Master thesis – Sustainable Development: Environmental Change and Ecosystems

Agroecology in Practice:

Designing a Food Forest in the Utrechtse Heuvelrug

Photos of the case study site taken at the same location in April (left) and July (right)

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Word count: 16045

Abstract

This thesis explores sustainable design principles for a climate-adaptive food forest (FF) at estate Zuylestein in the Utrechtse Heuvelrug. The landowner wished to integratea former forested area into the productional focus of the entire estate while restoring the look of a forest as required by national monument legislation and adapting to climate change. FFs represent an agroecological, sustainable way of producing food while benefitting the local community and nature. It can thus be seen to increase food sovereignty. For this purpose, the estate needed to be evaluated from a social-ecological system (SES) perspective to reveal constraints, opportunities, and goals for the FF. Further, benefits, services and income opportunities of FFs needed investigation. Lastly, the vision and priorities of the main stakeholders needed to be considered. Scientifically, this thesis systematically assessesgeneral design principles for FFs in temperate regions, with a focus on climate adaptation. Further, the approach of the thesis being transdisciplinary with a social-ecological lens, adds to literature on transdisciplinary projects.

In this thesis, transdisciplinary work means the co-production of knowledge with the main stakeholders as well as consultations with FF practitioners. Soil analyses were conducted to evaluate soil fertility and water availability. Interviews with the landowner completed the necessary social-ecological knowledge on the system. What the target state of the FF should be and how a transformation could be facilitated was further informed by conducting a scenario and backcasting workshop with the main stakeholders. Reviewing scientific and grey literature completed the picture.

By applying these methods, in an iterative process, design principles were derived. Most importantly, sufficient startup funds for the beginning years, when the system is still vulnerable need to be secured. Further, to establish resilience, effort should be put into increasing soil health by increasing the pH level and water availability through increasing the soil organic matter content. During the maturing of the FF the income streams need to be flexible as different produce can be grown at different succession stageswhilethe design of the FF becomes visible. To avoid disturbing the FF, most of it should not be publicly accessible. To gain revenue from food production, the layout should not be too complex to enable easy management and harvesting. These principles can be applied to sites with similar conditions. To ensure sustainability, the local social-ecological context should always be evaluated with care and transdisciplinary collaborations fosteredto ensure context-specific results.

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Food forest	FF
Social-ecological system	SES
Soil organic carbon	SOC
Soil inorganic carbon	SIC
Soil organic matter	SOM
Payment for ecosystem services	PES

1. Introduction

This thesis explores how agroecological food production in the form of a food forest (FF) can successfully be implemented at the Zuylestein estate in the National Park Utrechtse Heuvelrug, in the Netherlands (see map inFigure 2 below). At the estate a 2-hectare forested area, the *Sterrenbos*, was destroyed by strong fall winds in summer 2021. The landowner aims to restore the forest taking climate change pressuresinto account while embedding it into the food production orientation of the rest of the estate. Figure 1 below shows the general layout of the site (see Appendix A for full size map and Appendix B for pictures).The overarching goal is to create a resilient and productive forest system for the foreseeable future.

Figure 1

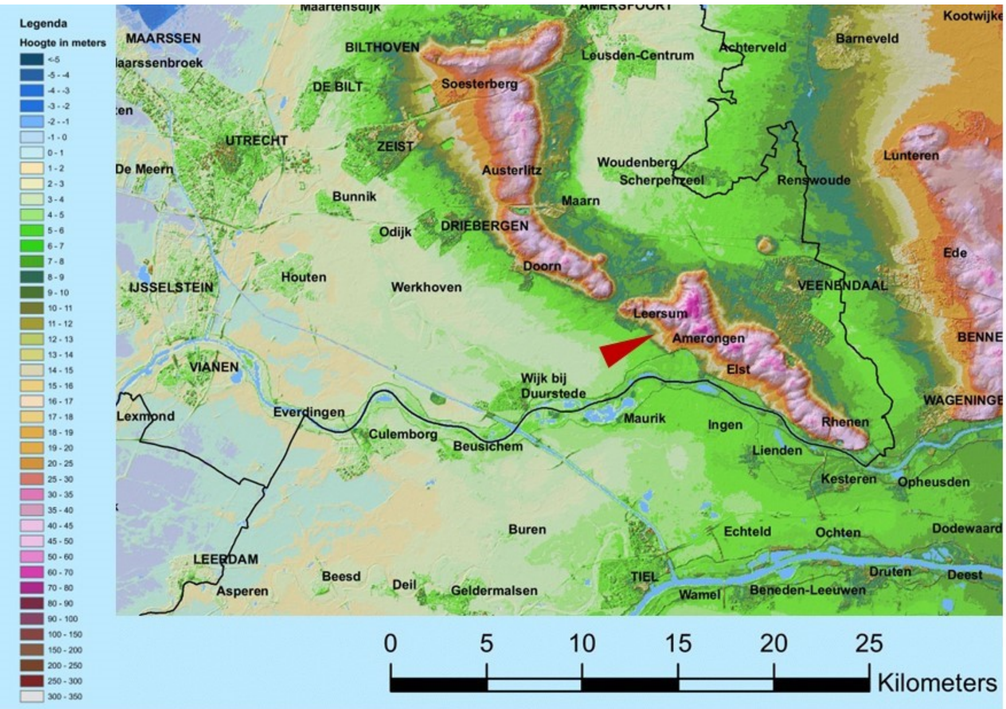
Map of the Sterrenbos area

*Note.*Map drawn by landscape architects in 2021 at scale 1:1000. Green areas with dark green circles represent the leftover forest area. The star shaped paths in the centre of the image gives the Sterrenbos its name. The light area indicates the destroyed forest. The light green circles along the paths are trees in planning.

In FFs, a natural forest ecosystem is mimicked, but the includedspecies are chosen according to human needs such as for sustenance(Crawford, 2016; Jacke & Toensmeier, 2005a). FFs can offer continuous nutritious, local food production. As FFs mature and the biogeochemical cycle of natural ecosystems is established,they need continuously less management (Albrecht & Wiek, 2021b; Nytofte & Henriksen, 2019; Toensmeier et al., 2020).FFs in this thesis are understood to enable four general types of benefits and services. In addition to food production, FFs can offer socio-cultural services such as education as well as environmental services such as an improved water cycle and increased biodiversity[1] (Albrecht & Wiek, 2021a). In application to sustainability, FFs further offer economic income opportunities addressing the third pillar of sustainability, next to the environmental and social pillars(ibid.; Fleurbaey et al., 2014). To create a FF system with a long-term (> 30 year) perspective, this is a crucial aspect to consider. Not including financial aspects has led to the failure of multiple FFs in temperate regions (Albrecht & Wiek, 2021a).

Figure 2

Elevation map of the Utrechtse Heuvelrug, with the location of estate Zuylestein marked in red on the flank of the Heuvelrug (WUR, n.d.)



1.1. The need for adaptation

Climate changeis a main motivation for the landowner to rethink the *Sterrenbos* site.The Netherlands has a warm temperate climate, meaning mild seasonal variations in amount of precipitation, warm summers, and cool winters. Most precipitation falls at the end of summer and in winter, the least in spring. However, as temperatures are higher in summer, much water evaporates before it is available to vegetation or reaches the groundwater storage. On average it rains 828,83 mm per year, the driest month is April,the wettest December and August. Table 5 and Figure 11 in Appendix C give an overview of the seasonal and annual temperature data and monthly average precipitation of the previous 30 years.

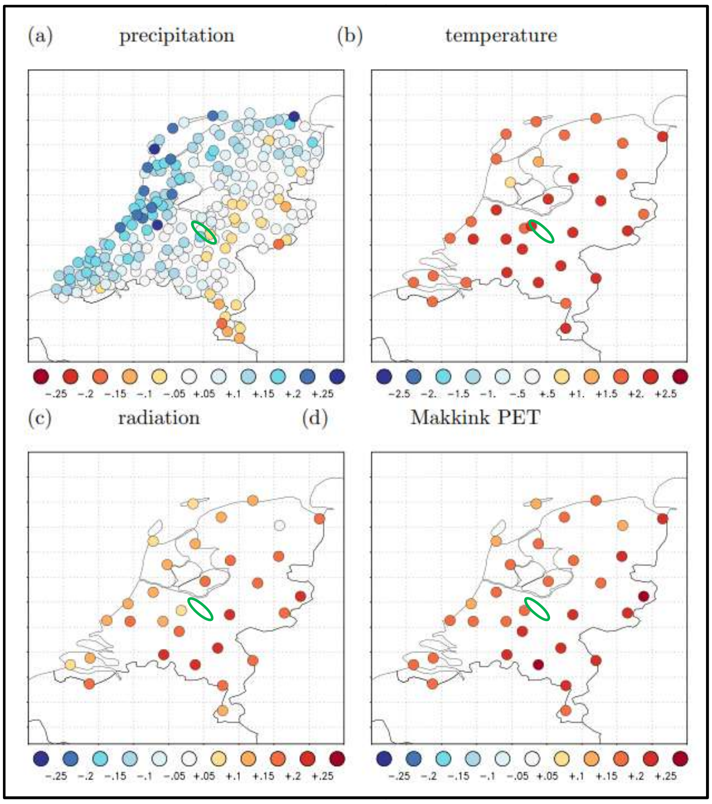
Long lasting droughts, higher temperatures and more extreme weather events are already impacting flora and fauna in the Heuvelrug area (Klimaatportaal, 2023; NPUH, 2020; van Ginhoven et al., 2022). In the Netherlands, the last 30 years compared to the previous 30 years exhibit increases in annual temperature, sun irradiation, and total precipitation amount according to the KNMI's climate report

[1] meaning the internal variety of species (genetic), diversity of species and of whole communities(IPBES, 2019; Sala et al., 2000).

(2021). A warmer climate and increased sun irradiance increase potential evapotranspiration (PET) and exacerbate meteorological droughts[2] in inland regions, despite increased total precipitation (KNMI, 2021; Philip et al., 2020).Figure 3 gives an overview of these components, showing that in the Heuvelrug temperature,radiation, and PET are increasing for the summer period (Philip et al., 2020). The Heuvelrug is characterized through local altitude heterogeneity and sandy grounds (compare map above). Due to the porous, well-draining sand grounds, drought leads to a quickly decreasing groundwater level.This puts pressure on young and already weakened trees, especially in groundwater dependent areas on the flanks where the estate is located. Especially during the drought years of 2018 and 2019 the local vegetation was under severe stress (KNMI, 2023; World Bank, 2023b).These factors had also made the forest at Zuylestein more vulnerable in the storm.

Figure 3

Climate change trends in the Netherlands



Note. Trends in (a) precipitation (b) mean temperature (absolute regression), (c) global radiation and (d) Makkink PET for the summer (April-September)through regression against global mean surface temperature (Philip et al., 2020, p. 7), the location of the Heuvelrug is indicated in green.

Extreme weather events, such as in 2021, are expected to get stronger and occur more often, particularly in summer (KNMI, 2021). The frequency of extreme precipitation events is increasing in the Heuvelrug area(ibid.). The intensity of short precipitation events is also expected to rise, making inundation a danger(Fowler et al., 2021).Nature as well as agricultural areas in the Heuvelrug are subject to climate and water stresses (van Ginhoven et al., 2022).Water stress is addressed in the*blue agenda*initiated by the National Park Utrechtse Heuvelrug organisation together with local stakeholders.It aims to promote a fair and sustainable water management in the area, enabling more water infiltration and increasing water storage (NPUH, 2020). Nevertheless, the landowners need to adapt on their land as well.

[2] Lack of precipitation

1.2. Agroecology and food sovereignty

Agroecology can be understood as principles and guidelines "for the transition to sustainable food and agriculture systems" (FAO, 2018). Key ways in which agroecology differs from industrial agriculture are taking the nutrient cycle into account and reducing the dependency on external inputs, strengthening biodiversity to increase resilience and utilising multifunctionality of plants (Tomich et al., 2011). In short: ecological principles are applied to agriculture. Community, knowledge sharing, multifunctionality, the protection of the natural environment and biodiversity are some of the key goals of agroecological food production[3] (Wezel et al., 2020). Agroecology designates a concept for agriculture, a research field as well as a social movement (Ferguson & Lovell, 2014; Wezel et al., 2020). It can be a way to exit the vicious cycle of industrial food production leading to land degradation, biodiversity loss and climate change and climate change in turn impacting food production (IPCC, 2019; McKay &Veltmeyer, 2021; Springmann et al., 2018). Agroecology represents a mitigation as well as an adaptation strategy in the food system, also integrating the social component of food production. A transformation and a fundamental change of practice are necessary, to prioritise the well-being of the natural environment and humans, addressing the social and environmental components of sustainability (Fleurbaey et al., 2014; Lenton et al., 2019; Loorbach&Rotmans, 2006). Small-scale farms utilising these principles contribute to food sovereignty as they benefit the community and increase local food security by growing produce in resilient, ecological ways (Altieri, 2009; Patel, 2009).By not complying to degrading methods of industrial food production with a focus on exports and revenues local community and nature are strengthened.

