulating ecosystem services – Farmers perceived that their way of farming contributed to climate regulation, pest regulation, water purification, regulation of soil quality and pollination (Fig. 1). Climate regulation was mentioned by farmers most frequently. Farmers perceived that their agroforestry systems were beneficial due to carbon binding from large root systems of the woody perennials. Additionally, by applying no-digging/tilling techniques and perennial crops, the agroforestry system became more resilient to droughts.

The farmers also brought up that their agroforestry systems contributed to pest regulation. As a number of farmers explained, some agroforestry systems were affected by pests (often by voles), but the pests were reduced by special modifications of the agroforestry systems. For example, farmers kept hens to protect fruit trees from voles, or added poles suitable for predating birds. *"On the poles, the predating birds sit, meaning this land (the alley cropping) has become beneficial for wildlife"* (F11). On other farms, insects have been observed, which were perceived to contribute to pollination. "Pollinating insects have been observed from early spring until late fall" (F1). Finally, the farmers dealt with eutrophication caused by leakage of nutrients from arable land by practising alley cropping on the fields, in which cereals and rows of fruits and berries were produced: *"Woody plants with deep roots could probably contribute to absorbing the nutrients since the root system of the perennials are there all year"* (F1).

Cultural ecosystem services – The farmers attributed multiple cultural ecosystem services to their agroforestry farms (see Fig. 1). The exploration of agroforestry systems was extensive and multifaceted. It included testing new species and varieties. For example, several farmers (F6, F8 and F10) tested around 400 species/varieties. Farmers explored the productivity, taste and adaptation to Northern climatic conditions of different species and the establishment of whole systems such as forest gardens, silvoarable systems or forest farming. "We test wide varieties of crops; they end up in our market garden. We do a lot of research and development work. We also test several methods to establish a forest garden and get it 'self-managed'" (F10). Learning from experiments with forest farming in mixed forests generated new cultivation practices, such as growing mushrooms on logs, and knowledge needed to provided multiple benefits, such as the conservation of the forest habitats and species, the storage of carbon and the provisioning of wood for various purposes. The restoration of traditional pastures to increase biodiversity also generated wellbeing for the farmers through furthering aesthetic qualities: *"We keep mountain-dwelling cows, sheep (for fur) and hens. We had them for a long time because we want to open up and restore these pastures, just because we like them, they are nice, they are beautiful"* (F4).

With regard to education and knowledge, farmers arranged short-term workshops or courses (on weekends) and were also engaged in relatively long-term formal learning programmes (6 months) with local folk high schools (F2, F6 and F10), in which their agroforestry systems were central or partly used in pedagogy. Knowledge was considered the main "product" for F10: *"Many people want to learn about this way of production because it is beneficial for the environment" (F10).* Several farms had extensive activities for knowledge sharing. F1 had a demonstration site for farmers with 140 perennial crops suitable for the arable field adjacent to the alley cropping test field. The agroforestry systems were often used for informal and formal learning. As one farmer explained, this was done "to create an educational environment for children and adults where one gets inspiration and can learn about ecology, forest gardens, food production and gardening" (F8).

Some farms were involved as partners in formal research ventures. Several farms let other researchers use their land (F1, F4, F6 and F13). Six farms (F1–F6) were partners in a participatory action research (PAR) project for four years (Björklund et al. 2018; Schaffer et al. 2019). F11 was a university test site for silvoarable systems. Some farms conducted own investigations and documentation, such as an inventory of biodiversity at F7. F10 produced reports about certain aspects of its agroforestry systems, such as water and nitrogen balances and the nutrients and toxic content of the crops. F1 had been a partner in several research and development projects on climate adaptation and carbon binding for farms in Northern climates.

Farmers also provided conditions for recreational activities: "The aim with our home garden, the forest garden, is to generate as much harvest as possible with as little work as possible and to create a place for recovering, restoration… (F10). Or another example, "…now the focus is to create a fantastic place for us, for visitors. Today having a rich biodiversity is more important than selling" (F9). Five farms (F2, F4, F6, F8, F10) had cafés and cottages for rental, or to host various events they organised. Some offered guided tours in which the agroforestry system was included. F5 ran an on-farm restaurant where visitors often spent time in the garden with a mosaic of trees and annual and perennial crops. In this way, "non-farmers" could see and learn about an "unusual" production system. "I live to inspire others, and since we are located in [an area for] extreme commercial tourism, we offer other things. Visitors can see recycling, close loop models in practice" (F5).

Farmers appreciated the biocultural heritage inhering in wooded pastures which provided habitats for certain species due to traditional silvopastoral practices (cultural heritage). *"In the wood pastures, there are roses, sloan, juniper, gooseberries, wild strawberries, chanterelles, oak, cherry, rowan* etc., all of which historically must have been important for livelihood for the farm. Birch for firewood is still harvested…some visiting experts perceived this landscape should be kept since it had been intentionally created" (F3).

Perceived challenges in practising agroforestry

Agroforestry farmers also explained the challenges they faced in their agroforestry practices, which we organised into four broad groups.

The first group was related to challenges in the management of agroforestry farms. For example, the high diversity of species in the forest gardens was perceived as too complex to get a proper quantity of products. *"My attitude towards forest gardens was always negative because we need large quantities of products (for our restaurant). Therefore, we also plant vegetables in rows"* (F5). There were also practical hindrances such as pests (voles). The problems with voles and the complexity of agroforestry systems were solved by decreasing the number of species and keeping hens. *"We have problems with voles, and therefore we have to keep the hens in the garden, and we don't have a planted ground layer but instead trees, shrubs and hens"* (F5).

The second group was related to a lack of technologies suitable for small-scale agroforestry farms and a lack of supplies. *"Technology and machines for small-scale users would be needed, such as two-wheel tractors, for making wood chips or rotary cultivation, there are no such machines in Sweden"* (F6).

The third group was related to lack of plant materials, including seedlings, which was crucial for scaling up agroforestry production. For example, several new species of edible perennials were popular, but the lack of seedlings was perceived as a limitation for the expansion of this type of agroforestry system: *"The supply of varieties of plants is a limitation (in Sweden). For example, everybody thinks Japonese quince is a fantastic, beautiful and useful fruit instead of citrus, but it is impossible to find seedlings here"* (F6). The farmers used their land as test sites to support research on production of seedlings, but they complained that the progression from a research site to production took a very long time: *"We cultivate for a test site for the university. Normally they do research on breeds, varieties and how to make the seedlings reach the market. It is a very long process through the value chain: the buyer must demand them, the stores must be willing to have a supply of them, and the farm and the market gardens need to cultivate the seedlings. This system, the long process, is a limitation for more farms to dare to test new varieties for seedlings on as much as several hectares"* (F6).

The fourth group of challenges was the lack of knowledge on establishing agroforestry on new land and maintaining it: *"We do experiments with grazing and forestry. The reforestation is a challenge"* (F2). There was both curiosity and doubt regarding scaling up agroforestry: *"[I] would like to explore the management of a whole agroforestry system. And agroforestry in a larger scale, what would that look like?"* (F5).

Discussion

Diversity of agroforestry systems in Sweden

This study addresses several knowledge gaps related to agroforestry systems in Northern Europe. We explored the perceived benefits attributed by farmers to diverse agroforestry practices within four distinct systems—silvopasture, silvoarable, forest farming, and forest gardens—in Sweden. Scholars have presented evidence that silvopastoral and silvoarable systems have the potential to enhance biodiversity, improve soil fertility, reduce erosion, enhance water quality, increase aesthetics, sequester carbon, and offer opportunities for recreation and tourism across various spatial and temporal scales (Jose 2009; Martín-López et al. 2012; Oteros-Rozas et al. 2014; Torralba et al. 2016; Burgess and Rosati 2018; Smith et al. 2022). Our study also supports these findings; however, we identified also perceived benefits attributed to forest gardens and forest farming—agroforestry systems, which have not been previously documented in Europe, including Sweden (Mosquera-Losada et al. 2018a, b). For example, our study documented that farmer attributed the production of 17 ecosystem services to forest gardens, spanning all four established categories—supporting, provisioning, regulating, and cultural.