1.3. SES and transformative adaptation

FFs are human created, their products and services are intended for human use. They have thus a strong social component in addition to the ecological. To account for the interconnectedness, the estate Zuylestein, including the *Sterrenbos*, can be described as a small social-ecological system (SES) (Salgueiro-Otero et al., 2022). SESs can be thought of as a network in which different components are linked as they affect each other (Janssen et al., 2006). Interdisciplinary methodologies are used to explore these systems.The SES perspective can show opportunities for a transformation towards sustainability. Climate pressures will continue to affect the site which makes climate adaptation a crucial aspect to consider for the FF. Salgueiro-Otero et al. (2022), when looking at climate adaptation, suggest that transformation in SESs can be necessary if small adaptations are not enough.The destroyed forest site will not be restored to its previous state but transformed to a FF, fundamentally changing the use of the area. The goal is to address and diminish the underlying factors that make the system vulnerable to the impacts of climate change. Thisshift can be called "transformative adaptation" (Fedele et al., 2019, p. 116).

1.4. Transdisciplinarity

Particularly for FFs, the specific local context is crucial to create a suitable and sustainable design (Albrecht & Wiek, 2021b). Björklund et al. (2019) found the success of their twelve established experimental FFs in Sweden to mainly depend on how well the social-ecological context was evaluated and considered. Including the social dimension of the SES requires the engagement and knowledge co-production with stakeholders in this case particularly the landowner as the main decision-maker(Vos et al., 2021). This relates back to the principle of co-creation in agroecology (FAO, 2018). Also, to understand the ecological dimension, FF practitionersoffer insights into the FF practice that

[3]The thirteen principles by Wezel et al. (2020) are: recycling; input reduction; soil health; animal health; biodiversity; synergy; economic diversification; co-creation of knowledge; social values and diets; fairness; connectivity; land and natural resource governance; participation.

cannot (yet) be taken from literature. Through a continuous exchange and integration of knowledge between the researcher and real-world actors, this research became collaborative and context-specific solutions for a transformative adaptation were developed (Horcea-Milcu et al., 2022; Lang et al., 2012). Thus, a transdisciplinary research approachwas required, which, as summarised by Brandt et al. (2013, p. 1), "*includes multiple scientific disciplines (interdisciplinarity) focusing on shared problems and the active input of practitioners from outside academia*".

1.5. Knowledge gap

In short to work towards a successful FF project at Zuylestein three components needed investigation. Firstly, FFprojects are limited by the ecological conditions. Factors such as soil quality, available water, and the local climate, including the climate change pressures and the surrounding ecosystem affect what plants can and willthrive in the area (Crawford, 2016; Jacke & Toensmeier, 2005b). This limits potential food production, environmental services, socio-cultural services, and income opportunities.Addressing the knowledge gap of ecological conditions set the baseline of what a FF can look like and achieve.Secondly, benefits, services and income opportunities can vary strongly depending on the design for the FFin the context of a SES. Further,trade-offs exist between services.To be able to plan and make decisions, the knowledge gap of what benefits, services and income streams are possibleat Zuylestein and how these could be achieved needed to befilled.Thirdly, evaluating the landowner's preferences and priorities was crucial, especially in cases where two services excluded each other. The capacities of the landownerregarding development and long-term management also influence what was realistic and was an important aspect of the preferences and priorities.These knowledge gaps address *system, target* and *transformation knowledge*, crucial in transdisciplinary processes for transformations towards sustainability (Lang et al., 2012). These are explained below.Additionally, the scientific knowledge gap of climate adaptive and sustainable design principles for FFs in temperate regions, especially considering economic opportunities, needed addressing. Further, the knowledge gap of how a social-ecological transdisciplinary approach contributes to the enabling of a transformative adaptation in form of a FFwas addressed.

1.6. Research aim

In this thesis, sustainable design principles for a FF in the SES of the Zuylestein estate were developed in a transdisciplinary process. The aim was to therewith aid a transformative adaptation with ideally long-lasting positive effects for the estate, the landowner, the community, and nature around. This was done by considering both social and ecological factors and their interplay, to develop a realistic plan and a long-term vision. Constraints and needs of the SES informed a favoured design. The transdisciplinary methods considered the primary viewpoints and objectives of the key parties involved, thus the social side. A focus was put on the ecological side of the project since this is the basis to the provision of any FF services. This is highlighted by the starting point of the project being the destruction of the local ecosystem because it was not adapted to climate change effects and theclimate vulnerability of all land types in the Heuvelrug.To add to the scientific literature on FF, general sustainable design principles for climate adaptive FFs were abstracted and the transdisciplinary method reflected. The following questions summarise the research aim and address the knowledge gaps:

RQ: What are sustainable design principles for a climate adaptive food forest in the social-ecological system of the Zuylestein estate within the Utrechtse Heuvelrug National Park?

SQ1: What is thesocial-ecologicalcontext of the site at Zuylestein?

SQ2: What are the potentialproductional, environmental and social-cultural services and functions a food forest can provide in the rural and temperate context of the Zuylestein estate?

SQ3: What are promising business models in terms of revenue generation and risk distribution?

SQ4: What are key stakeholder's desired scenarios for a Food Forest at Zuylestein and what are potential design pathways to reach those scenarios?

SQ1 covers the necessary evaluation of the SES, its constraintsbut also needs and opportunities. SQ2 resulted in an overview of what FFs can achieve already considering the estates situation. Insight into business opportunitiesare includedwith SQ3. The key stakeholder's perspectivesand goals wereconsideredthroughout the process and their input guided the research focus (SQ4). This ensured real-world applicability.

The following chapter contains a practical definition andgeneral principles of FFs in rural and temperate regions andan overview of FFs in the Netherlands.Typologies of FFs are explored to showthe multitude of factors and choices that make each FF unique.As the focus of the thesis is the ecological component, a theory section on the influence of local conditions such as soil texture, organic matter content and pH is explained to contextualise the results. In the methods, the approach of this transdisciplinary project is explained followed by data collection and analysis. The results are presented after, following the SQ order and then discussed.

2. Background

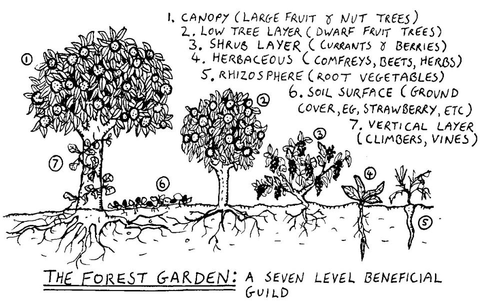
2.1. Food forests

FFs, also named forest gardens, are a specific form of agroforestry. This isan approach to agriculture where trees and shrubs are intentionally integrated with plants for food production or pasture systems (Coleman et al., 2022; FAO, 2018; Hart, 1996; Jose et al., 2022; Munsell et al., 2022). Food forestry at small scale has been practised by Indigenous communities for many millennia (Ford & Nigh, 2009; Torralba et al., 2016). In recent decades, FFs have become more wide spread in temperate regions as an alternative to monocultural food production (Albrecht & Wiek, 2021b; Björklund et al., 2019; Jose et al., 2022; Torralba et al., 2016). Perennial plants, vegetables, legumes, herbs and nuts are grown. These mainly provide food but also medicine or building materials (Albrecht & Wiek, 2021a). In the Netherlands, many FFs exist, starting in 2009 with *Voedselbos Ketelbroek.* This was inspired by Martin Crawford who started his forest garden in the UK in 1994 (Albrecht & Wiek, 2021b; Crawford, 2016).From 2018 until 2021 the project *GreendealVoedselbossen* was active in the Netherlands, bringing together participants from government organizations, non-profits, researchers, and professionals which shows the national interest in alternative forms of agriculture. The afterwards created Stichting Voedselbosbouw (2023a) provides an overview of 78 FF projects in the Netherlands on their website.

The guiding principle of FFs is permaculture. The term was defined in the 1970s as an "integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man" (Holmgren, 2012, p. 3). FFs are commonly structured into seven layers. They start at the top with the canopy layer and reach until the root layer as depicted in Figure 1. Enabled by this structure, a FF includes mainly perennial crops using sunlight, water, and nutrients efficiently (Jacke & Toensmeier, 2005a; Nytofte & Henriksen, 2019; Wiersum, 2004). For temperate regions, Albrecht and Wiek's FF definition is most suitable: "a coherent, multistrata space with a majority of edible perennial plants, a minimum size of 1 acre (~0.5 ha), and 10% canopy cover to provide forest-like ecosystem services and significant food production." (2021b, p.

Figure 4

The 7 layers of a food forest by Graham Burnet (via Wikimedia Commons)



;

184). Stichting Voedselbosbouw describes FFs to be human designed, self-fertile, with high biodiversity that supplies humans with food, mainly from crown perennial trees, in addition to high soil quality and soil life (Buiter, 2022).

2.2. General ecologicalfood forest principles

FFs provision humans in ways that promote regeneration, suit the local conditions, and withstand challenges like environmental and biological pressures (Wartman et al., 2018). They make use of natural processes that occur in forests. Most importantly, the soil of FFs stays undisturbed. Without tilling and fertilisation, the soil in FFs it can regenerate and accumulate soil organic matter (SOM) which has long lasting benefits for the area (Park et al., 2018). The soil can then host a functioning net of mycorrhizawhich distribute nutrients and water (Crawford, 2016). This leads on the one hand to a closed nutrient cycle and therefore self-fertility. This is enhanced by focussing on perennial species and leaving biomass in the system to decompose and release nutrients (Belcher et al., 2005).Tree roots can access and share nutrients from deep in the ground, benefitting the whole system (Lehmann et al., 2019).On the other hand, the undisturbed soils in combination with perennial species support an enhanced water cycle. SOM increases soil water holding capacity and thus water availability to plant roots (Lal, 2020).Transpiring and evaporating water is further kept in the system by the canopy which also intercepts precipitation, reducing soil erosion (Jacke & Toensmeier, 2005b). Ground cover vegetation increases surface roughness, slows down water on the surfaceand reduces evaporation. In combination with improved infiltration capacity through SOM, the water infiltrates rather than running off (Collentine & Futter, 2018). FFs are highly productive systems. Fertile and moist soils facilitate healthy and fast plant growth (Dawson & Smith, 2007).A micro-climate is created as, the canopy leads to more warmth being kept in the system in winter by insulating and cooling in summer by shading. Trees and hedges buffer against strong and cold winds (Crawford, 2016). Fostered beneficial relationships between plants enhance growth following permaculture ideals. Plants that repel pests, fix nitrogen into the ground are included to benefit the whole system(Schafer et al., 2019). High productivity is further ensured by exploiting the different niches offered through the multistrata concept (Björklund et al., 2019). This created biodiversity also offers diverse habitats for pollinators and other animals. Regarding FF development, guided succession is an important principle. Succession in natural ecosystems describes the development or recovery of the local flora and fauna after disturbance such as forest fires (Young, 2017). This is mimicked when a site is developed into a FF, e.g. by integrating plants that utilise the amount of light available before trees grow large enough to provide shade. This enables productivity and biodiversity while the system develops (Breidenbach et al., 2017). Succession is guided through planting, watering preferred plants, weeding and mulching (Park et al., 2018).

2.3. Uniqueness and purposes

Apart from the main principles,in practise FFs are unique andsuited the local conditions (Pilgrim et al., 2018). Theyhave different priorities, mainly determined by the landowner's or manager's needs and interests. Stichting Voedselbosbouw differentiates FFs by the main service they provide (Voedseluit het bos, 2022c). In*Experience*FFs,encounters with nature, a space for gatherings and activitiesare possible, which means they must be diverse and interesting.*Biodiversity* FFs mainly support and increase local biodiversity.Plant choices and layout need to be suited for this and disturbance through visitors reduced. *Gastronomy* FFs focus on supplying restaurants with interesting produce that is in demand. Lastly, *Production*FFs are meant to provide wood and food at a large scale. The last two types need to be easily accessible for harvesting while the plant choices differ according to the business model. In their master thesis on FF business models in the Netherlands, van Gent(2019) developed four archetypes after the exploration of 14 FFs in the Netherlands. FFs can be publicly accessible or private. The latter enabling higher production as the system stays undisturbed. Two FF design types can be discerned in practise. Romantic FFs are characterized by high biodiversity with many edible plants for foraging.The rational FFhas well-defined paths and less species variety. The romantic-public*Recreational* FF archetype serves the community as a space for recreation, workshops, community building and nature connection. These usually depend on volunteers and funding from the outside. Public-rational*Communal*FFs provide community benefits and produce food. Therefore, they can become economically independent. Private-romantic *Experimental*FFs include many species where research and experiments are conducted. *Productional*FFs, being private-rational, focus on food and other products and try to find costumers for these fast. FFs further differ as they are in different succession stages depending on age and starting conditions, have different sizes and local infrastructure.

2.4. Ecology theory

Water availability is the most important boundary and determinator of terrestrial plant growth and a main concern at Zuylestein due to past, and most likely future, water stress (Chapin et al., 2011). The quality of the soil can be defined as: "The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health." (Doran & Parkin, 1994, p. 7). This is thus crucial to consider for the FF project. This section explains the processes underlying the described general principles. The commonly used differentiation of soil health components into physical, biological and chemical is followed(Bünemann et al., 2018).

2.4.1. Physical

The physical properties of the soil are of interest due to their influence on how much water is available to plants. Plant available water in the primary root zone up to 20 cm is crucial especially in the beginning years of the FF (Lerch, 1972). Deep rooting perennials do not reach deeper in the beginning stages either. Deeper, the capillary water layer from the groundwater table can become a water source. Soil texture including porosity, compaction and infiltration capacity are often considered indicators as they affect the soils water holding capacity(Bünemann et al., 2018; Sabareeshwari et al., 2018).How much of the water is retained in the soil depends on how porous and compacted the soil is. Space between ground particles are relevant as very dense grounds do not provide space for water accumulation which is available to plants (Allen et al., 2011). In porous grounds, such as sand, water quickly drains downward (Lerch, 1972). Present organic matter increases water holding capacity(Lal, 2020).

2.4.2. Biological

The biological or biogeochemical component includes the carbon to nitrogen ratio and SOM, which give an important indication of nutrient cycling as well as water holding capacity(Allen et al., 2011; Ehrenfeld et al., 2005). Carbon is crucial for chemical and biological processes in the soil and the release of nutrients as it feeds soil organisms. Soil organic carbon (SOC) in particular is the basis for water holding capacity, stability and nutrient cycling (Margesin& Schinner, 2005; Runhaar et al., 2010; Trivedi et al., 2018). Managing SOC properly is crucial for sustainable agriculture whilealso storing carbon(Allen et al., 2011; Raza et al., 2021).The CN ratio is measure of the biodegradability of organic substances and is thus an important insight into soil fertility (Lou et al., 2012).Biodegradation results in SOM plus sets nutrients free (Allen et al., 2011). For microorganisms to process the litter most efficiently, a ratio of 24:1 is ideal as this allows them to maintain their inherent ratio of 8:1 as they process the carbon and respirate (USDA, 2011). If the ratio is too high microbes immobilise nitrogen, making it unavailable to plants.

SOM denotes theportion of the soil made up of plant, animal, and microbial remains at various decomposition stages, plus durable humus (Nelson & Sommers, 1996). It is comprised of roughly 58% SOC (Trivedi et al., 2018). Water can be retained better and made available to vegetation if SOM is high (Wosten et al., 2019). Increasing the amount of organic matter in the soil leads to improved soil structure, resulting in enhanced infiltration capacity and reduced surface runoff. This has apositive impact on water retention and has the potential to decrease peak discharges (Wosten et al., 2019). To give an indication of the impact of SOM content, according to Wosten et al. (2019), if the ground is mainly composed of sand and SOM below 1%, every percent increase will lead to 3-4 mm of more water that can be used by plants in the root zone. If the SOM content is already above 3% every percental increase leads to 1mm more available water. SOM also makes the ground softer, which facilitates root growth (ibid.).

2.4.3. Chemical

Chemical properties such as nutrient availabilityand the pH impact conditions for vegetation (Allen et al., 2011; Bünemann et al., 2018). Nitrogen and Phosphorus are the key limiting nutrients for plant growth and yield (Guignard et al., 2017). Phosphorus is a finite resource that in a FF cannot be influenced[4].Nitrogen however can be fixed by plants from the air, especially by legumes. It is then also available to other plants and organisms. pH designates the concentration of hydrons (H^+) with high concentration meaning an acidic environment. The pH of the soil is a crucial factor for soil health and has many effects which are scientifically still highly contested(Hartemink& Barrow, 2023). Important here is, that the acidification of soilsleads to a dissolution of carbonates[5], a buffering mechanism as H^+ is bound (Raza et al., 2021). Soil inorganic carbon (SIC) mainly consists of carbonate minerals (Nelson & Sommers, 1996). Jin et al. (2018) found a strong positive correlation between pH and SIC content in soils. Precipitation further leads to a dissolution of carbonates, decreasing SIC. Below a pH of 6.5 carbonates are no longer present and other buffering mechanisms occur, which are however much less efficient in absorbing hydrons. Acidification processesaccelerate in higher temperatures, thus through climate change (Raza et al., 2021). In acidic soils (below 5.5), most important nutrients,such as nitrogen are less available to plants. Phosphorus is an exception which is soluble and then easier available to plants (Penn &Camberato, 2019).

2.4.4. Groundwater

As well as the soil water holding capacity, maximum and minimum groundwater levels affect the local vegetation growth and which species thrive (Runhaar et al., 2010). The most direct influence is the moisture provision to plant roots from the capillary layer above the groundwater layer if this is not too low(Brolsma &Bierkens, 2007).The more porous the ground, the lower capillary capacity becomes. In coarse sand the capillary rise is up to 50 cm, in fine and loamy sand it can be more than 100cm (Lerch, 1972; Runhaar et al., 2010). Roots will not grow into the groundwater due to the anaerobic conditions there (Lerch, 1972). Particularly in fast draining,sandy soils groundwater is a very important water source, particularly in dry summers (Runhaar et al., 2010).

3. Methods

3.1. Research framework

The following chapter gives a theoretical overview of the chosen transdisciplinary approach and describes the types of necessary knowledges generated to contextualise the research approach. Transdisciplinary projects are commonly structured into three phases (Lang et al., 2012). First the sustainability problem is identified and structured into a subject of research. This step includes building relationships with the stakeholders and co-developing a research interest(seeProject establishment). The second phase of problem analysis denotes the “co-creation of solution-oriented and transferable knowledge” (Brandt et al., 2013, p. 2). In the third phase, the gained knowledge is integrated and condensed addressing the sustainability problem, which in this case means informing how a transformative adaptation can be facilitated at the estate. Phase one was the basis for this research project and thus underlies this piece. The second and third phase are what this thesis contains explicitly.

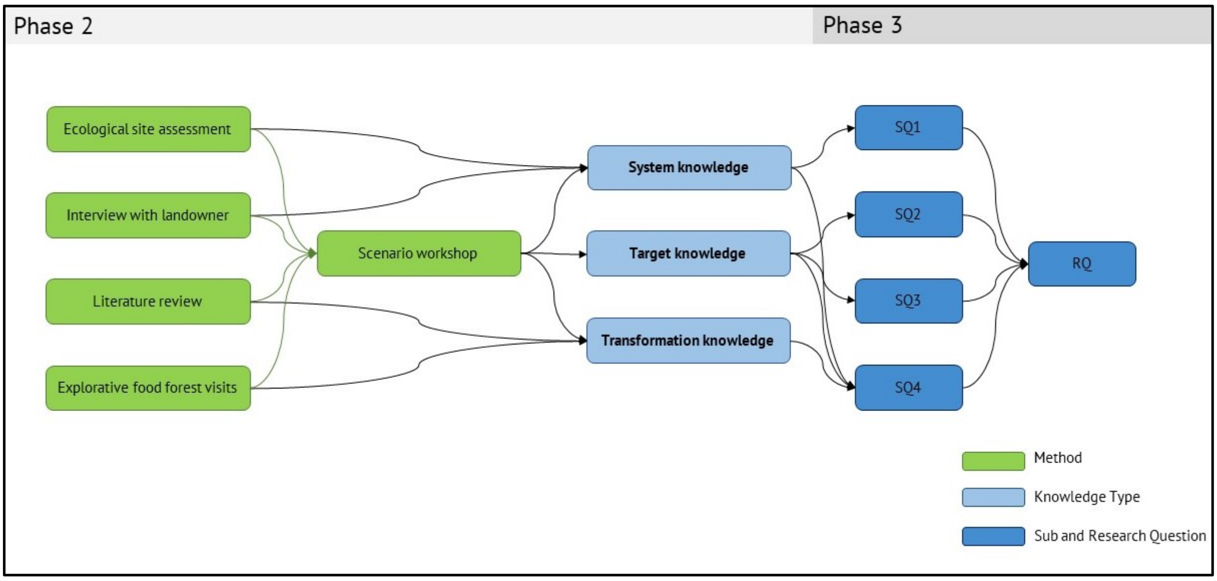
To systematically approach the second phase and to make transdisciplinary research more comparable through a shared language, *system*, *target* and *transformation knowledge*were discerned and structure

[4]In contrast to industrialagriculture, whereminedphosphateis used asfertiliser(Guignard et al., 2017)
[5]ForthechemicalreactioncompareFigure 3 in Raza et al. (2021)

the following chapters (Brandt et al., 2013). *System knowledge* designates observations of the SES of interest to comprehend the environmental factors and actors involved.This knowledge enables the conceptual co-development of a target state that addresses the sustainability problem and thus constitutes the *target knowledge*. *Transformation knowledge* designates the exploration of what is necessary to enable and aid the transformative adaptation in the form of a FF development. Uncertainties and their associated risks and potentials must be considered to maintain feasibility. These knowledge types are then reintegrated and applied to the scientific and real-world context in the third phase (ibid.; Horcea-Milcu et al., 2022). To gain *system knowledge***,** the ecological context was assessed by investigating mainlythe soil conditions including pH and water availability as well as the local weather including climate change (SQ1). The social context was mainly integrated in an explorative way through exchange with the landowner (SQ1, part of SQ4). For acquiring *target knowledge*, possibilities of FFs were investigated, the results from the previous steps integrated and contextualised with literature (SQ2 and SQ3). This was further informed through explorative visits to established FFs in the Netherlands. The landowner'slong-term vision and the development priorities were systematically assessed in a scenario workshop also resulting in *target* as well *transformational knowledge* (part of SQ4). Figure 5 summarises this approach.

Figure 5

Research framework



Note. The three key knowledge types identified by Lang to bring about social ecological transformation provide the core of the research framework. The methods applied to derive these different knowledge types are indicated in green and each knowledge contributes to answering one or more of the RQs as indicated by the arrows.

Multiple methods were applied to acquire the different knowledge types. This is common in transdisciplinary projects, especially in application to SESs (Brandt et al., 2013; Janssen et al., 2006). In addition to the main relations represented in Figure 5continuous exchange with the landowner, the FF visits and literature research shaped the process as more aspects and priorities were discovered. System knowledge further is the basis to gain target knowledge as it discloses constraints of the target system. An iterative process and continuous flexibility were crucial (Brandt et al., 2013; Norström et al., 2020).Addressing the sub questions by considering the different knowledge types lead to design principles that were specifically suited to the landowners transformative adaptation goal. Further, transferable design principles were abstracted to add to the scientific knowledge on agroecological projects and climate adaptive FFs in temperate regions. The following sub-chapters describe the methods in detail.

3.2. Data collection and analysis

3.2.1. Project establishment

After meeting the landowner for the first time and hearing about the idea to develop a FF at Zuylestein, the estate was visited multiple times. In conversations with the landowner a research interest was jointly developed. This was written down in multiple proposals and shared with them.

3.2.2. Ecological site assessment

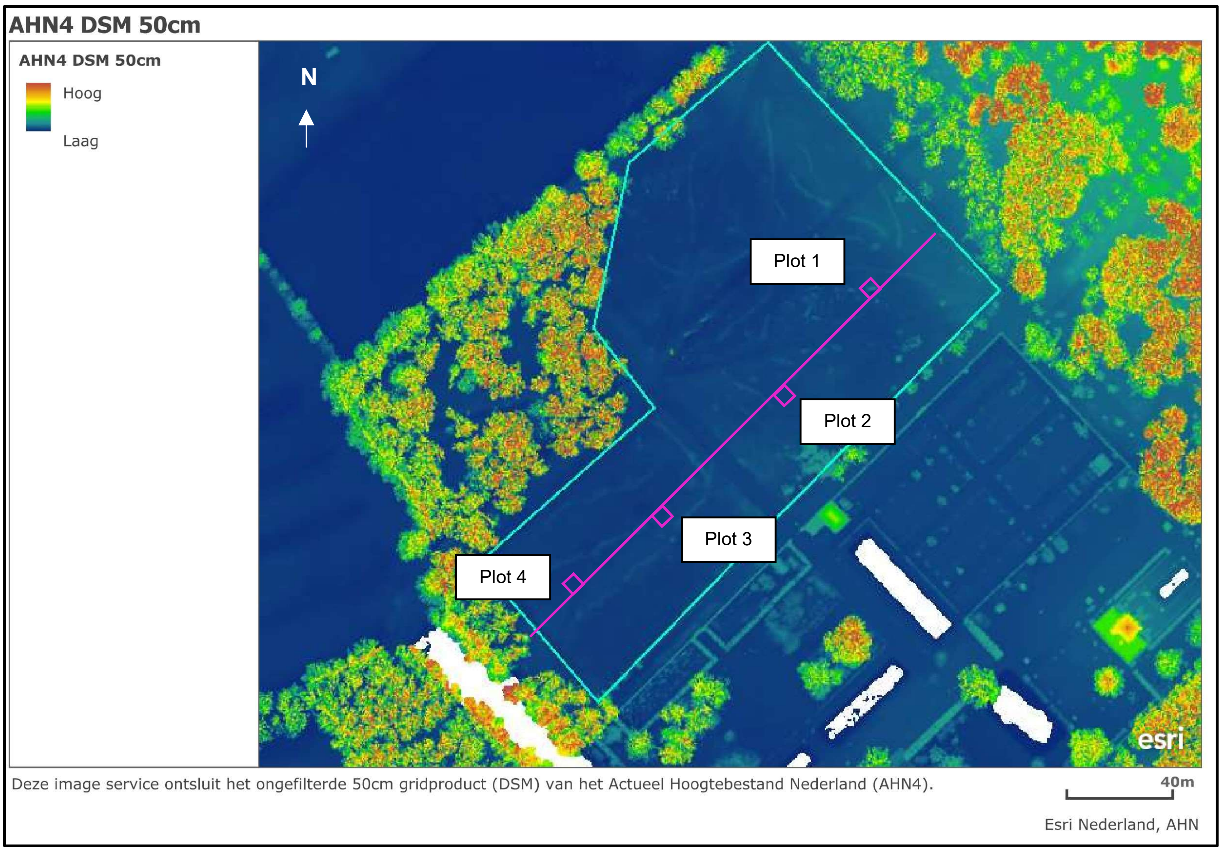
Like natural ecosystems, FFs should be adapted to the site's conditions.Only FF relevant elements that were mentioned in scientific literature or handbook resources were considered. Further, only data that could be compared to other available data points or available classification and interpretation on what effects thesecan have, were evaluated. Lastly, a limiting factor was lab access which prohibited e.g., the analysis of the microorganisms present in the soil. Biodiversityis not a limiting factor to FF developmentand was not included here (Jacke & Toensmeier, 2005a). Instead, it was assessed on the side using earthwatch methods and entered in their database. Being an easily replicable method, it enables future regular assessments to track progress as this is an important goal for the landowner and might be important for future income opportunities.