Another finding is that farmers incorporated multiple agroforestry systems on their farms. Specifically, two farms implemented three agroforestry systems—silvopasture, silvoarable, and forest garden/or forest farming, while five farms integrated two agroforestry systems (Appendix 1). We argue that combining different agroforestry systems within a single farm is a dynamic and innovative approach that reflects the adaptability of agroforestry practices to create a more resilient and diverse agricultural landscape. One advantage of combining different agroforestry systems is the optimization of land use. Each system contributes unique benefits—silvopasture integrates livestock grazing with trees, silvoarable combines trees with annual crops, and forest gardens foster a diverse range of perennial plants. By incorporating these systems, farmers can make efficient use of space and resources, enhancing overall productivity. From an economic perspective, diversifying agroforestry systems within a farm can lead to multiple income streams. Farmers can harvest timber, fruits, nuts, and other products from various components of the agroforestry landscape. This diversification not only enhances the resilience of the farm against market fluctuations but also provides a more or less steady income throughout the year.

Additionally, we recorded multiple perceived cultural ecosystem services attributed to all studied agroforestry systems. In total, farmers associated 11 different cultural ecosystem services with their agroforestry systems—a category that has been under-researched until now (Fagerholm et al. 2016; Torralba et al. 2016; Sollen-Norrlin et al. 2020).

Farmers as designers of multifunctional agroforestry farms in Sweden?

One of the main findings of this study is that the multifunctionality of all studied agroforestry systems arises from farmers' motivation to design such systems. The farmers were driven by the desire to be designers of multifunctional landscapes, and they consistently merged their intentions to derive food and materials from their farms with the deliberate pursuit of multiple ecosystem services, driven by both motivation and necessity. In the context of initiating agroforestry practices in Sweden, farmers were motivated by four broad groups of factors—sustaining one's household economy, supporting environmental sustainability, adapting and mitigating climate change, and providing landscape stewardship. Existing literature demonstrates similar motivations among agroforestry farmers across Western Europe (Graves et al. 2009; García de Jalón et al. 2018; Hernandez-Morcillo et al. 2018; Rois-Diaz et al. 2018; Sandberg and Jakobsson 2018; Johansson et al. 2022). All interviewed farmers expressed a concern for the natural environment and recognised the cultural value of the landscape. They envisioned agroforestry as a platform for introducing new ideas and practices to mitigate the negative impact of farming on the environment while sustaining the cultural value of the landscape.

Biodiversity conservation, carbon storage, soil quality and resilience to extreme weather conditions were identified as primary environmental concerns that farmers sought to address through diverse management strategies on their agroforestry farms. Farmers also perceived agroforestry as a solution for maintaining the aesthetic qualities and the cultural value of landscapes which their ancestors created. Thus, farmers perceived their role not only as food producers, which is traditionally the primary goal of farmers, but also as landscape stewards. The goal was not to reach maximum profitability but to find a balance between economic, environmental and cultural farm outputs. Albrecht and Wiek (2021) assessed the sustainability benefits of forest gardens in Europe, North America and South America, and concluded that they performed better environmentally, culturally and socially, but were weaker in relation to profitability, which is in line with our findings.

Regarding which kinds of service contributions were seen as most necessary, we can say that multiple cultural ecosystem services such as social relations, education and knowledge, recreation and tourism were crucial to getting a sustainable supply of provisioning services. For example, learning from each other was essential for farmers to generate new knowledge and deal with challenges in practising agroforestry. Providing opportunities for events such as education and tourism were vital to sustaining the economy of agroforestry farms. Supporting soil quality and regulation of pollination were crucial for the sustainable supply of provisioning services.

Our results enable us to identify key factors influencing farmers' decisions to practise agroforestry. Over the last few decades, scholars have delved into the behavioral factors shaping farmers' decisions to adopt environmentally sustainable practices, including agroforestry. In their review of such studies, Dessart et al. (2019) proposed three types of behavioral factors impacting farmers' decision-making: dispositional factors, related to the personal qualities and values of farmers; social factors, encompassing social interactions with other individuals, including social norms and motives; and cognitive factors, involving farmers' perceptions of the relative benefits, costs, and risks associated with a particular sustainable practice. Our study demonstrates that all three types of factors influenced farmers' behavior in practising agroforestry; importantly, these factors acted simultaneously.

Farmers had environmental concerns, practised long-term strategic thinking and were open to new experience (dispositional factors) on sustaining their household economy through diversification of farm products and services. For example, they introduced extensive farm management to reduce management costs and labour, as well as to diversify and maintain household income while reducing the negative impact of their activity on the natural environment. The combination of farming with educational courses, guided tours, and small-scale businesses (e.g. cafés) is another example of strategies pursued (linked to social and cognitive factors). These activities generated income and promoted environmental awareness to develop new food and wood production methods in line with sustainable development principles.

Other scholars (Wilson and Lovell 2016; Sollen-Norrlin et al. 2020) also have showed that diversification of income from products and services is essential for sustaining agroforestry farms. For example, mushroom cultivation on logs combined with forestry could contribute to income in the short-term and the long-term. Similarly, the farmers in our study were innovative (dispositonal factors) to begin practising agroforestry from scratch. They had to decide what type of agroforestry to choose, how to integrate different agroforestry practices in space and time, etc. All farmers were keen to learn continuously from other farmers and from collaboration with researchers to test new management options to improve land management which would be less harmful for the natural environment (cognitive factors). This learning was essential to generate new innovative agroforestry practices so as to maintain complex spatial and temporal arrangements of crops, trees and animals on different types of land: forested land (e.g. forest farming), predominantly forested land with some agricultural use (e.g. forest grazing), or agricultural land with the introduction of trees (e.g. alley cropping). We posit that the sustained adoption of agroforestry practices over a relatively extended period of time has resulted from the cumulative impact of dispositional, social, and cognitive factors. This resilience allowed farmers to persist in agroforestry despite facing multiple challenges.

Our study shows that each farmer deliberately organised farming activities to get a bundle of ecosystem services produced belonging to four categories—provisioning, regulating, supporting and cultural. In this study, we understand ecosystem service bundles as "sets of ecosystem services that repeatedly appear together across space or time" (Raudsepp-Hearne et al. 2010), being positively (synergy) or negatively (trade-off) associated with each other (Mouchet et al. 2014). The delivery of ecosystem service bundles resulted from the diversification of forestry and agriculture at the farm level. Agricultural measures undertaken included, for example, the diversification of silvopasture systems through the integration of crops with livestock, diversification of crops, and the implementation of multilayer systems of perennial and annual plants, creating structural elements in the fields (e.g. alleys). Diversification forestry measures involved applying continuous-cover forestry, maintaining the diversity of deciduous tree species and preserving the multilayer structure of forests.

Recently, issues of synergies, trade-offs and bundles have gained the attention of scholars to better understand how to manage multiple ecosystem services across landscapes (Rodriguez et al. 2006; Raudsepp-Hearne et al. 2010; Plieninger et al. 2015; Eak et al. 2016; Hanes et al. 2017). Scholars argue that applying the ecosystem service bundles approach could be a helpful tool in identifying landscapes with different degrees of multifunctionality and in analysing direct and indirect drivers that underpin synergies and trade-offs among ecosystem services (Saidi and Spray 2018). Our study shows that from the farmers' perspectives, their agroforestry systems support synergies among provisioning, regulating, supporting and cultural ecosystem services. At the same time, farmers realised that by enhancing regulating and supporting ecosystem services, they might reduce quantity in the production of food, fodder, timber or other provisioning services. Farmers lowered costs by reducing labour input and machinery to handle such trade-offs. Other scholars (Decocq et al. 2016; Burton et al. 2018; Hardaker et al. 2021) show that the integration of trees and woodlots within agricultural landscapes as land-sharing measures supports the delivery of a wide range of in-situ (e.g., food production) and ex-situ (e.g., carbon sequestration and flood mitigation) ecosystem services. In their review of studies on diversified farming systems, Rosa-Schleich et al. (2019) concluded that diversified farming systems, including agroforestry systems, offer significantly greater benefits for biodiversity and associated ecosystem services compared to conventional agriculture. However, the ecological advantages for farmers were partially insufficient to outweigh economic costs in the short term, despite numerous examples illustrating that diversified practices led to higher and more stable yields, and reduced risks in the long term. We argue that further research is needed to explore synergies and trade-offs of ecosystems services generated by different agroforestry practices in diverse biophysical, cultural and socio-economic contexts, to better understand the extent to which agroforestry contributes to landscape multifunctionality at different spatial and temporal levels. Our study also raises the question of whether development and mindful inclusion of agroforestry modes of production at the farm scale could contribute to a mosaic at the landscape scale that even may transcend the land-sharing/land-sparing dispute. Might such a strategy result in multifunctional landscapes with areas of intensive production combined with agroforestry, where supporting and regulating ecosystems services, conservation and landscape connectivity is assured, resolving or at least addressing the trade-off between complexity and quantity?