Sample selection

For the field methods, a stratified sampling approach was chosen to explore the length of the area, since not much information on hydrology and soil texture was available beforehand. In this way, the area close to the remaining forest (see Figure 6, plot 1) but also close to the water catchment (plot 4) were included and differences could be assessed. Further, the site in this direction has a height difference of circa 5 meters and potential effects of this were therefore included. Along the transect, in 4 locations plots of 5x5m were measured in which samples were taken.Depending on the accessibility due to vegetation and leftover wood, the plots were created on the left or right side of the transect. The field work was conducted on the 28th of April 2023 in rainy conditions.

Figure 6

Sample plots at the Sterrenbos site



Note. Plots and transect in pink in ArcGIS Image using AHN4 Digital surface map with 50cm resolution showing the height of all elements in relation to sea level.

Soil fertility: C & N assessment

To analyse Carbon and Nitrogen content,10 samples were taken in a random zig zag patternin each plot. This was done for 0-10cm and again for 10-30cm with an auger. Most organic matter is found in the topsoil (30cm) of the ground, which is also the main rooting zone. According to the IPCC standards and FAO guidelines 0-30cm depth are appropriate (Conijn&Lesschen, 2015; FAO, 2019). Lower SOC is less subject to change und thus not as likely to increase through management practices (FAO, 2019). The samples were combined per depth and plot to form a bulk sample, thus avoiding the possibility of an extreme value result (FAO, 2019). Of both composites some soil was taken for lab analysis. The soil was dried in a Binder ED53 and ground in a Herzog HP-MA to increase homogeneity of the sample (Nelson & Sommers, 1996).A CN ratio analysis was done in the stable isotope lab of the UU using the Thermo Scientific Elemental AnalyserIsolink CN with the common Dumas combustion configuration.

Soil organic matter

In acidic soils SIC can be extremely low. For simplicity thus total carbon here is assumed to be equal to SOC. By multiplying this with the van Bemmelen conversion factor 1.724 the value for SOM was derived. This is an approximation but delivers a reasonable result (Heaton et al., 2016)

Soil pH, texture, compaction and infiltration

From the 0-10 cm composite a small amount was taken for the pH assessment from each plot. A commercially available pH test kit was used to estimate the soil pH level. The soil texture assessment was conducted through applying a methodology used and developed by earthwatch for tiny forests (earthwatch Europe, 2023b). The tool was made to be easy to use for people including school children. This simplicity is conducive for long-term monitoring and is focussed on forest ecosystems, enabling comparison. The soil texture was assessed by shaping a handful of the composites at each plot, testing how well they could be formedwithout falling apart using the earthwatch resources for comparison. Texture indicates the proportion of the typical particles clay, silt or sand which is an important indicator for how fast the soil drains (Kettler et al., 2001).For further detailed information, 36 m deep borehole data from DINOloket from 1988 was considered (de Vries et al., 2017; DINOloket, 2023). The location wasat the southwest end of the *Sterrenbos* (compare Figure 12 in Appendix F). Soil compaction was evaluated by using a penetrometer pushed into the soil at each plot (expressed in kg/cm2) (earthwatch Europe, 2023b). Compaction and soil texture together indicate soil permeability for roots and water(Sabareeshwari et al., 2018). Water infiltration was then evaluated through an earthwatch method by pouring 450 ml water in a 30 cm diameter tube planted in the soil and measuring the time necessary for infiltration at each plot.

Groundwater
The groundwater table was investigatedutilising a permanently installed measure close to the site. Next to the water in the soil, the groundwater can be an important water source for plants (Runhaar et al., 2010). The data of this station was sourced from DINOloket (2023).

3.2.3. Interviews

To grasp the social context of the project, a semi-structure interview with the landownerwas conducted at the end of April 2023 (Adams, 2015). This had the purpose to gain insights into how the estate functions, the goals and ideas for its future and its network as well as where and how products are distributed. Due to the time constraints of the landowner only one interview, next to casual exchange, could be conducted.

3.2.4. Literature review

FFs are scientifically still understudied due to their heterogeneity,complexity and novelty (Björklund et al., 2019).However, student project reports and thesis projects provide valuable insights on FF projects. Many case studies are systematically described in books and articles but have not gone through the peer-review cycle (Wartman et al., 2018). Handbooks by experts and FF owners further offer guidance and knowledge on FF ecology and practical development (Albrecht & Wiek, 2021b). This available grey literature andscientific publications were reviewed focussing on FFs in temperate rural regions, their benefits and services and what these depended on. Furthermore, literatureon business opportunities was reviewed, which is scarce[6]. Due to the dependence on the site conditions, if a point was related to a specific FF, their basic characteristics are included in the footnotes.Research on other forms of intercropping, permaculture and agroforestry systems was not considered. As much as possible the focus was put on what was expected to be applicable for Zuylestein.

3.2.5. Ethnographic food forest visits

To gain insights into existing FFs the qualitative, participatory research method of ethnography was used. Observation and interviews wereconducted in natural circumstances to get an in-depth understanding of the situation and investigating local actors' perspectives (Nurani, 2008; Queirós et al., 2017). Sangaramoorthy and Kroeger (2020) were followed. They designate a *rapid ethnographic as-*

[6]The business component of FFs is currently being researched in the scientific research project "Van waardenaar geld" as part of the TKI research project "'Wetenschappelijkebodemvormingonder de voedselbosbouw", a cooperation between Wageningen University & Research (WUR), NederlandsInstituut voor Ecologie (NIOO-KNAW), the Centrum voor Bodemecologie (CSE), Stichting Voedselbosbouw, thehogescholen HAS green academy and Aeres Almere, and some regions, provinces and water boards, https://www.voedselbosbouw.org/nieuws/voedselbossen-van-waarde-naar-geld/

sessment. This aims at providing fast, necessary knowledge for action by focussing the field work well and assessing the results from the perspective of multiple disciplines and in the context of other findings. By using this approach, exploring multiple FFs was possible, which avoids the inherent problem of ethnography to only produce knowledge about one specific context. Participant observation was done by participating as much as possible in the FF. During the participation, casual interviews were conducted to further explore aspects of interest (Nurani, 2008). The ways of participation differed between the FFs and depended on the caretaker's needs. Using the *GreendealVoedselbossen*overview rural FF projects were contacted via e-mail. The deciding factor foravisit was if the caretakers were enthusiastic about it. Additionally, they had to be reachable from Utrecht without a car. Lastly, they needed to represent different ages, sizes, and purposes to give an insight into the various types described above. At FF *Binnenbos*[7]a whole day was spent helping the caretaker with planting activities and talking about the project. At *Den Food Bosch*[8] a public was joined. At FF *Haarzuilens*[9], a harvesting, organised monthly for the self-harvesting subscribers of the project was joined. After all activities conversations were had about their adaptations to the site conditions, to climate change, the benefits, and services of their projects and successful or planned business models. In this way, the knowledge gaps were addressed also from a non-academic side, relating back to the principles of agroecology and transdisciplinary working.The notes taken (see Appendix D) were analysed systematically afterwards to extract benefits and services of FFs and transferable knowledge to the Zuylestein context. The experiencescontinually supported reflectivity in the transdisciplinary process (Brandt et al., 2013). The consent form can be found in Appendix E.

3.2.6. Scenario Workshop

AsFFs are location dependent and unique, no general design or framework could be applied to Zuylestein. Instead, starting from the SES context, of which the landowner has the best knowledge, in combination with their priorities a vision for a FF needed to be created. For this purpose, a workshop with the landowner and the estate's advisor[10] was held towards the end of the project when the results of the previously described methods had been collected.The role of the scientist was to be a source of information and knowledge that can be activated (Henrichs et al., 2010).Here, additionally the role of discussion facilitator was taken on. Gained knowledge was actively applied if trade-offs between priorities or goals were noticed.

The "scenario-axes technique" (van Vliet & Kok, 2013, p. 3) provided a frame to systematically approach alternative future scenarios. Here, different FF typologies were mapped onto scenario axes. The workshop participants set priorities and mapped the FF on the axes. In this way a focus could be put on "key unknowns" (Pereira et al., 2018, p. 4).Building on this, a desired long-term normative scenario of the FF in 30 years was jointly developed. A scenario is an outline of a realistic future which takes into account external and internal drivers and uncertainties and shows their effects (Henrichs et al., 2010; van Vliet & Kok, 2013).The participants were motivated to create an engaging story for the FF. Motivational and ambitious narratives play pivotal roles in facilitating the transition towards sustainability (Pereira et al., 2018).In contrast to exploratory scenarios the focus did not lie on evaluating what could be possible but on what was wanted (van Vliet & Kok, 2013). Thereafter, with an interactivebackcasting approach, important milestones, hurdles, and necessary interventions were identified. To help the discussion, guiding questions were asked for each time step. The approach, as

[7]Binnenbos: ca. 4 ha, Langbroek (Heuvelrug), Started in November 2021, mostly clay ground(K. Biesemans-Hoogewijs, personal communication, 29 March 2023)

[8] Den food bosch: 0,8 ha, Sint Michielgestel near s'Hertogenbosch, since winter 2017/18, design follows ErnstGötsch's concept of syntropic farming(M. Lokin & M. Ramaker, personal communication, 1 April 2023)

[9]Haarzuilens, 5 ha, since 2015, south-west of Utrecht, heavy clay ground(J. Degenaar & M. Schrama, personal communication, 20 May 2023)

[10] The landowner was given the choice to invite stakeholders they deemed useful to participate in this workshop

discussed in van de Kerkhof (2006), enables the derivation of a way to a desired future instead of planning for a realistic one which might come short to what would be possible. It further facilitates a productive discussion as in general thinking about the future includes an overwhelming amount of uncertainties which are already limited through the scenario.The workshop enabled sharing knowledge gained on the different realisations of FFs and the associated benefits and trade-offs as well as the results of the ecological site analysis with the stakeholders. It aimed to make the FF vision more tangible, narrow down realistic goals and encourage decision-making (Henrichs et al., 2010).

4. Results

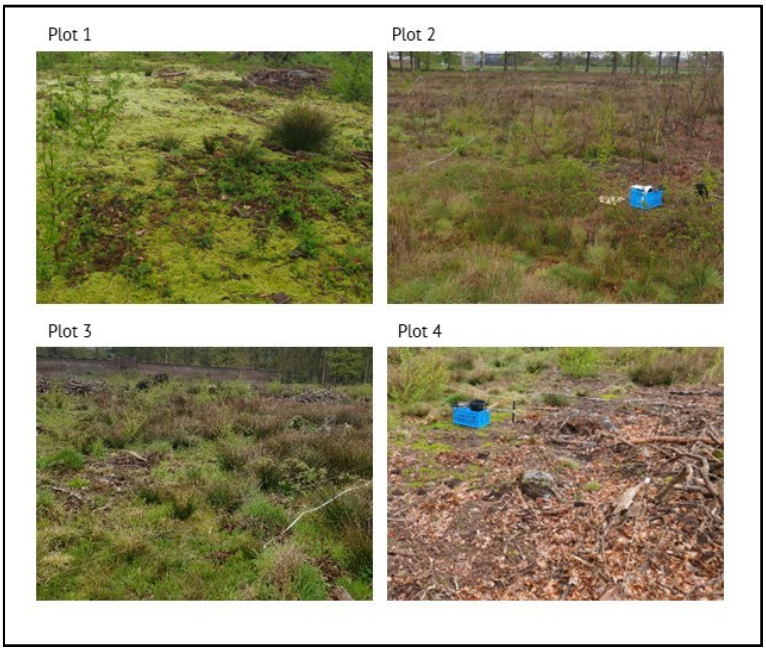
4.1. The ecological context of the site

4.1.1. Soil Fertility: Carbon, nitrogenand SOM

The vegetation differed in all locations, starting with moss cover in Plot 1, bare soil with bushes growing in Plot 2, Plot 3 with sturdy grass and plot 4mostly bare as shown in the images below.

Figure 7

Plot fotos with local vegetation, taken on 28th April 2023



The components for soil fertility are represented inTable 1per plot and for each depth. N%and C% values resulted directly from the CN analysis. The ratio was calculated by multiplying both values with the N-Coefficient to result in N=1. As the pH results were very acidic, one test was also done with regular potting soil to test the pH measuring kit. As that sample turned out blue (neutral pH), the kit seemed to work properly.

Table 1

Soil analysis results for soil fertility indicators, including the percentage of total carbon and nitrogen, the calculated CN ratio using the N-Coefficient, given per plot and per depth.

Sample	Location & depth	%N	%C=SOC	N Coefficient	C:N Ratio		pH result and photo of test sample	
					C	N		
1.1	Plot 1: 0-10 cm	0.36	8.01	2.75	22.07	1	Ca. 4	
1.2	Plot 1: 10-30 cm	0.10	0.85	10.27	8.72	1		
2.1	Plot 2: 0-10 cm	0.45	9.75	2.21	21.54	1	Ca. 4	
2.2	Plot 2: 10-30 cm	0.20	3.42	5.04	17.24	1		
3.1	Plot 3: 0-10 cm	0.51	10.94	1.96	21.42	1	Ca. 4	
3.2	Plot 3: 10-30 cm	0.14	2.02	7.13	14.37	1		
4.1	Plot 4: 0-10 cm	0.30	6.85	3.30	22.62	1	Ca. 4	
4.2	Plot 4: 10-30 cm	0.08	0.47	11.85	5.53	1		

4.1.2. Water availability

Table 2 below presents the soil type found at the plots per depth.In all four plots the 0-10 cm depthwas loamy sand, meaning the handful of soil could be formed into a ball. Below (10-30 cm) this was not possible as only sand was found. Further, the infiltration time for 450 ml water and compaction measured is given for each plot. The proportion of SOM resulted from multiplying carbon contents from

Table *1* which are assumed to equal SOC with the van Bemmelen factor for each plot and depth.

Table 2

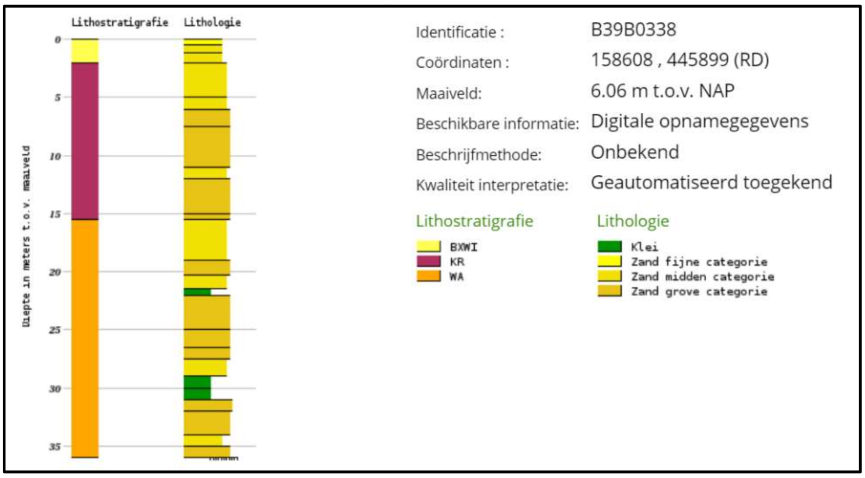
Soil analysis results for water availability indicator, including soil texture, SOM, infiltration time and compaction per plot and per depth.

Sample	Location & depth	Soil texture	%SOM (=SOC*1,724)	Infiltration time (in minutes)	Compaction (in kg/cm2)
1.1	Plot 1: 0-10 cm	Loamy sand	13.82	4:36	2.3
1.2	Plot 1: 10-30 cm	Sand	1.46		
2.1	Plot 2: 0-10 cm	Loamy sand	16.82	3:52	1.8
2.2	Plot 2: 10-30 cm	Sand	5.90		
3.1	Plot 3: 0-10 cm	Loamy sand	18.86	3:47	1.5
3.2	Plot 3: 10-30 cm	Sand	3.47		
4.1	Plot 4: 0-10 cm	Loamy sand	11.81	7:59	1.6
4.2	Plot 4: 10-30 cm	Sand	0.80		

The ground consists mostly of fine sand interchanged with coarse sand and clay layers at 21.5-22 meters and 29-31 meters deep. See the right column ("Lithologie") in Figure 8 below for details. With depth the sand becomes coarser.

Figure 8

Bore hole profile at Sterrnebos Zuylestein (DINOloket, 2023)



Note: Legend explanation for theleft column.Yellow:Formatie van Boxtel, Laagpakket van Wierden – meaning sand deposition from the last glacial period; Purple: Formatie van Kreftenheye – sand and gravel from Late Pleistocene and Early Holocene; Orange: Formatie van Waalre – sand and clay deposition from the Rhine in the Late Pliocene to the Early Pleistocene.[11]Legend explanation for right column. Green: clay; Light yellow: fine sand; Medium yellow: medium coarse sand; Dark yellow: coarse sand.

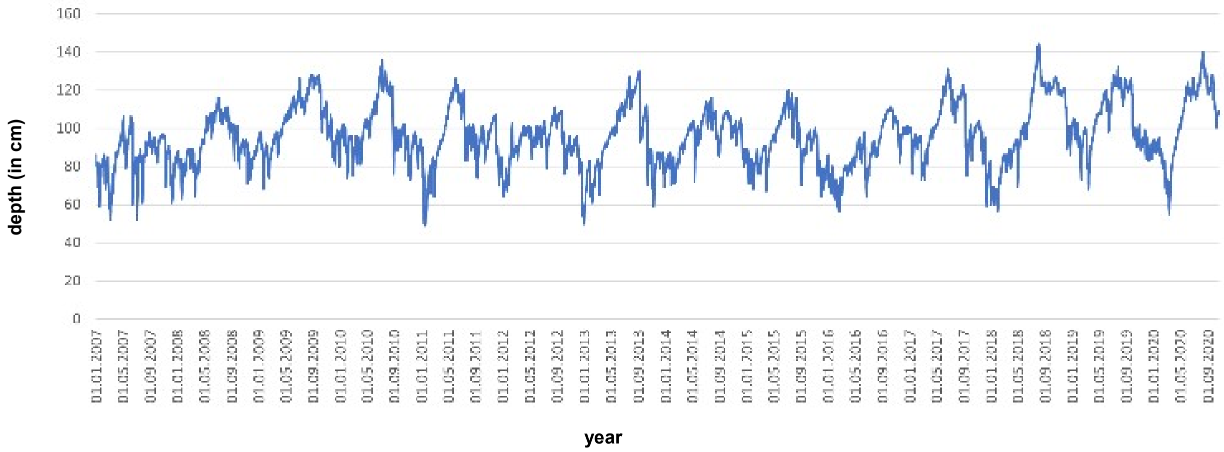
[11]Compare nomenclator: https://www.dinoloket.nl/stratigrafische-nomenclator/formatie-van-kreftenheye

4.1.3. Groundwater levels at Zuylestein

At the location in the southwest of the *Sterrenbos*, a filter was placed which has been measuring the groundwater levels since 1989 until October of 2020 (GDN, 2023). Due to data gaps, here the data from 2007 until 2020 was used (see Figure 9 below).

Figure 9

Depth of Groundwater level



Note. Y-axis indicates the depth meaning the distance in cm from the surface, 2007-2020(own representation) (GDN, 2023).

The minimum water level was recorded at 147 cm under the surface in August 2018[12]. The maximum of 52 cm deep underground was recorded in January 2011[13]. The median and average value lie close together at 98 and 99 cm depth respectively[14]. In general, the groundwater fluctuates in a pattern. It is highest at the end of winter (around March) and lowest at the end of summer (around September). This, as described above, is not due to less precipitation falling but due to more evapotranspiration which prevents groundwater recharge. The 10 and 90 percientel of groundwater measurements equal to 122 and 81 cm underground respectively.

4.2. The social context of the site

4.2.1. The estate and its network

There is already a variety of agricultural activities at the Zuylestein estate. Vegetables are grown, bread is made with locally grown cereal and meat from pigs which rotate on small areas in the forest and on the *Sterrenbos* site is produced. Products are distributed through the small shop on the estate on the weekends.The building includes a kitchen. In the vegetable garden they also have an area with herbs and flowers that customers are allowed to harvest themselves, which works very well. Zuylestein already delivers produce to six restaurants in the area, with another one in discussion. They are all higher-end restaurants with focus on local and seasonal produce.One of them has a green Michelin star. A cooperation exists with a voedsel collective[15] in Utrecht for vegetables. Volunteers are engaged in the food production process and general nature-management at the estate. The main decision maker

[12] This is sometimes expressed the other way around, counting from the NormaalAmsterdams Peil (NAP). The local surface level is 609 cm above NAP. The groundwater level corresponding to 147 cm under the surface is then 462 cm above NAP.

[13] 557 cm above NAP

[14] 511 and 510 cm above NAP

[15] Members subscribe to local farms and receive produce in a set rhythm (e.g. weekly), compare e.g. VoKo Utrecht

on the estate is the landowner whose family has owned the estate for many centuries (J. de Brauwere, personal communication, 28 April 2023).

4.2.2. The Sterrenbos as a Rijksmonument

The *Sterrenbos* used to be a hunting forest. Since the estate is registered as a historical landmark ("Rijksmonument"), the landowner cannot freely choose the use of the estate. The forested are that was destroyed needs to be reforested, creating a full canopy again. As an additional constraint, exclusively endemic species can be used. A FF could recreate the imagery of the hunting forest but harvesting would replace hunting (J. de Brauwere, personal communication, 28 April 2023). Previously the forest consisted mainly of beeches and oaks. These need to be replanted which is already in planning. Beeches will be planted along the star-formed paths. The destroyed area will be reforested with elm trees, linden, beech, oak, rowanberry, sweet chestnut, elder and hazelnut (compare map in Appendix A). For this the regrown vegetation since the storm will be completely removed.

4.3. Benefits and services of food forests

In the following sub chapters potential benefits and services of FFs will be presented to explore what aFF could contribute to Zuylestein. The literature review is structured into production, focussing on food provision, socio-cultural and ecological benefits,and, building upon these, the economic opportunities.

Table *3* at the end of this chapter summarises the results.

4.3.1. Production

Björklund et al. (2019) explored the potential of food provision in 12 experimental FF projects with farmers in Sweden[16]. They were able to harvest salad ingredients over most of the year as the forest included so much variety in leaves, herbs and traditional salad greens and different growing seasons, extending harvesting opportunities. As the FF matures this can be exploited more and more.Also, a variety of seeds, nuts and fruit provided proteins and carbohydrates. Including a variety of berries makes it easy to cover human vitamin and mineral requirements. From leaves, flowers and berries teas could be made. Nytofte and Henriksen (2019) provide the only detailed scientific exploration of how much nutritional yield could result from a temperate FF. They investigated the Garden Cottage FF in Scotland[17]. The FF grows annual and perennial species producing fruits, vegetables, mushrooms, herbs and nuts. Per year the FF generates 713 kg of produce, per hectare that would mean 8913 kg. Most of this weight comes from perennial fruits such as apples and cherries (53%), nuts contributed only 1%. According to their nutritional analysis the FF produces "9868 g protein, 8394 g fat and 85627 g carbohydrates" (Nytofte & Henriksen, 2019, p. 4) per year. Proportionally fats and proteins are underrepresented which stresses the importance of including crops such as nut species. From the 0.08 ha FF, 5 people could be provided the recommended amount of vegetables and fruits by the WHO. However, this waives requirements for protein and fat intake and for diversity in food, as much harvest comes from single species such as apples.

At Ketelbroek[18]products from perennial trees dominate production, resulting in mostly flowers, fruits and leaves. The creator, van Eck, stresses in an interview that yield estimations are very difficult as many factors, such as the weather one night or animals can affect the harvest drastically (van Gent, 2019). Boulestreau and van Eck(2016) theoretically designed a 1ha productive FF and evaluated its performance and estimated yield in a student project. Thirteen species were selected according to factors such as yield, lifespan, market value, compatibility with each other and many more. In this model, maximum yield is achieved after 50 years. The overall output of the system grows as it ages, beginning at approximately 0.8 tons and eventually surpassing 8 tons. Fastest growth occurs within the initial ten years, as the plants reach maturity and begin to produce high yields. The assumed yield increase of the different crops was assumed to be linear between smallest and maximum yield. Naturally, the chosen plant species play a role here too. Nonetheless, this gives an indication of how much a 1ha FF could produce. Significant yields are usually not achieved before trees mature for at least 5 years (Pilgrim et al., 2018). According to a student project report that investigated three FFs in the Netherlands, production can start after roughly 7 years and highest yields are achieved at 15 years (Nabisubi et al., 2020). In a report analysing 33 FFs of different ages in the Netherlands, yields seemed to steadily increase after 3 years (Wendel et al., 2023).

In some FF food is directly processed into e.g., jams. This makes long lasting products available. Other products from FFs can be herbs for medicinal use, plants to be used for crafting such as for dying clothes, or wood and other materials such as resin for building (Park et al., 2018). FF yields can also be used as feed for animals or fuel (Wartman et al., 2018). Further, FF can include a nursery with seeds or propagated vegetation which they can use themselves but also offer to costumers (Albrecht & Wiek, 2021a). Wood can also be a product coming out of aFF(Björklund et al., 2019).