Another issue that our study highlights is that people-nature interactions are a core characteristic of agroforestry systems which are the product of a delicate balance of multiple human activities, transforming ecosystems. Thus, the multiple tangible and intangible benefits derived from agroforestry should be considered as "social-ecological services" rather than ecosystem services (Elbakidze et al. 2021; Huntsinger and Oviedo 2014). Furthermore, some of these services are only apparent at the landscape scale, where patches with different densities and structures of land cover types are combined. Consequently, some have suggested a transition towards "landscape services" for the planning and management of ecosystems of cultural nature (Termorshuizen and Opdam 2009). Additionally, our study shows that farmers attributed multiple values to their agroforestry farms. which are increasingly acknowledged as a key research priority for agroforestry systems' sustainable governance and management (Arias-Arévalo et al. 2017; Plieninger et al. 2013). Gaining a better understanding of such values is an essential step to better disentangling the societal relevance of agroforestry systems under different biophysical, social-cultural, economic, and governance conditions (Fagerholm et al. 2016; Plieninger et al. 2015).

Recently, the nature's contributions to people (NCP) analytical paradigm and the multiple-value approach (Díaz et al. 2018; Pascual et al. 2017) have been introduced in the conceptual framework of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). The NCP approach recognises the central role that culture and local knowledge play in defining all links between people and nature (Díaz et al. 2018), while the multiple-value approach acknowledges culturally different worldviews, visions, and strategies to achieve an improved quality of life by considering a widened rage of nature-related values, including the values attributed and perceived by indigenous people and local communities (IPBES 2019). Elbakidze et al. (2021), in their study applying the multiple-value approach, provides strong evidence that agroforestry systems in north-eastern Europe contribute multiple benefits important for people's quality of life and show that relational values were attributed to agroforestry systems by the majority of respondents across all contexts. We argue that more studies applying different methods and approaches are needed to capture the complexity of agroforestry systems, including the multiple benefits they provide and the diversity of values attributed to these systems by various stakeholders (including farmers). Such studies will contribute to a higher recognition of agroforestry systems in policy and planning decisions and underpin more sustainable management strategies and pathways.

Perceived challenges

We grouped challenges that farmers experienced in practising agroforestry into four groups, such as complexity of agroforestry management, lack of technologies suitable for small-scale agroforestry farms, lack of plant materials (including seedlings), and lack of knowledge about how to do agroforestry. These findings are in line with the challenges identified among agroforestry farmers in Europe. For example, the study by Garcia de Jalon et al. (2018) that involves four types of agroforestry across Europe, as well as the study by Graves et al. (2009), showed that farmers perceived similar challenges regarding silvoarable systems, such as lack of farm machinery and increased work complexity but also feasibility.

However, several of our findings contradict the results of other studies. For example, one common challenge which is often brought up regarding adopting agroforestry relates to high initial costs (Garcia de Jalon et al. 2018; Sollen-Norrlin et al. 2020). Our study shows that the farmers did not address financial constraints as a challenge. One potential explanation for this could be that at least 11 out of 13 farmers could be seen as agroforestry pioneers. Despite the lack of financial support, they were highly motivated to test new sustainable practices. However, if more farmers would follow this path, more financial support might be needed (among other things). Smith et al. (2022) show that agroforestry may have greater financial margins than traditional systems due to the diversification of practices and activities such as, for example, combining the production of various products with on-farm courses and workshops.

Another common challenge addressed in other studies, for example in Sollen-Norrlin et al. (2020), is that “agroforestry is unknown”, but this was not a major concern among the farmers in our study. One potential explanation for this could be that many of these farmers met a lot of people on their sites that visited the farm in order to learn more about agroforestry.

Development implications of agroforestry in Sweden

Considering the multiple benefits attributed by farmers to diverse agroforestry systems, we argue that agroforestry farms could be seen as hubs of rural development in Sweden. Sweden’s rural areas play a vital role in the country’s development. Beyond their economic contribution, rural landscapes offer crucial living environments, supply a diverse range of cultural ecosystem services (Garrido et al. 2017a, b), and are essential for supporting nations’ biodiversity (Gustavsson et al. 2007). However, rural areas face long-term challenges, including a significant reduction in the number of active agricultural and forestry enterprises, with over 66% of the remaining small-scale farm enterprises relying on off-farm incomes (Swedish Board of Agriculture 2017) and the loss of human and social capital. This has resulted in a demographic imbalance, with fewer younger people and women in rural areas, alongside the erosion of trust, traditional relationships and identities associated with rural landscapes. Moreover, climate change has emerged as a significant driver of change in rural production (Grusson et al. 2021). Our study shows that agroforestry farms and farmers provide multiple cultural ecosystem services that could contribute to maintaining social and human capital, cultural identity and rural landscape value, which are needed to sustain and maintain rural areas as attractive living environments. Regarding climate change, our study and also other scholars show that agroforestry systems help to adapt to and mitigate climate change. More importantly, considering that farmers engage in continuous learning, we might argue that they would learn how to adapt production to new climate conditions through pursuing agroforestry.

The challenges in rural development are not unique to Sweden but are common across Europe, despite substantial investments in rural areas through the CAP (EU 2016). Various policy initiatives have been developed at both the EU and national levels to address these challenges. A central component of these initiatives is the promotion of entrepreneurship and innovation in agriculture and forestry. The aim is to create new employment opportunities, sustain commercial and public services, and make rural areas attractive places to live and work. In this context, agroforestry systems might contribute to the development of new and more sustainable ways of production, as well as producing high-quality products, leading to the diversification of household income in rural development, sustaining human and cultural capital as well as landscape value.

Regarding policy implications, Plieninger et al. (2020) argue that the UN Sustainability Development Goals (SDGs) can be concretised through agroforestry. Agroforestry could also contribute to the implementation of several European-level initiatives such as the Pan-European Biodiversity and Landscape Strategy, and the European Landscape Strategy (Forest Europe 2018). For farmers in the EU member states, the CAP is crucial. Scholars argue that agroforestry could fulfill what CAP aims to a much larger extent than what has been done so far (Mosquera-Losada et al. 2018b, 2023; Santiago-Freijanes et al. 2021). However, the existing policy tools to enhance and support agroforestry systems remain inefficient. One indicator supporting this statement is the sharp decline of agroforestry systems across the EU (Eichhorn et al. 2006; Plieninger et al. 2015; Almeida et al. 2016; Godinho et al. 2016). Our study underscores the pivotal role of farmers as the architects of agroforestry systems. Drawing on Deaasart et al. (2019), we argue that understanding farmers' behavior and integrating behavioral factors into agri-environmental policies might lead to more effective and realistic policy outcomes supporting the development of agroforestry systems.

Limitations of the study

The selected farmers met the criteria outlined in this study (see Methods); however, it is worth noting that a significant proportion of these farmers were well-educated, actively participated in various projects, owned land, and generated additional income. Consequently, our sample primarily represents a specific subgroup of farmers, and caution should be exercised when generalizing our findings. Furthermore, our primary emphasis was on exploring farmers' motivations, perceived benefits, and challenges associated with practicing agroforestry in Sweden. Consequently, we did not delve extensively into the specific business models adopted by farmers. Nevertheless, as this aspect emerged during our study, we were able to provide an overview of the business models, albeit without exhaustive details.

Conclusions

Many studies indicate that agroforestry systems offer multiple benefits crucial for biodiversity and human well-being. However, there exists a significant gap in studies on agroforestry systems in North Europe, including Sweden. This study addresses this gap by documenting the perceived benefits attributed by farmers to diverse agroforestry practices within silvopasture, silvoarable, forest farming, and forest gardens in Sweden. The two latter systems were documented in relation to this perspective in Europe for the first time.

This study shows that the multifunctionality of studied agroforestry systems are the result of farmers' multiple motivations to practise agroforestry, such as generating income, supporting environmental sustainability, mitigating and adapting to climate change, and being a landscape steward. Each farmer deliberately organised their farming activities to produce a bundle of ecosystem services belonging to provisioning, regulating, supporting and cultural services. In pursuing such action, agroforestry farmers make use of special personal qualities, such as long-term strategic thinking on sustaining their household economy through diversification of farm products and services, and being innovative in dealing with multiple challenges related to practising agroforestry. Key behavioral factors influencing farmers' decisions include dispositional, social, and cognitive factors. Additionally, farmers incorporate multiple agroforestry systems on their farms, optimizing land use, making efficient use of space and resources, enhancing overall productivity, and diversifying income streams to increase farm resilience against market fluctuations, providing a relatively steady income throughout the year. However, farmers experienced challenges in practicing agroforestry, such as the complexity of agroforestry management, a lack of technologies suitable for small-scale agroforestry farms, a shortage of plant materials, and a lack of knowledge about how to implement agroforestry. More studies are needed to explore the diversity of business models applied by farmers belonging to different groups based on factors such as age, experience, and financial conditions. These studies should be conducted in different contexts, considering the various agroforestry systems in practice.

Considering the multiple benefits attributed by farmers to diverse agroforestry systems, we argue that agroforestry farms could be seen as hubs of rural development in Sweden. We argue that understanding farmers' behavior and integrating behavioral factors into agri-environmental policies might lead to more effective and realistic policy outcomes on the ground. Additionally, more studies employing different methods and approaches are needed to capture the complexity of agroforestry systems, including the multiple benefits they provide and the diversity of values attributed to these systems by various stakeholders, including farmers. Such studies will contribute to a higher recognition of agroforestry systems in policy and planning decisions, supporting more sustainable management strategies and pathways.

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Author contributions All authors contributed to the study conception and design. Material preparation, data collection and initial analysis were performed by CS. The first draft of the manuscript was written by CS. ME and JB read, edited and commented on the paper throughout. All authors read and approved the final manuscript.

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Declarations

Conflict of interest No conflict of interest.

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IV

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CONCEPTUAL ANALYSIS
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Salutogenic Affordances and Sustainability: Multiple Benefits With Edible Forest Gardens in Urban Green Spaces

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With increased urbanization, ecological challenges such as climate change and loss of biodiversity, and stress-related disorders globally posing a major threat to public health and wellbeing, the development of efficient multiple-use strategies for urban green spaces and infrastructures is of great importance. In addition to benefits such as climate and water regulation, food production, and biodiversity conservation, green spaces and features have been associated with various health and wellbeing outcomes from a psychological perspective. Research suggests links between exposure to green environmental qualities and restoration from psycho-physiological stress and attention fatigue, promotion of physical activity, increased neighborhood satisfaction and even reduced mortality. Especially strong associations have been observed in urban and socio-economically challenged areas. Usually such salutogenic, i.e., health-promoting, effects are explained through theories related to the notion of *biophilia*, i.e., the idea that humans share innate tendencies to attend to natural environments and features that have been beneficial during evolution. This paper assumes an ecological approach to perception and behavior to be fruitful in order to analyze the salutogenic potential of environments such as urban green spaces and to step beyond the "green vs. gray" dichotomy that has been prevalent through much of the research on health-promoting environments. Through an analysis of environmental affordances for certain perceived qualities such an approach is explored through a proposed concept for urban green space use and management, *the edible forest garden*. Such gardens, based on agroecological principles, have emerged as one of the most promising models regarding ecologically sustainable food production. In addition to potential contributions of importance for urban sustainability and biodiversity, we argue that the inclusion of edible forest gardens in urban green spaces – today globally dominated by lawns – also potentially could reinforce several affordances of salutogenic importance, both in terms of, e.g., social cohesion but also in regard to restoration from psycho-physiological stress and attention fatigue. Increased opportunities for contact with nature and processes of food production may also reinforce pro-environmental behaviors in the population and thus also affect long-term sustainability.

Keywords: salutogenic affordances, multiple-use, urban green spaces, green densification, sustainability, agroforestry, edible forest gardens

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INTRODUCTION

More than half of the human population resides in urban settings, and urbanization is an ongoing trend (WHO, 2014). By 2050 66% of the world's population is expected to be urban, as compared to 30% a hundred years before, in 1950 (ibid). Urbanization thus poses a major current and future challenge that affect how people interact with their close living environment, including potentially diminished contact with the natural world in terms of both quality and quantity (Markevych et al., 2017). Robert Pyle remarked that "local and tacit knowledge related to agriculture is disappearing from metropolitan landscapes, creating an 'extinction of experience' of human–nature interaction and a collective 'forgetting' of how to grow food" (Pyle, 1978). Such an experiential lack may lead to a degradation of public health and wellbeing, a loss of emotional affinity to nature and a decline in pro-environmental attitudes (Soga and Gaston, 2016). It has also been shown that various mental disorders, such as depression and even schizophrenia, are more common in urban than in rural areas (Peen et al., 2010). This has been attributed to higher stress levels in urban settings, and brain imaging studies have suggested that residents of urban areas often have a lesser capacity to cope with stress than rural dwellers (Lederbogen et al., 2011).

Meanwhile, non-communicable diseases such as cardiovascular disease, stroke, diabetes type 2, obesity, stress-related mental disorders, depression, and anxiety dominate the global disease burden and both insufficient physical activity and chronic stress are recognized as risk factors for such disorders (WHO, 2010). In Sweden the trend of sick leave due to mental health problems is increasing and according to a Swedish Social Insurance Agency (2013) report in the most common cause of sickness absence from work was stress-related mental illness. Globally, mental health problems are estimated to be among the major contributors to ill health and work disabilities (Salomon et al., 2012; Vos et al., 2013). A lack of green space access in urban areas have been linked to more self-reported mental distress and greater rates of anxiety and depression (Maas et al., 2009; van den Berg et al., 2010; Nutsford et al., 2013), as well as premature death (van den Bosch and Bird, 2018). The latter link applies to all-cause mortality but in particular to increased mortality in cardiovascular diseases (van den Berg et al., 2015; Egorov et al., 2016). Such findings could partly be explained by reduced green space access leading to decreased opportunities for physical activity (e.g., Konijnendijk et al., 2013) and restoration from high stress levels (Hartig et al., 2014; Braubach et al., 2017). Especially pronounced effects have been observed for people with lower incomes (Mitchell and Popham, 2008), highlighting the potential of using urban green spaces as a means to mitigate health inequalities in socioeconomically challenged areas, as discussed by e.g., Skärbäck et al. (2014). In addition, Hanski et al. (2012) have suggested that the reduced biodiversity in urban settings also may lead to decreased diversity of gut and skin microbiota. This in turn has been associated with inflammatory conditions, including asthma, allergic and inflammatory bowel diseases (IBD), type1 diabetes, and obesity (Haahtela et al., 2013).

POTENTIAL BENEFITS OF URBAN GREEN SPACES

Urban green spaces and infrastructures may contribute to the reduction of noise, filtering of air, and to the adaptation of climate change effects such as regulation of temperature, water run off, function as carbon sinks, while simultaneously serve various aesthetic and social purposes (e.g., Bolund and Hunhammar, 1999; Berghöfer et al., 2011; Gómez-Baggethun et al., 2013). Such functions is part of the Nature Based Solutions approach suggested by the European Commissions, and is often less expensive than technical solutions (Bauduceau et al., 2015). Regarding adaption benefits it seems that a heterogeneous vegetation structure is preferable and that trees with large and dense canopies are the most effective for both cooling and rainfall interception (see Brink et al., 2016). In addition to climate change, recent research also reveals an exceptionally rapid decline of plant and animal populations over the last century due to human actions (Millennium Ecosystem Assessment, 2005; Ceballos et al., 2015, 2017). Habitat loss is considered a main driver of this development, and although urbanization has had a negative impact on many species urban areas can support native biodiversity and even threatened species (Hall et al., 2016; Ives et al., 2016). Due to the possibilities of rapid development and change, urban green spaces may provide opportunities for instant and continuous creation of new habitats (Beninde et al., 2015).

Meanwhile, lawns dominate urban green spaces (**Figure 1**) and occupy around 70–75% of such areas globally (Ignatieva, 2010; Ignatieva et al., 2015). In Sweden, close to 25% of the cities are covered by lawns according to Hedblom et al. (2017) and it has been suggested that lawns contribute to increasingly uniform urban environments around the world (Ignatieva, 2010). In addition, traditional lawns are expensive and resource demanding to manage and rather poor in terms of biodiversity (ibid). They are green, but may in spite of this be rather weak regarding support for some important human needs, such as restoration from attention fatigue and psycho-physiological stress. There is a need for development of strategies that allow for urban environments and green spaces to be efficiently used in order to simultaneously meet the current ecological and social challenges. The development and employment of such multiple-use strategies for urban green spaces and infrastructures

FIGURE 1 | Lawns dominate urban green spaces globally.

may be seen as a process of "green densification", aimed to optimize the design and planning of such features in order to provide multiple benefits addressing the various current challenges.