[16]Distributed throughout Sweden, 4 years old, each 60m²
[17]Garden Cottage FF: Scotland, 0.8 ha, at river side, started in 1991 - at time of study: 26 years old, with 6 years of yield data of 99 species)
[18] Ketelbroek: Near Nijmegen (NL), 2.4 ha, 14 years old, minimum maintenance approach, 400 species

4.3.2. Social-cultural benefits

"[T]he forest gardens had become beautiful, harmonious and pedagogic places that they [creators]highly appreciated being in."(Björklund et al., 2019, p. 1116)

Community building and connection to heritage
FFscan contribute to community building by providing a space to discover nature and interact.People can meet each other and share an interest and activity by e.g., volunteering (Wendel et al., 2023).Experts and FF practitioners in North America and the UK stress the opportunities to gain ecological knowledge but also increasing social capacities and learning from each other (Park et al., 2018). FFs can provide a space for intercultural connection and integration by being a place where different people can participate and connect to the landand its history (Pilgrim et al., 2018). The use of native species, and the rediscovery of some of them can facilitate a connection of the local community to cultural heritage (Park et al., 2018). Depending on the size and concept of the FF, jobs can be created for the local community (Park & Higgs, 2018). At the publicly accessible FF Haarzuilens[9] people with food subscriptions meet and engage as they participate in monthly joint harvesting days (J. Degenaar & M. Schrama, personal communication, 20 May 2023).

Recreation
FFs can be a place of recreation, where people can connect with nature, have an aesthetically pleasing surrounding and relax. At Hotel Haferland[19], the FF includes a space to sit and enjoy the surroundings for the guests of the hotel (Albrecht & Wiek, 2021a; Hotel Haferland, 2023). At Haarzuilens[9] people can come at any time, enjoy the variety, and taste fruits and herbs. The human nature connection can be increased by inviting people to interact with the FF (Park et al., 2018).

Education
Education can be provided in the form of workshops, guided tours or advisory services. These can be on FF functioning, business models, nature conservation, food production, permacultureor climate adaptation strategies (Albrecht & Wiek, 2021a). FFKetelbroek[18] offers workshops on FF development and guided tours as a main part of their concept(greendealvoedselbossen, 2023).At Den Food Bosch[8]the managers share their knowledge on food forestry and explain the project at a guided tour every month (M. Lokin & M. Ramaker, personal communication, 1 April 2023).The visited Binnenbos[7]aims at being an example of agroecological food production to inspire industrial farmers to rethink their ways of production (K. Biesemans-Hoogewijs, personal communication, 29 March 2023). Children can also learn about their environment in FFs. Hammarsten et al. (2019) found in their experimental study that children interacting with FFs as part of their everyday school lives were showing increased ecological literacy. Primary school kids were also found to feel a stronger connection to the non-human world, showing that FF excursions can influence children's relation to their environment and introduce sustainability (Almers et al., 2018).By creating opportunities for volunteers, people in the area can gain in-depth knowledge on sustainable agriculture and biodiversity (Albrecht & Wiek, 2021a).

4.3.3. Environmental services

Ecosystem services
FFs provide many ecosystem services. These are products and services provided by ecosystems that enable and benefit humans and their well-being (Guerry et al., 2015). Supporting and regulating ecosystem services are inherent to the logic of FFs. Supporting services are the provision of habitats and the maintenance of genetic diversity. Regulation is provided through improved air quality, water cycle,

[19]FF Hotel Haferland, North Germany at the Baltic Ocean, 0.2 ha, older than 10 years

erosion prevention and soil fertility, pollination, biological control the function as a carbon sink and buffering against extreme weather events (TEEB, 2010).

Biodiversity and pollination

Depending on the FF, plant biodiversity can be very high, at Ketelbroek[18] around 400 species co-occur (greendealvoedselbossen, 2023). This diverse surrounding provides manifold habitatsfor insects and other animals (Albrecht & Wiek, 2021a; Breidenbach et al., 2017). Including local varieties of plants further adds to genetic biodiversity (Pilgrim et al., 2018).The biodiversity in FFs and the often intentional design to include species that flower at different times of the year, provides food and habitat for pollinators (Björklund et al., 2019).These then do not only benefit the FF but also all species around by facilitating pollination.Breidenbach et al. (2017) compared the species richness of FF Ketelbroek[18] to a nature protection area close by for pollinators, breeding birds, moths, and ground beetles. While different species occurred at the two sites, the number of different species was almost the same, showing that the FF supports biodiversity.

Resilience and climate adaptation capacity

Resilience means the capacity to withstand a disruption in the environment without transitioning to a different condition and the speed at which it returns to its original state (Scheffer et al., 2012). Ecosystems with high biodiversity are better equipped to withstand environmental disturbances because they host a larger variety of species that can step in and fulfil the roles of lost species (Nytofte & Henriksen, 2019; Willis et al., 2018). FFs are thus much more resilient than monocultural systems. The enhanced nutrient cycle and water holding capacity, as well as the cooler micro-climate in mature FF further add to resilience. Resilience and high biodiversity also meanenhanced capacity for climate adaptation (Björklund et al., 2019; Park et al., 2018).FFs can buffer the effect of heatwaves and droughts through their cooler micro-climate in summer and water holding capacity of the soil. Storms and extreme precipitation have less impact as the canopy intersects precipitation,soil infiltration capacity is high, and run-off and erosion areprohibited (Albrecht & Wiek, 2021a; Jose et al., 2022; Nytofte & Henriksen, 2019).Through these mechanisms how often and how strongly floods occur can be reduced(Collentine & Futter, 2018). Adaptation to climate change can further be increased through using species from different regions that are suited for the conditions developing in the location of the FF which is done at the Haarzuilens FF[9] (J. Degenaar & M. Schrama, personal communication, 20 May 2023). Also, for the general warming and irradiation trend, the microclimate and shade of FFs are valuable protections (Albrecht & Wiek, 2021a).

Carbon sequestration

High productivity and thus biomass creation in perennials creates a carbon sink and thus climate change mitigation(Toensmeier, 2016). Particularly young forests that increase fast in biomass sequester much carbon. This is stored in plant material and the soil (Raza et al., 2021). As the soil stays mostly undisturbed, little carbon is released into the atmosphere (Dawson & Smith, 2007). Carbon sequestration is determined by the ratio of carbon acquired through photosynthesis and the carbon released through respiration (Schafer et al., 2019). Schäfer et al. (2019) calculated the carbon sequestered in trees that are taller than 2m are more than 2 cm thick at breast height in 2017 at Martin Crawfords FF in Devon, UK[20]using allometric equations. Including the carbon stored underground this resulted in circa 39.53 tonnes per hectare of FF, only in trees. Lehmann et al. (2019) investigated how much carbon is stored in the understorey at the same FF in Devon. This is relevant as in temperate regions FFs much biomass is included in the understorey as trees provide too much shade. Shrubs and small trees with a thickness smaller than 2cm diameter at breast height were considered. Their analysis resulted in 2.36 tonnes per hectare carbon storage, including shrubs, shrub-like species, bamboo, small trees, and groundcover species.Wendel et al. (2023), estimate that a 30 year old FF can store between 50 and 150 tonnes C/ha above ground.

[20]FF Devon: used to be pasture, since1994 (at time of measurement 24 years), 0.64 ha

4.4. Economic opportunities

In a recent review of agroforestry practices in the Netherlands Wigboldus et al. (2022) describe FFs as still too young to prove rentability.Comparisons are difficult as size, age, design, plants, and conditions varies. In the Netherlands, only FF Ketelbroek[18] is economically viable.Recently developed FFs Hoogerheide[21], Schijndel[22] and Welna[32]by Stichting Voedselbosbouw are the first ones planned including a business model (van Gent, 2019). Of 15 FFs in Flanders only twoowners could support themselves exclusively through the FFaccording to a master thesis (Daems, 2022).

4.4.1. Possible Income Streams

Product sales

The main stream of income for FFs is to sell the produce. According to Björklund et al. (2019) if a forest garden is utilized for commercial harvesting purposes, it is essential to concentrate on a limited number of high-value products that can be easily maintained and harvested. Keeping the supply chain short and aiming for speciality or premium prices are ways to achieve necessary revenues according to a student analysis of two FFs (Doomen et al., 2019). Trust on the locality of the products and a personal connection to the managers or owner is seen by practitioners to make official certifications such as “organic” superfluous (Doomen et al., 2019). The opportunity to harvest through most of the year makes continues produce selling possible. Food Processing can be an opportunity to sell higher value products, such as jam instead of berries. Products such as tea and creams made with herbs can also be a product to sell (Park et al., 2018). One FF in the UK is using the growing interest into medicinal plants and herbs to receive a sufficient income (Pilgrim et al., 2018).FF Welna[32]was planned as a production FF and assumed to create a turnover of 10.000€ per hectare per year after 10 years(Stichting Voedselbosbouw Nederland, 2018). FF managers in the UK indicated that the types of more wild foods can be difficult to sell as people are not used to more bitter and unusual tastes (Pilgrim et al., 2018). By 2021, which marked 11 years since the initial planting, Ketelbroek's[18] net earnings per hectare stood at €3500 from produce sales (Wendel et al., 2023).

Vegetables, fruits, nuts or herbs can be sold directly to customers. Harvested produce can be sold at the FF site. At the FF Café Botanico[23] dishes are served seasonally with produce from the FF. At Castle Garden Café[24], teas and jams are served on location. However, the staff for FF maintenance, food processing and serving is more expensive than the revenue streams there (Albrecht & Wiek, 2021a). Self-harvesting of consumers can be an option to reduce labour costs. Further, it engages the costumers more closely with the system. However, costumers need to be educated well on where and how to harvest. A certain rational layout is necessary to be able to guide customers according to the initiators of Haarzuilens FF[9](J. Degenaar & M. Schrama, personal communication, 20 May 2023).

Another common strategy is to deliver directly to restaurants. Ketelbroek[18]supplies a Michelin star restaurant close by (Albrecht & Wiek, 2021a). Employees harvest together with the owners at Ketelbroek and Haarzuilens[9] every week (J. Degenaar & M. Schrama, personal communication, 20 May 2023). In their internship report on FF and restaurant cooperations, van Capellen (2020) stresses that successful partnerships are built on direct supplier relationships and offering unique niche products. In an internship report about Voedselbos ‘t Mortelke[25], Swart (2022) similarly concludes that high end restaurants show most enthusiasm for the FFs’ products, as they value quality. The greatest challenge in this potential collaboration lies in achieving efficient harvesting. Another way to support the FF is the concept of community supported agriculture (CSA). At ÖkohofWaldgarten[26], 200 people are sup-

[21]Hoogerheide: 2ha, 2018
[22]Schijndel: 16 ha high production FF and 4 ha experimental and educational area, 2018, has business model
[23]Café Botanico: Germany, Berlin, 0.2 ha, 5-10 years old
[24]Castle Garden: UK, 0.04 ha, 5-10 years old
[25]Voedselbos ‘t Mortelke:Noord Brabant, 2019, 2,5 ha
[26]ÖkohofWaldgarten: Germany, 2 ha, 17 years old

plied with produce from the FF and vegetable garden in this way. The members support the project also by volunteering some days in summer (Albrecht & Wiek, 2021a). Delivering to a food distributor such as FF Hoogerheide[21] does, is also a way to distribute at a short chain. This way the product value stays high and not much money is lost. Ketelbroek[18], next to the restaurant sales also supplies a local catering services, organic shop and apples to a local brewery (ibid.; Wendel et al., 2023).A more mature FF can be utilised by selling seeds, cuttings and grown plants (Park et al., 2018). At Mienbacher-Waldgarten[27] seeds and small crops are sold through the internet. Successful operations include specialty plants or operate on a large scale (Albrecht & Wiek, 2021a).

Education and activities
Education on FF, ecology and ecosystems is an opportunity for the owner to create revenue apart from the harvest (Albrecht & Wiek, 2021b; Hammarsten et al., 2019; Wartman et al., 2018). These services as well as recreation can be a source of early income, when production has not yet taken off (Doomen et al., 2019). A master thesis on 15 FFs and their revenue models in Flanders, tours and workshops were the most important source of income for the caretakers and owners (Daems, 2022). For Ketelbroek[18] workshops, guided tours and education on FFs is the main income (Albrecht & Wiek, 2021a). The focus lies on the interested community including courses on the basics of food forestry as well as how to plan and design one. These workshops last several months and cost between 550€ and 800€ per person including workshops on FF sites as well as theoretical workshops (Voedseluit het bos, 2023).Mienbacher Waldgarten[27] shares insights on their main value self-sufficiency in workshop form (Albrecht & Wiek, 2021a). As another community activity, at Essgarten[30,] dinners in smaller circles where produce from the FFis consumed gained popularity (Albrecht & Wiek, 2021b). School classes can also be invited to the FF to increase their ecological literacy (Hammarsten et al., 2019). Kees Van Veluw who initiated VoedselbosDroevendal[28] is experimenting with a primary school, where kids will join for 15 days in the FF (van Gent, 2019). Educational activities can be utilised for a revenue stream directly but also integrating visitors in the maintenance of the FF can save labour costs (Albrecht & Wiek, 2021a).