MOVING BEYOND THE "GREEN VS. GRAY" DICHOTOMY WITH A SALUTOGENIC PERSPECTIVE

The term "salutogenesis" describes an approach focusing on factors that support human health and wellbeing, rather than on "pathogenesis," i.e., factors that cause disease (Antonovsky, 1996). The relationship between health and disease is seen as a continuum rather than as a dichotomy. Individual or environmental factors that push an individual toward the disease end of this continuum are termed *stressors* and factors that work in the opposite direction, toward optimal health and wellbeing, are called *salutogens*. According to Antonovsky, human health and wellbeing ultimately depend on the individual's ability to create and maintain a "sense of coherence" and meaning, thus strengthening the capacity to cope with life's various stressors (ibid). Salutogenic strategies, aimed at supporting such processes, may then complement pathogenic strategies that primarily strive to mitigate or eliminate stressors (Antonovsky, 1996; Becker et al., 2010).

Markevych et al. (2017) suggest that beneficial effects on human health and wellbeing from natural environments and green spaces work through three main complementary pathways; (1) *mitigation* ("reduction of harm," e.g., reducing exposure to air pollution, noise and heat, etc.), (2) *restoration* ("restoring capacities," e.g., attention restoration, physiological stress recovery, etc.), and (3) *instoration* ("building capacities," e.g., encouraging physical activity, facilitating social cohesion, etc.). In the light of salutogenic theory, mitigating strategies could be considered as primarily pathogenic, i.e., focused on harm-reduction, whereas support of restorative and instorative pathways could be considered as fundamentally salutogenic, i.e., focused on restoring and strengthening the capacities needed to cope with life's various stressors and ultimately facilitating a sense of coherence and meaning in life. Salutogenic pathways could arguably be seen as distinguished in comparison to most mitigating services in that they primarily depend on environmental support for certain experiences and behaviors, i.e., rely on a level of analysis that takes human psycho-physiological needs and preferences into account in order to be properly understood.

Although existing reviews and meta-analyses (e.g., Egorov et al., 2016) seem to confirm causal relations at population level between various beneficial health outcomes and access to natural environments and green spaces, Markevych et al. (2017) also highlight the fact that some epidemiological studies have failed to support such connections. Such findings might indicate that green spaces can support salutogenic pathways to different degrees. Furthermore, salutogenesis can also include more subtle effects of, e.g., aesthetic appreciation that may or may not be visible in epidemiological studies, arguably often focused on less subtle health and wellbeing outcomes. The same is arguably also true for various urban/built environments and psychologically relevant qualitative differences may exist here as well, as highlighted by, e.g., Stigsdotter et al. (2017a). Sallis et al. (2016) report that, in addition to the number of parks, the population density, intersection density, and public transport density all were positively related to physical activity in urban contexts in several cities across multiple countries and continents. It thus seems clear that both "green" and "gray" environments and features may function as salutogens in various ways and that research in health-promoting environments need to move beyond this dichotomy, arguably until recently prevalent in the field. There is thus a need to identify in more detail the specific qualities important in order for different environments to support salutogenic processes efficiently. This paper focuses specifically on urban green spaces and qualities within these that may contribute to their potential as salutogens in people's lives. This is done without thereby dismissing the importance of other urban qualities.

AFFORDANCE THEORY TO ANALYZE THE SALUTOGENIC POTENTIAL OF URBAN GREEN SPACES

We believe that much of the salutogenic potential of environments could be understood through an ecological approach to perception and behavior, by analyzing the environmental support for certain *affordances* in people's living environment. Introduced by Gibson (1979), an affordance is regarded as a perceivable and utilizable possibility for a certain behavior or experience, provided to individuals by environments. We here consider affordances primarily as relations between the individual and the environment, in accordance with the affordance theory developed by Chemero (2003, 2009). As such they are situation-dependent and are shaped between the abilities and needs of the individual and the present socio-material environmental conditions. Previous studies have applied the affordance concept to investigate how outdoor environments can afford, e.g., physical activity levels (e.g., Cosco, 2006; Björk et al., 2008) and independent mobility (Kyttä, 2003), socialization (Clark and Uzzell, 2002), self-regulation, (Korpela et al., 2002) and play behaviors (e.g., Heft, 1988; Zamani and Moore, 2013) among children. Kyttä (2002) revealed rural environments to have higher potential in providing affordances for play and social behaviors among children than urban environments. Other studies have used an affordance approach to investigate the potential of different environmental settings to aid in the restoration of stress and stress-related illness, such as rehabilitation gardens (e.g., Stigsdotter et al., 2017b) and forest environments (Stoltz et al., 2016).

Understood as dynamic human-environment relations, the affordances perceived are affected by various aspects regarding individual needs and characteristics, social factors, and physical environmental conditions. For instance, the perceived neighborhood safety may be regarded as one important factor that may shape the perception and utilization of green space affordances, as shown through epidemiological research by, e.g., Weimann et al. (2017). Such results indicate the importance of accounting for the broader socio-material context to understand how green space affordances are shaped and utilized. In general, salutogenic effects from urban green spaces have been related primarily to the amount of time spent there (Grahn and Stigsdotter, 2003) and research has shown both the use rate and time spent in urban green spaces to decrease markedly already in the interval of 100–300 m away from the dwelling (Grahn and Stigsdotter, 2003; Nielsen and Hansen, 2006). It is thus important to identify factors that make urban green spaces afford actual use and it seems clear that accessibility, not the least through physical proximity, is key in this regard. The perceived biodiversity of urban green spaces has been identified as another important factor for visit rates (Gyllin and Grahn, 2015; Sandifer et al., 2015; World Health Organization [WHO], 2015), thus also indicating a general importance for the qualities perceived within green spaces. In order to analyze the salutogenic potential of urban green spaces in more detail, however, and possibly come up with evidence-based design and management suggestions, we would need a deeper understanding for the qualities of such environments that are important in shaping affordances of salutogenic significance. Also from a planning perspective this would be important to be able to identify which needs that are well catered for in a given environment and those that might require improved environmental support.

NATURAL ENVIRONMENTS AS A SALUTOGENIC FACTOR

Human connections and interactions with green and natural environments have been the focus of much research from various perspectives. Physical, mental, and spiritual perspectives have been highlighted and associated with various health and wellbeing outcomes. Research has described how perceptions of natural environments and features may impact various aspects of human health and wellbeing (e.g., Ulrich, 1984; Nilsson et al., 2011; Haluza et al., 2014), cognitive functions (e.g., Kaplan, 1995; Ottosson and Grahn, 2005; Berman et al., 2008) and stress-related aspects such as parasympathetic nervous system activity (Annerstedt et al., 2013), cortisol levels (Ward Thompson et al., 2012; Roe et al., 2013) and blood pressure and heart rate (e.g., Ottosson and Grahn, 2005). Such environmental influence has also been studied in various kinds of rehabilitation contexts (e.g., Ottosson, 2001; Pálsdóttir, 2014) and nature-based rehabilitation for individuals with stress-related disorders has been performed in various settings (e.g., Sonntag-Öström et al., 2014, 2015; Pálsdóttir et al., 2017; Stigsdotter et al., 2017b). Sahlin (2014) describes how such environments could promote and facilitate high-order cognitive behaviors such as existential reflections that aid in shaping experiences of meaning, coherence, and acceptance. Influence of natural and green environments has also been studied from a children's perspective. Mårtensson et al. (2013) for instance investigated relations to physical activity among school children. Carrus et al. (2015) showed how contact with nature could positively influence both cognitive capacities and social behavior among preschool children.

The Psycho-Evolutionary Theory; Restoration From Stress

Commonly, such effects from natural environments and features are explained with theories related to the *Biophilia*-hypothesis (Wilson, 1984; Ulrich, 1993), i.e., the idea that humans tend to respond in favor to natural characteristics that have been beneficial to survival and wellbeing during human evolution. The often-cited *psycho-evolutionary* theory (PET; Ulrich, 1986; Ulrich et al., 1991) focuses mainly on restoration from psycho-physiological stress. It holds that immediate affective responses, to a large degree dependent on common evolutionary traits, are important for how we respond to different environments. Responses of approach or avoidance depend on how environmental perceptions are interpreted and valuated in regard to survival and wellbeing, much in line with the evolutionary approach to motivation and valuation suggested by Mercado-Doménech et al. (2017). In accordance with Orians (1986); Ulrich (1986) suggests that our genetic configuration explains a preference for "savannah-like" environments consisting of layered vegetation with a mix of trees, grasses, and shrubs, preferably with visible water features, as well as support for the "prospect/refuge" dimension, i.e., opportunities for sheltered overviews and outlooks, as previously proposed by Appleton (1975). Empirical evidence in support of these theoretical claims has been reported by, e.g., Falk and Balling (2010). Such environmental characteristics are suggested to trigger stress-reducing responses whereas threatening or adverse conditions may induce stress (Ulrich et al., 1991). In general, PET suggests urban environments and stimuli to be significantly more stressful and less restorative than natural settings and features (ibid).

The Attention Restoration Theory; Restoration From Attention Datigue

Another influential model in the field is the *attention restoration* theory (ART; Kaplan and Kaplan, 1989; Kaplan, 1995). It shares with PET the basic idea that evolutionary traits play an important role in how humans perceive and react to environments. Instead of psycho-physiological stress, however, ART instead focuses on our capacities for attention where it distinguishes between two basic kinds; "directed attention" and "soft fascination." ART suggests that our directed attention has a limited capacity and gets exhausted if overused. Typically the use of executive functions, such as planning and problem solving, require the activation of directed attention (Kaplan and Berman, 2010), as do many urban environments with an abundance of signals, information, and noise that the brain needs to sort through and handle. Circumstances that instead trigger our soft fascination, or "spontaneous" attention, e.g., certain natural environments and features according to ART, allow our directed attention to rest and its capacities to restore (Kaplan, 1995). In order for such restoration to occur, ART suggest that the environment should: (1) offer a sense of *being away* from the everyday environment, (2) give a sense of *extent*, of an uninterrupted world in itself, (3) offer opportunities for *fascination*, through, e.g., natural features, and (4) be *compatible* with individual needs and abilities (Kaplan and Kaplan, 1989). ART, however, does not go into further detail in explaining how environments need to be physically structured in order to support these factors at the level of planning and design of public environments and urban green spaces.

THE SUPPORTIVE ENVIRONMENT THEORY; AN ECOLOGICAL APPROACH

The *supportive environment theory* (*SET*; Grahn et al., 2010) represents an approach to account for restorative and instorative processes (Stigsdotter and Grahn, 2003) that acknowledges the basic mechanisms and pathways suggested by both PET and ART, but emphasizes human's embodied relations with the environment and its affordances for certain experiential qualities termed *perceived sensory dimensions*. The theory suggests eight such qualities to be of particular importance to account for salutogenic effects. These have been revealed through factorial analysis of several different survey studies regarding people's green space preferences and use. They are based on people's reported needs regarding environmental support in their daily lives and do not rely on, e.g., image studies which has otherwise been common in the field. They may thus be regarded as ecologically valid categories in terms of green space qualities of potential salutogenic importance. Grahn and Stigsdotter (2010) term these qualities as (1) *Serene*, (2) *Nature*, (3) *Rich in species,* (4) *Space,* (5) *Prospect,* (6) *Refuge,* (7) *Culture,* and (8) *Social.* **Table 1** presents brief descriptions of each perceived sensory dimension.

TABLE 1 | Eight perceived sensory dimensions associated with affordances supporting different needs.

Perceived sensory dimension	The environment affords behaviors/experiences associated with...
(1) Serene	Peace, silence and care. Sounds of nature. Freedom from disturbances.
(2) Nature	Fascination with the natural world; the "self-made" as opposed to the man-made. Seemingly self-sown plants, a sense of untouched nature.
(3) Rich in species	A sense of abundance and variation, a large diversity of different species of plants and animals.
(4) Space	An experience of entering a world in itself, a coherent whole.
(5) Prospect	Views of the landscape, a sense of openness, prospects, vistas and stays.
(6) Refuge	Shelter and safety. Possibilities to relax and, e.g., let children play freely.
(7) Culture	A sense of fascination with human culture and history, the course of time and human efforts.
(8) Social	Social activities and interactions.

After Grahn and Stigsdotter (2010).

Each dimension indicates a generally perceived need that requires support in the environment (Grahn and Stigsdotter, 2010; Grahn et al., 2010) and people tend to agree as to which level an environment support a quality or not, making them suitable for objective environmental evaluations (see e.g., de Jong et al., 2011, 2012; Stoltz et al., 2016). Such general agreement may be important in the context of design and planning of public environments such as urban green spaces where individual tailoring is not applicable. It may also be considered as in line with the notion that humans share certain tendencies regarding environmental preferences due to common evolutionary traits, as held by PET and ART. A key assertion of SET, however, is that preferences and valuations (Mercado-Doménech et al., 2017) of each quality vary with changing needs, depending on, e.g., stress levels (Grahn et al., 2010). This has also been clear when studied in various rehabilitation contexts. For instance, Pálsdóttir et al. (2017) investigated which qualities that were considered the most restorative in a rehabilitation forest environment. The results showed the perceived sensory dimensions Serene, Space, Refuge, and Nature to be rated highest in this regard and the Social quality to generally be seen as the least restorative, all in line with previous studies (e.g., Grahn and Stigsdotter, 2010). This indicates that salutogenic design and planning of urban green spaces should take into account the need for variation in terms of perceived environmental qualities in order to satisfy different needs in the population.

The perceived sensory dimensions may thus be considered as quite stable in the environment regarding their general presence/support, while their actualization as perceived affordances will vary depending on individual needs. This makes them interesting as a framework through which affordances of salutogenic importance, although always realized as unique human-environment relations, may be considered in a more general and objective sense for purposes of design, planning and evaluation of public environments. Following these assertions, public health and wellbeing outcomes may to some degree depend on the affordances for the different perceived sensory dimensions in people's close living environment. Such relations have been investigated in epidemiological studies. Björk et al. (2008) found an association with the number of dimensions perceived as supported in the neighborhood green spaces and reported neighborhood satisfaction. The opposite association was found regarding body mass index (BMI; ibid). These effects were, perhaps not surprisingly, most pronounced among tenants as compared to house-owners. de Jong et al. (2012) found an association with increased physical activity and the number of supported dimensions in the neighborhood green spaces. These results were all adjusted for in regard to individual characteristics such as age, sex, educational level, and income, suggesting that the observed effects indeed share a common driver in the structure of the physical neighborhood environment. In line with such findings, Stigsdotter et al. (2017b) suggest that the perceived sensory dimensions framework is valid for use as a guideline in the design and evaluation of salutogenic environments.

THE EDIBLE FOREST GARDEN

The edible forest is one of several agroforestry practices based on *agroecological* principles (Gliessman, 2007). Agroecology is a scientific discipline derived from agronomy and ecology that studies productive lands through an understanding of the workings of natural ecosystems (ibid). The edible forest garden describes a low maintenance, productive and species rich cultivation system with its origins in the tropics (Hart, 1996; Crawford, 2010). It is modeled after the structure of young natural woodland and consists of edible perennials such as fruit and nut trees, shrubs with berries, herbs, vegetables, flowers and fungi that are intercropped in layers in a so-called *multi strata* system (**Figure 2**). The edible forest garden thus resembles a forest more than a conventional horizontal garden and the management methods used mimics the cycles in natural ecosystems (Crawford, 2010). No external inputs of resources such as irrigation, pesticides, or fertilizers are used and digging/tilling techniques are avoided. Instead recycling of organic matters on the ground makes the soil fertility self-generative, the moist is kept and green house gas emissions are low or even negative (ibid). Natural pest control is accomplished through the high species richness – usually about 100–200 species per garden – and the forest garden is also resilient of weather extremes as well as demanding lesser labor for maintenance and weeding than annual crops (ibid). Edible forest gardens exist as home gardens in the tropics (Bardhan et al., 2012) and in temperate areas such as in the United Kingdom since a few decades (Hart, 1996; Crawford, 2010). In Sweden, their ecological benefits have been highlighted through an applied pilot project on 13 smallholdings (Björklund et al., 2018).

Edible Forest Gardens and Urban Sustainability

From the literature on food production the edible forest garden is considered as promising regarding ecological sustainability (Crawford, 2010). Russo et al. (2017) include edible forest gardens in their concept of "edible green infrastructures" and the city of Seattle, United States, has an ambitious tree-planting program in order to create edible urban landscapes supporting urban sustainability (McLain et al., 2012). Clark and Nicholas (2013) have investigated 37 existing urban "fruit forests" in the United States and address their multiple benefits regarding sustainability. Furthermore, edible forest gardens can increase urban biodiversity; even a small bed could consist of +100 species and this high biodiversity could contribute to ecological values, especially when compared to traditional lawns (cf. e.g., Ignatieva, 2010; Ignatieva et al., 2015). Since it consists of trees and shrubs the overall structure resembles a forest/orchard with shelters, providing habitats for organisms such as birds and insects (Björklund et al., 2018). Even smaller forest gardens (≈60 m^2) can exhibit these qualities (ibid) and thus contribute to increased urban biodiversity. On the landscape level edible forest gardens could strengthen the green infrastructure through contributing to ecological connectivity (Russo et al., 2017). Bohn and Viljoen (2011), under the concept of the Continuous Productive Urban Landscape (CPUL), have suggested cities to have continuous productive stretches with room for green areas, mobility without vehicles, and urban agriculture. Edible forest gardens could be part of such a strategy.