Other income opportunities
Stichting voedselbosbouw (2023b) suggests exploring opportunities of subsidies to help fund the FF, especially in the early years. FFs potential to store carbon can further be monetised. However, of the analysed 14 FFs in van Gent's (2019) master thesis only Houtrak[29] and Droevendaal[28] had managed to monetise their carbon capture by directly collaborating with an energy provider who uses the projects for their PR. Further, FF Haarzuilens[9]indirectly captures carbon for money by cooperating with a foundation and crowdfunding campaign. This can be called "voluntary carbon market". Selling credits through Emission Trading Systems (ETS)is difficult to estimate as this is a free market (World Bank, 2023a). Selling carbon credits to companies or organisations is a promising way to finance FFs as interest in the carbon market increases (Wendel et al., 2023).Payments for ecosystem services (PES) are developing around the world and might be a future way of earning revenue (Salzman et al., 2018). PES EU-policies exists in the form of agri-environmental schemes but only for agricultural lands through the Common Agricultural Policy (CAP) (Bazzan et al., 2023). Some FFs receive subsidiesfor sustainable water managementfrom the Dutch government (van Gent, 2019).

4.4.2. Diversity of Income streams and trade-offs
The way existing FFs that have reached an advanced stage are financially feasible is through a combination of these diverse revenue streams or by focusing on a small number of highly popular products or services, such as Essgarten[30] and Ketelbroek[18] (Albrecht & Wiek, 2021a). "Diversifying revenue

[27]MienbacherWaldgarten: Germany east of Munich,1.5 ha, 5-10 years
[28]Droevendal: Wageningen, 1 ha, since 2018, sandgrounds
[29]Houtrak:since 2017, 6 ha, between Haarlem and Amsterdam
[30]Essgarten: 33 years, 2,5 ha, Germany

streams" (Albrecht & Wiek, 2021b, p. 195) is a common tactic as FFs can provide so many services, especially in comparison to industrial agriculture. Offering tours or workshops and selling the produce is a common combination. Often additional grants or subsidiesprovide stability (Albrecht & Wiek, 2021a). However, various benefits and services exclude each other or create trade-offs. An example of this could be to strive for creating fast and high yield while hosting many activities in the FF, disturbing the system.

4.4.3. Costs and investments

Financial investment and care in the setup years are large and unavoidable. To establish a FF the main costs can be expected for the site preparation, payment of caretakers and plant costs (Crawford, 2016). Size, starting conditions and goals strongly influence these. The site preparation usually involves material costs but mostly labour hours. A calculation tool[31] was developed by Stichting Voedselbosbouw and *has* students in collaboration with WUR. The main expenses included are hours a farmer spends harvesting and maintaining (Bouwmans et al., 2022). Volunteers can decrease costs, but require coordination and flexibility (Albrecht & Wiek, 2021b). How much maintenance is necessary, especially for food production is still being explored. Generally, the more yield is desired, the higher the management and harvesting needs (Björklund et al., 2019). Schijndel[22] and Hoogerheide[21]serve as experiments on the impact of management (van Gent, 2019). This point is also picked up by Schaffer et al. (2019) who argue that at high labour costs, either volunteers or technologies need to be implemented to uphold rentability of agroforestry and FF projects. Doomen (2019) in their project report on FF business models calculated that if a FF labourer works 40 hours per week they can manage 2 hectares by themselves. This is dependent on their skill level and the design and purpose of the FF in question. However, no empirical data has yet been collected to proof these estimations (Wendel et al., 2023). In a well-established, mature FF, only controlling weeds, planting more species and harvesting are the tasks left (Pilgrim et al., 2018). How long The FF takes to mature is not given but depends on what, when, how and where species are planted and taken care of (Boulestreau & van Eck, 2016). Phosphor and nitrogen contents can support FFs for many decades in temperate systems, as harvesting does not remove many nutrients, according to a student internship report (Pepels, 2019). Exceptions are nut focussed FF, where n-fixing plants are recommended to maintain yields. A successful mature FF requires almost no maintenance, only harvesting (Albrecht & Wiek, 2021b; Crawford, 2016).

Plant costs vary greatly with nut trees being the most expensive common species. Self-propagation and using own seeds is possible. This saves costs but delays harvests. At FF Binnenbos[7] many trees were also sourced for free from local nurseries if these could e.g., not be sold (K. Biesemans-Hoogewijs, personal communication, 29 March 2023). The FF in Haarzuilens[9], carried by the foundation Lekkerlandgoed planned with investment costs of 100.000€ (J. Degenaar & M. Schrama, personal communication, 20 May 2023). Interviewed practitioners and experts in a student project on FF financing estimated plant costs between 8000€ and 20.000€ per hectare (Nabisubi et al., 2020).

4.4.4. Risks and uncertainties

The business side of FF is subject to multiple risks and uncertainties. The FF in its early succession stages is vulnerable until it becomes resilient. Natural disturbances such as the weather, exacerbated by climate change,and animals canimpact the FF development and yields. In the 15 FFs in Flandersthe primary cause of unexpected difficulties was the weather, particularly the dry summers of 2019 and 2020, along with the wet summer of 2021(Daems, 2022). Citing van Eck, van Gent (2019) stresses the point that weather conditions, such as frost later in the year than expected can negatively affect the harvest. Wild animals damaging plants are another factor that cannot be adequately modelled, making predictions about yields uncertain (K. Biesemans-Hoogewijs, personal communication, 29 March

[31] Link to download the Rekeningtool excel sheet: https://www.wur.nl/nl/show/rekentool-4.0-zip.htm

2023). Additionally, young plants are susceptible to the harsh local microclimate found in barren lands, which includes strong winds, significant temperature variations, floods, and droughts (van Gent, 2019).Damages to the FF as well as high management needs especially in the beginning stages lead to higher costs for labour hours and plant replacements(Albrecht & Wiek, 2021b; Pilgrim et al., 2018).As simultaneously productivity is affected, costs increase und revenue opportunities decrease.Selling produce or engaging in educational activities can only happen after initial investments which creates risks for investors (Nabisubi et al., 2020). Additionally, van Eckstresses the uncertainties around how efficient the harvesting can become, which is an important expenditure(Bouwmans et al., 2022; van Gent, 2019).

Table 3

Summary of the possible benefits and services and possible income streams

Food production	Social-cultural services	Environmental services	Income opportunities
High quality, nutritious produce	Education: ● on FF production ● on sustainable agriculture ● on ecosystem functioning and biodiversity ● on plant types and uses	Further improve biodiversity: ● Through including diverse species ● Through creating or improving habitat and sustenance for animals	Produce sales: ● To businesses ● To restaurants ● To customers directly (shop or self-harvest) ● CSA
High variety production	Providing space for community gatherings	Further improve resilience to weather and climate extremes	Workshops and tours (for adults/children)
High yields	Promoting integration through volunteer community/ action days	Creating pollinator habitats with benefit for the whole landscape	Activities such as dinners/ harvesting together events/cooking together/processing food together
Long growing season throughout the year	Providing a space for recreation	Further improve carbon sequestration	Subsidies
Including unusual species (old varieties/ speciality plants)	Job creation	Further improve water retention	Payment for carbon sequestration or ecosystem services
Non-food products (wood, seeds)	Facilitating connection to land and heritage	Further improve self-fertility	Selling cuttlings/ seeds/ processed products
	Experiments and research	Further improve soil quality	
		Further improve flood prevention	
		Further improve resilience	

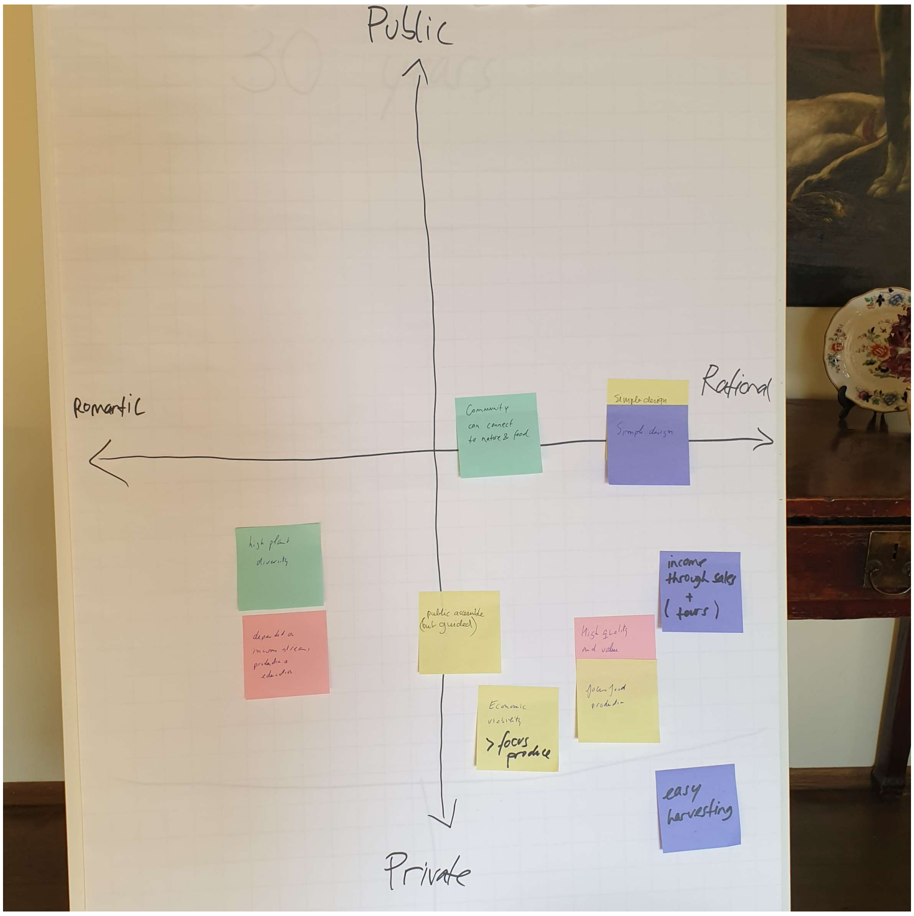
4.5. Workshop outcomes

4.5.1. Priorities and placement along axes of uncertainty

At the workshop after having been presented with the results of the previous research, the participants discussed aspects loosely based on the introduced four archetypical FF concepts: *Recreational* (using turquoise post-its), *Communal* (yellow), *Experimental* (pink) and *Productional* (purple). The chosen aspects were placed in a priority list ranging from "very important" over "nice to have" to "not so important" (find an image of the ranking results inAppendix). Seen as most important were high plant diversity creating animal habitat, economic viability, income through produce sales. Additionally, diverse income streams through having the possibility to offer educational tours on food forestry were favoured.For food production, quality was preferred over quantity. They would also like visitors to connect to nature and food in connection to the heritage of the site. The layout of the FF should be simple, directing towards rational. Most of the area should not be publicly accessible unless through a tour to leave the system undisturbed. However, they were interested in having a small part of the FF be open to everyone. They were clear in having no interest in creating a space for recreation and self-harvesting was not perceived as a realistic option as this would require specific infrastructure. From the exercise and discussion about their priorities the post it notes were reviewed together. These were then placed along romantic-rational and public-private axes of uncertainty, following van Gent (2019) as can be seen in Figure 10.

Figure 10

The stakeholders' priorities organised along the axes of uncertainties



*Note.*The colours of the post-itsrelate back to the four types of FFs as described above. However, as aspects of the types overlap, this is notmeaningfulby itself.

As a result, the FF should mainly be focussed on production, however that the "community can connect to nature and food" was an element from the *Communal* archetype that was found important. The post-its in the bottom left *Experimental* corner indicate that a higher variety of plants is wished for than what is typically included in a *Production* FF.

4.5.2. Scenario-building and backcasting

The FF outline created through this was the used as a base for a scenario built for the FF in 30 years. An open discussion over how the FF could look like in the future was encouraged. Afterwards, goals for 15 and then 5-7 years were thought about. At 15 years the FF realistically can begin to function as a forest ecosystem and high yields start to be possible (Boulestreau & van Eck, 2016; Nabisubi et al., 2020). Since at 5-7 years trees start to reach maturity and significant yields are enabled this was another milestone considered (Pilgrim et al., 2018). These are only rough estimates but help think long term, nonetheless.The participants were given

Table *3* containing possible benefits, service, and income streams for inspiration. To engage thoughts about particular aspects, the participants were asked about benefits, services and income streams they would like for each time step. Further, what products they would like to offer then and who they imagined spending time in the FF was deliberated. The green rows in Table 4 contain the results of this scenario exercise.What the FF should look like came up repeatedly and was thus included as a category next to the already established benefits, services, and income opportunities. For the backcasting the participants collected hurdles they could imagine preventing the visions of the scenarios to become reality (red row). Lastly, necessary interventions to enable each vision are included in the brown row.