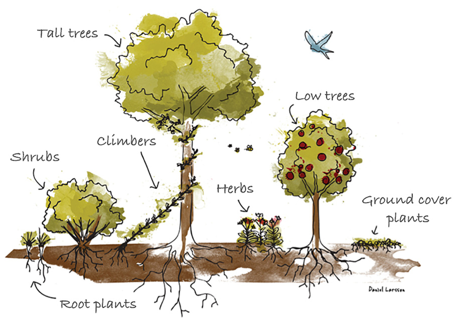

FIGURE 2 | The multi-strata (layered) system of an edible forest garden (illustration by Daniel Larsson).

To our knowledge there are not yet any published literature on temperate zone urban edible forest gardens. We suggest, however, that they have great potential in these areas as well. They are more robust than annual cropped gardens and therefor allow other activities such as room for play or for people that do not want to garden themselves. Edible forest gardens could be integrated in the ordinary maintenance of outdoor-areas performed by public (e.g., municipalities) or private (e.g., housing companies) actors. They demand less labor, resources, and land area than annual cropped gardens (Hemenway, 2009; Crawford, 2010; Björklund et al., 2018) and could therefor also be less expensive. Edible forest garden could thus be an alternative for municipalities with constrained budgets. Stockholm for instance is a segregated city (Bremberg et al., 2015) and since the municipality owns 70% of the land forest gardens could contribute to urban sustainability in underprivileged districts by urban agriculture in the forms of edible forest gardens and community gardens. In a small-scale study on edible forest gardens in residential areas in Stockholm, Schaffer (2016) highlighted the multiple user-groups that visited the gardens, thus indicating a potential for broad social benefits. If space is limited, forest gardens can be kept small and fit in well in existing urban environments, e.g., in between apartment blocks (**Figure 3**).

COMMUNITY GARDENING IN URBAN AREAS

Social factors such as neighborhood interaction patterns, social cohesion (Wilkinson, 1996), social capital (Giordano et al., 2012), and a shared sense of coherence and safety (Taylor et al., 1997) have important influences on health and wellbeing. Urban agriculture in general is suggested to contribute to multiple dimensions of sustainability depending on organizational form, location, size, and gardening methods (Guitart et al., 2012; Mok et al., 2014; Eigenbrod and Gruda, 2015). As an organizational form the *community garden* have been highlighted

FIGURE 3 | View from a young edible forest garden in Bagarmossen, south of Stockholm, Sweden. It is located close to the metro station and a shopping mall in an area with apartment blocks without own gardens.

in the literature. Hale et al. (2011) argues that the relational qualities from community gardening contributes to social health, since it nurtures relations such as those between gardener-plant, gardener-gardener and the garden/gardener-the local community. Community gardening could increase the social capital (Firth et al., 2011) and contribute to learning and a sense of place (Bendt et al., 2013). Gardening as an activity also contributes to health for gardeners from a physical activity perspective, and for others as well since the garden could be the attraction for a trip or a walk (Hale et al., 2011). Various forms of urban gardens, such as edible forest gardens, allotment gardens, etc., organized as community gardens may contribute to social capital (Firth et al., 2011) and a sense of place (Bendt et al., 2013). In a recent study by Bonow and Normark (2018) on community gardens in Stockholm, the many social qualities generated are highlighted versus the rather small amount of food produced.

Clavin (2011) identified features of sustainable design in community gardens in the United Kingdom that had impact on wellbeing. Factors that affected wellbeing were related to agency (both individual and collectively) from experiential learning (learning by doing) and having choice (freedom) to work in one's own manner (to be both slow or busy, to be both alone or work with others), and having choice of a variety of tasks suitable for different people different days. Community gardens as a form of do-it-your-self urbanism (Finn, 2014) enable people to participate in the design of their own neighborhood. Such gardens might thus afford an arena where urban citizens can be more than voters/consumers, but also actively engage as co-creators of the city. In allotment areas ecological knowledge is shared among gardeners and over generations (Barthel et al., 2010) and this could also be true for community-based forest gardens. Edible forest garden may also afford learning opportunities, as described by, e.g., Askerlund and Almers (2016) who studied how edible gardens could support children's learning on ecology. When located in urban areas edible forest gardens may provide increased possibilities of interaction with the natural world, thus aiding an increased sense of connectedness to nature (Hale et al., 2011), support environmental awareness and pro-environmental behaviors (cf. e.g., Annerstedt van den Bosch and Depledge, 2015). Arguably, forest garden could thus somewhat remedy the "extinction of experience" mentioned by Pyle (1978).

PERCEIVED SENSORY DIMENSIONS OF EDIBLE FOREST GARDENS

We argue that edible forest gardens in urban green spaces is an interesting concept to explore, both in regard to such dimensions of ecological and social sustainability as has been outlined above, and in terms of affording perceived qualities of salutogenic importance, which could be highlighted using the perceived sensory dimensions framework described above. Compared with lawns, edible forest gardens seems particularly promising in supporting perceived sensory dimensions such as Nature, Rich in species, and Refuge; dimensions that have been described in the literature as important to support restorative processes (e.g., Grahn et al., 2010; Pálsdóttir et al., 2017; Stigsdotter et al., 2017b). **Table 2** relates typical features of the edible forest garden with each perceived sensory dimension of the SET theory.

The use of trees and other perennials, a core principle of agroforestry, could be an efficient means to reinforce affordances for the perceived sensory dimension of Nature; especially so when given an impression of being "self-sown" (Grahn and Stigsdotter, 2010). The general salutogenic potential of urban trees in particular have been highlighted in previous research (e.g., Kardan et al., 2015), as have the salutogenic potential of forest environments (e.g., Sonntag-Öström et al., 2014, 2015). In addition, trees can often be made visible from the windows of houses that in dense urban areas often reach several floors above ground and thus increase the need for vertical green structures in order to be visible from inside the dwellings. The salutogenic potential of having access to trees outside the window has not the least been highlighted by Ulrich (1984) in a well-known study. Support for the perceived sensory dimension of Nature would possibly increase over time as the forest garden grows and matures; a sense of nature's "untouched" development over time is indicated as important to strengthen this perceived quality (Grahn and Stigsdotter, 2010). Compared to, e.g., lawns – that arguably will look almost the same even after 50 years of cultivation – a forest garden with 50-year-old fruit and nut trees would give quite another impression in such terms. Experiences of the passage of time in nature could further be reinforced through the high biodiversity of the forest garden with a large variety of plants that may mature at different times during the season, thus changing the environmental impressions as time passes.

The high biodiversity could also strengthen the affordance for the Rich in species dimension and the perceived biodiversity, as already mentioned linked with use rates of urban green spaces (e.g., Sandifer et al., 2015). Again, when compared to traditional lawns, the potential difference here seems obvious (**Figure 4**). The emphasis on edibles in the forest garden does not exclude plants that are just there for aesthetic or other reasons (e.g., pest control or other functions), however, the edibility factor arguably offer even more ways to interact and relate to nature in meaningful ways using the whole body and all its senses. Forest garden environments may also support affordances important for

TABLE 2 | Typical features of edible forest gardens in relation to eight perceived sensory dimensions (after Grahn and Stigsdotter, 2010).

Perceived sensory dimension	The environment affords behaviors and experiences associated with. . .	In relation to features of the typical edible forest garden
(1) Serene	Peace, silence and care. Sounds of nature. No disturbances.	Edible forest gardens, especially when mature, could provide habitats that attract singing birds and humming insects. Sounds of wind blowing through the trees etc. could also reinforce affordances associated with this dimension.
(2) Nature	Fascination with the natural world; the "self-made" as opposed to the man-made. Plants seem self-sown, a sense of untouched nature.	Mimicking the natural ecosystems of young woodlands, the mature edible forest garden could provide plenty of affordances associated with this dimension, e.g., trees and plants with interesting shapes, a sense of nature's power to grow and create through the passing of time.
(3) Rich in species	A sense of abundance and variation. A large diversity of different species of plants and animals.	Edible forest gardens typically exhibit a very high biodiversity. Usually +100 plant species, most of them edibles. The forest garden environment could also attract various animals through the different habitats created by the various plants and the young woodland, *multi-strata* structure.
(4) Space	An experience of entering a world in itself, a coherent whole.	May be reinforced through the *multi-strata* structure the forest garden, adding to a sense of 3-dimensional "spaciousness" and of entering into "another world, a coherent whole." An entrance gate may further strengthen such affordances. It would, however, be important for the forest garden to be large enough in order to fully support associated experiences and behaviors (e.g., "wandering around").
(5) Prospect	Views of the landscape, a sense of openness, prospects, vistas and stays.	Affordances associated with this dimension are generally better reinforced by, e.g., lawns rather than by edible forest gardens in themselves. However, from a distance the forest garden might provide for a pleasant "view" or "scenery" that are important aspects of this dimension.
(6) Refuge	Shelter and safety. Possibilities to relax and, e.g., let children play freely.	Could be reinforced through the *multi-strata* structure of the forest garden with trees and shrubs of various heights mixed with more open parts. A gate to the garden may further strengthen affordances that allow for a sense of shelter and privacy and to "see without being seen."
(7) Culture	A sense of fascination with human culture and history, the course of time and human efforts.	An edible forest garden represents a highly cultivated environment. Crops could be chosen that relate to cultural heritage. With time a growing sense of appreciation for the history of the place and the human labor put into the garden might grow, thus further strengthen associated affordances.
(8) Social	Social activities and interactions.	Especially true when realized as community gardens in public green spaces close to dwellings. Opportunities for learning, workshops, gardening activities, etc. have been highlighted in the literature.

FIGURE 4 | In front of the public sports hall in relatively low-income and culturally diverse suburb of Fisksätra, southeast of Stockholm. A lawn has been planted with around 130 different plant species to form an edible forest garden. On regular basis children from a nearby kindergarten visit the garden to learn about ecology and explore the affordances of the garden.

species other than humans, such as singing birds, insects, and other animals that further may strengthen the Rich in species quality. Many times forest gardens also include the presence of an "insect hotel" – a structure made to provide shelter for insects – that in addition may contribute with, e.g., pollination functions.

Singing birds, sounds of wind blowing through the trees, etc. could also reinforce the affordances for the Serene dimension through the presence of various "sounds of nature" (Grahn and Stigsdotter, 2010). In addition, the potential to use trees and other vegetation to reduce, e.g., traffic noise levels have been highlighted in the literature (e.g., Bolund and Hunhammar, 1999; Gómez-Baggethun et al., 2013). Evidence also suggests that green features might mitigate annoyance associated with such noise in urban environments, and that the type and structure of the greenery matters in this regards. Li et al. (2010) for instance investigated Hong Kong residents and found "garden parks" visible from home to reduce noise annoyance to a greater degree than "grassy hills". Renterghem and Botteldooren (2016) reached a similar result and concluded that visible outdoor vegetation was essential for the reducing effect on noise annoyance at home.

Trees and other perennials in the semi-open *multi-strata* structure (**Figure 2**) of the edible forest garden could furthermore support affordances for Refuge through the creation of shelters and hideaways. Such affordances have been described as particularly important from the perspective of stress restoration (Grahn et al., 2010; Pálsdóttir et al., 2017; Stigsdotter et al., 2017b). This has also been indicated in forest rehabilitation contexts (Sonntag-Öström et al., 2015). A sign and a gate that marks the entrance of the garden could further enhance such affordances (Pálsdóttir et al., 2017). If large enough to provide a sense of "coherent whole," and of "entering a world in itself" (Grahn and Stigsdotter, 2010; Pálsdóttir et al., 2017), an edible forest garden may also afford of the perceived sensory dimension of Space to some extent.

Over time, an edible forest garden could also support opportunities to experience and appreciate the work and efforts of "previous generations," thus affording the perceived sensory dimension of Culture (Grahn and Stigsdotter, 2010). Artifacts such as "sculptures" or "ornaments" (ibid), made with a sensibility for the qualities of the place could be used to further strengthen this dimension. A lawn would generally better afford the Prospect dimension than a forest garden in itself. However, from a distance a forest gardens could potentially aid in providing a pleasant "view" or "vista" that also are important aspects of this dimension (ibid). The potential of edible forest gardens to support various social affordances in urban areas, especially when implemented as community gardens, have already been pointed out above and will not be further discussed here. What may be important to highlight here though is the conflict that has been observed in empirical studies between highly restorative qualities such as Serene and the Social dimension (see e.g., Pálsdóttir et al., 2017). This implies that a balance is needed between the support of social affordances and the potential for restorative qualities in the forest garden if the environment is to support such opposing needs. For instance, this could be done by making sure that social activities in the garden is not overly promoted and that time slots are reserved where the garden can be available for those in need of a more solitary experience.

How the Perceived Qualities of Edible Forest Gardens May Support Restorative Processes

Pálsdóttir et al. (2017) investigated the potential of a forest garden environment to support the rehabilitation process of individuals with stress-related mental disorders. Participants described how the "natural appearance" of the forest garden environment appealed to them and was perceived as "calming and safe." Participants described how they felt that "nature was strongly present" in the forest garden, that "they could think without effort" and find a "way back to peace and quiet" (ibid). Other participants in this study mentioned the restfulness of the "overgrown and wild-like nature." The forest garden environment was described as embedded in "lush vegetation" and participants mentioned how the wild attributes of the forest garden provided opportunities for "undemanding and restful" experiences. Some participants also mentioned regaining a feeling of "natural origin" and a strong "belonging to a greater whole" (ibid.). Participants in the study shared how they, in the forest garden environment, could "closely interact with nature" and "dared to expose their deepest feelings and thoughts." The "smell of grass," "the taste of berries," the "sounds of the wind" and "bird twitter and songs" were other experiences mentioned. In the winter participants reported seeing tracks from animals in the snow, giving an indication that restorative processes may be supported during all seasons. The forest garden environment also allowed participants to "hide and find a nice, sheltered place" and "move around without being heard or seen." Some participants "walked slowly or strolled around" in the forest garden, while others "just sat somewhere and enjoyed the surroundings" (ibid). Stigsdotter et al. (2017b) conclude that spatial aspects are important in order for environments to support restorative processes. Environments with a "natural and wild appearance," "diverse vegetation," and a "balance between enclosed, dense growth and open views" were found to be generally preferred in this regard. The dense growth should have "the appearance of a den and offer experiences of privacy" (ibid.). These are all descriptions that would suit the typical, mature forest garden well.

SUMMARY AND CONCLUSION

We have highlighted several factors that present edible forest gardens based on agroecological principles as an interesting model to explore in order to achieve efficient multiple-use of urban green spaces. We have pointed to the potential of several ecological benefits from such a design and management strategy, not the least in terms of increased urban biodiversity, which could be achieved while simultaneously increasing affordances and perceived qualities important for human health and wellbeing. The global prevalence for diseases highly linked with lifestyle and living environment, in turn affected by increasing urbanization, stresses the importance of supporting such affordances in people's close living environment. Not the least opportunities to restore from stress and attention fatigue seems important, but also possibilities to shape an increased sense of connectedness to nature and to processes of food production. This could also encourage pro-environmental behaviors that could further benefit long-term public health and wellbeing and mitigate ecological challenges. The importance of accessibility, not the least expressed in terms of physical proximity, for the perception and utilization of such green space affordances highlights the need to place edible forest gardens in public green spaces, at street level, close to dwellings and accessible for all. The general potential of green space affordances to mitigate socioeconomic differences in health and wellbeing can make edible forest gardens extra interesting to implement in socioeconomically challenged areas. Further research is encouraged in order to establish a deeper understanding for how affordances and qualities of salutogenic importance may be supported through urban green spaces and infrastructures. The potential of edible forest gardens in urban areas to contribute to biodiversity through the creation of new habitats, i.e., to also support affordances of importance for species other than humans may also be interesting to further investigate.

AUTHOR CONTRIBUTIONS

JS conceived to original idea for the paper and took responsibility for the overall structure and writing of the final manuscript. CS provided expertise and knowledge about urban sustainability, gardening, and edible forest gardens.

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Monocultural land-use systems, narrowly focused on production, need transformation toward practices that recognise and integrate multiple benefits. Agroforestry systems (AFS) – the deliberate integration of trees, crops, and/or livestock – offer such a model by linking agriculture and forestry while delivering environmental, economic, and social advantages. This thesis aims to understand agroforestry systems in Sweden including novel types of silvopastoral, silvoarable, forest farming and forest garden systems.

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