Table 4

Condensed final results from the scenario building and backcasting workshop

	5-7 years	**15 years**	**30 years**
Food production	● High berry production already	● High food production	● Nut production high ● Mushroom production ● general focus on shade-loving species
Social-cultural benefits	● Many happy visitors ● Tours are given through non-public parts ● People know about the story of the estate and how the FF fits into it	● Tours are offered to share the idea behind the FF at Zuylestein	● Feels like a secret FF and gets visitors curiosity ● Included old species offer a way to connect to natural heritage ● inclusion of volunteers
Environ-mental benefits	● Trees are well established ● Some shade is already created	● Strong increase of organic matter ● pH levels have levelled	● Animal biodiversity is high ● Resilient ● Self-fertility is established ● "all environmental benefits"
Income oppor-tunities	● Selling produce ● Tours	● High food production and sales ● Selling processed food and products	● Achievement of payments for ecosystem services ● Saving labour cost through volunteers ● Nut sales
Design and look	● Trees are well established and create some shade	● The design becomes visible	● Full canopy is established with oaks and beeches ● Looks like the historical hunting forest ● *Sterrenbos* design is included ● Old species are included ● Includes a small public part for foraging ● Different layers are established ● Including animals such as chickens and the pigs
Hurdles	● Inefficient harvesting ● Dry summers ● Dangers of extreme und much precipitation (damage/funghi/snails)	● Uncertainty about possible ways of harvesting ● Lethargy of staff/volunteers at this time ● Competition with animals for harvest	● Climate change effects ● Full canopy affecting productivity of the system
Inter-ventions	● Creating a design that takes especially environmental hurdles into account	● Grow in abundancy to have enough food for animals and for harvesting ● Innovation to make harvesting more efficient ● Establishing a system for processing plants (e.g., into	● Creating very high species diversity also genetically (partially to adapt to climate change) ● Adjust product selection to forest: e.g.,berries, mushrooms, nettles

		pesto or medicinal creams) to be able to sell for longer	

For all time steps reinstating a healthy system with high biodiversity and high resilience is a priority. The participants further stressed the wish to monetise ecosystem services in the future. The most important result wasthat the goals had to change at the time stepswhile the site grows a full canopy. In the first years utilising typical FF species is possible. However, plants such as berry bushes will yield much less in full shade, making a shift to more shade loving species such as mushrooms necessary-when the forest matures.

5. Discussion

In this thesis the *Sterrenbos* site at Zuylestein was explored from a social-ecological perspective to derive site-specific design principles for a climate adaptive FF. The following sub-chapters discuss the relevant results structured in the *system, target* and *transformation knowledge* framework. Further a reflection on the research process is included.

5.1. The system

The exploration of the ecological conditions indicated on the one hand constraints and hurdles that will affect the FF development. On the other hand, it brought opportunities to light where a FF can alleviate stress.

5.1.1. Water availability

The texture across the whole site was found to be loamy sand and sand becoming coarser with depth. High porosity indicates well-draining soil which leads to low water availability to plant roots(Lerch, 1972). However, this also means low danger of inundation. SOM is particularly important in sandy soils as it increases water holding capacity and improves infiltration. SOM at 0-10 cm ranged between 11.81 and 18.86%. The lowest value was found closest to the water ditch. Spatial heterogeneity might be due to more composting material closer to the forest and the pigs that were kept at different locations. The different vegetation at each location shows this heterogeneity (compare Figure 7). Increasing SOM further couldlead to 1 mm more available water per % SOM (Wosten et al., 2019). This is animportantadaptation opportunity (Allen et al., 2011). Infiltration time fluctuated around 4 minutes in the first three plots. At plot 4, it took double the time. On the edges of the 149 tiny forests investigated in the UK,infiltration took only 3.5 minutes on average (earthwatch Europe, 2023a). A reason for differences may have been the rainy conditions and thus already wet soils during sample collection.The 5 m height difference might have had an impact but was not investigated further as reliability of the infiltration and compaction results was limited by only one measurement per plot. For tiny forests in sandy soils a strong decrease of infiltration time was observed before and after forest establishment, suggesting that the FF can improve this value. Compaction ranged between 1.5 and 2.3 kg/cm^2. It was lower throughout the *Sterrenbos* than on the edges of the comparison tiny forests(average 2.51 kg/cm^2).The pigs rotating on the site as well as the machinery used to remove the wood after the storm might have increased compaction. Inside the tiny forests compaction was much lower, suggesting that it can reduce with a FF, especially due to the undisturbed soil principle. This wouldfacilitate water and root permeation(Allen et al., 2011; Wendel et al., 2023; Wosten et al., 2019).Groundwater measurements equalled 122 and 81 cm underground for the 10 and 90 percientel respectively.In fine and loamy sand due tocapillary rise even in summer water could be available at only 20 cm depth (Runhaar et al., 2010). In practise however, conclusions are different.At the FF Welna[32]average groundwater levels comparably range between 80-140 cmat the highest and >120 cm at the lowest. (Voedseluit het bos, 2022b). In another FF it ranges between >80 cm and >140 cm (Voedseluit het bos, 2022a). For both practitioners, the experience was rather dry conditionswith precipitation-dependent vegetation. Despite groundwater theory it should thus be expected that groundwater is not a water source.

[32]Voedselbos Welna: 14 ha testing the four types of “verdienmodellen” of voedseluit het bos, since 2018

5.1.2. Soil fertility

Soil fertility is of crucial importance for the development of a FF and thriving of plants. The carbon content is an indicator for the soil's stability and nutrient cycling as well as water holding capacity (Runhaar et al., 2010).At the *Sterrenbos* these ranged from 10.94% to 6.85%in 0-10 cm with decreasing values below due to organic matter accumulating on the surface. These are in the upper ranges of the successfully implemented FFs in Sweden, indicating promising conditions (Björklund et al., 2019). The two highest values in Sweden were 9.69 and 18.28%, both of which were also former forest areas which is likely to explain the high carbon in the Zuylestein soil as well (Conijn&Lesschen, 2015).The important plant nutrient nitrogen was also present at the site, despite sandy soils usuallybeing poorer in nitrogen (Wendel et al., 2023). Phosphorus is likely available atsites in temperate regions and because it ismade soluble by lower pH, it should be directly accessible to plants(Penn &Camberato, 2019; Pepels, 2019). Indicating high fertility, the carbon to nitrogen ratios especially in the upper soil were close to the ideal ratio of 24:1 (USDA, 2011). They ranged from 22.07 to 11.81. The highest and lowest ratio were found closest to the intact forest and water ditch again suggesting the forest biomass influence.

A main concern for the site was the low pH around 4 indicating acidic conditions. This negatively affects how rich the biodiversity and species can be at the site as many nutrients become unavailable to plants (Ponton &Remiarz, 2022; Raza et al., 2021). Low pH further impedes root penetration as the soil increases in bulk density. As described in the background section in already low pH conditions, buffering mechanisms are weaker, making further acidification a danger. Climate change accelerating acidification is another concern (Raza et al., 2021). The forest history and sand grounds are likely explanations for pH.Acidic grounds in combination with fluctuating groundwater levels were found to hinder the growth of perennial fruit trees and vines in their FF projects(Björklund et al., 2019). The two lowest pH levels found were 4.0 and 4.8 also in former forest areas. Two of the 20 analysed FFs by Daems (2022) in their master thesis also had sand ground and were forests before. Both also had pH values below 4.5. However, these are measurements from already established FFs. The thesis does not include size or age in the data, limiting the comparison opportunity. A conclusionafter assessing 33 FFs in the Netherlands was, that FFs on sand tended to have decreasing pH over the years (Wendel et al., 2023).

5.1.3. Social opportunities and constraints

Zuylestein is already well connected in the local community. FF products could easily be sold using the already existing routes of distribution to local costumers, food collectives and restaurants.Processed products, which last longer than fresh produce, could be produced and sold at the location on site. The estate in general attracts visitors who enjoy the nature, explore the history of Zuylestein and buy produce. They might also be interested in FF activities. An existing volunteer network is further a great opportunity for the establishing years of the FF. A constraining factor is that the *Sterrenbos* site is a designated Rijksmonument, meaning that the restoration of the site needs to result in the pre-existing forest and only endemic species can occur.

5.2. The target

The long-term target state (30 years) of the *Sterrenbos* site is a climate-adaptive, self-fertile, resilient FF with endemic species and a full canopy to resemble a forest.The goals relate mainly to the productional FF type, including educational activities for the community and surrounding estates. The FF should further be resilient, biodiverse, and ideally fulfil all environmental services (compare

Table *3*). The multiple layers of a FF should be established at this point providing habitats, especially for pollinators.Management needs of the mature FF would ideally be low and volunteers could help especially with the main task of harvesting.

Food production, at this point particularly nuts and mushrooms, is the desired focus of the FF.Nut trees are already incorporated in the plans for the site. The full canopy will however affect productivity. High producing FFs have 10% canopy cover to allow sunlight to reach most plants in temperate regions (Albrecht & Wiek, 2021b; Crawford, 2016). Resembling a forest also requires a more romantic design with more species variety than focussed production FFs have, reducing harvesting efficiency (J. Degenaar & M. Schrama, personal communication, 20 May 2023). However, more species can be utilised to extend the harvest season, distributing harvesting over time and being able to sell fresh produce for longer.From the business perspective, selling high value produce such as nuts is a recommended strategy for FFs (Björklund et al., 2019). The kitchen, shop, and other existing routes of distribution enable necessary short supply chains and on-site processing of fresh produce. As most costumers are already familiar with Zuylestein, labels such as "organic" to justify premium prices, are likely unnecessary (Doomen et al., 2019). Nevertheless, with the reduced productivity revenues such as Ketelbroek's[18]or Welna's[32]will not be achieved. To support the system's productivity, it was discussed that the FF should be closed off, potentially with a small part publicly accessible to spark visitors' interest. It would also allow them to harvest, interact with the system and connect to nature and the history of the site, especially since the *Sterrenbos* layout will be preserved (Albrecht & Wiek, 2021a; Park et al., 2018). The separate public area could be more romantic and the productional area rational. Schijndel[22] and other FFs also have multiple areas with varying designs, e.g., for educational purposes (Park & Higgs, 2018).

In the closed off FF areas, it was envisioned that private tours could be organised. This would generate further income and diversify income streams reducing investment risks (Albrecht & Wiek, 2021b, 2021a). It would however disturb the system and paths need to be wider and areas for gatherings included. The opportunities in this field depend on the existing competencies. As Zuylestein is aiming at being an example of a functional ecological estate, the landowner could facilitate targeted tours to other estate owners.Generating income through PES was also of interest to the landowner which might become an option in the future (Bazzan et al., 2023). Carbon storage which is highest in the canopy can be expected to be high, offering opportunities for selling carbon credits (Schafer et al., 2019; Wendel et al., 2023). There was no interest in offering other activities at the FF.

5.3. The transformation

5.3.1. Addressing the main constraints

To achieve the main goal of a fully functioning FFwith the benefits of self-fertility, an enhanced water cycle, resilience, and productivity, the ecological constraints at Zuylestein need addressing. Particularly, climate change, soil quality and water availability. Especially climate adaptation was a hurdle identified for all milestones.The soils are likely to acidify further due to sand grounds, less buffering capacity and higher temperatures (Raza et al., 2021; Wendel et al., 2023).Crawford (2016) recommends treating very acidic soils with liming materials such as silicate. Stabilising the pH at a required level might take multiple years. At the Devon FF[20], as the system matured, and the nutrient cycle was established after ca. 8 years the pH was raised from 5.7 to 6. However, at the FF Steward Community Woodland Devon[33] that had initially a 4.4 pH levelthe FF still was too acidicafter 10 years and continuous liming (Ponton &Remiarz, 2022). The owner's experience was that such acidic soils will not

[33]Steward Community Woodland Devon: 0.12 ha, loamysand, low pH (4.4), UK, previouslydegradedwoodland, started in 2011

be convertible with lime and plant choices must simply be adapted. An option are ericaceous species which require low pH conditions such as blueberries, or shrubs like hawthorns which however do not provide edible fruits for humans (Crawford, 2016). For climate adaptation specifically, increasing water holding capacity and infiltration by increasing SOM content should be a focus (Farley et al., 2004; Rawls et al., 2003). Common methods are to focus on high biomass producing species in the FF and then using that plant material for mulching, resulting in SOM[34] (Crawford, 2016; Jacke & Toensmeier, 2005b; M. Lokin & M. Ramaker, personal communication, 1 April 2023). This can buffer against droughts as well as extreme precipitation events which will become more frequent due to climate change.Especially since groundwater levels can drop very low in sandy soils (Runhaar et al., 2010). The canopy but also the important ground-cover vegetation should be developed well to reduce evaporation.Applying the agroecological principles of plant multifunctionality, the benefit of biodiversity and principles of permaculture should create symbiotic relations in the system, increasing resilience further (Buiter, 2022; Tomich et al., 2011). Climate adaptation by using species adapted to changed conditions from other areas is not possible. However, high genetic biodiversity also increases resilience and can be facilitated by planting local varieties of the desired species (Pilgrim et al., 2018). Using old varieties also fits the restoration storyline, makes the history tangible, and can be shared with visitors.

5.3.2. Transformation from milestone to milestone

FFs are complex systems that can be guided through succession in different ways, enabling a variety of services and benefits and income opportunities along the way(Jacke & Toensmeier, 2005a). Den Food Bosch[8] provides a good example of planning with the successional phases, removing plants as the canopy grows or integrating more shadow loving plants (M. Lokin & M. Ramaker, personal communication, 1 April 2023). For the first milestone at 5-7 yearsthe open space, as a first succession phase, should be utilised for berry production according to the stakeholders. The planned trees should be well established and starting to create shade. Income was imagined coming from direct berry sales in addition to income from tours. As continuously growing harvest can be expected, establishing food sales here is important (Wendel et al., 2023).Discussed hurdles,next to climate adaptation, were damage by animals and inefficient harvesting. Harvesting has the potential to become more efficient through technology, however this is difficult to predict (Stichting Voedselbosbouw, 2023b). It was discussed to rely on volunteers. This could save costs (Björklund et al., 2019). Extending the harvest season is another possible strategy as described above. From literature and FF visits it was taken that protection in the beginning years is very important. To deal with animals the stakeholders themselves would prefer growing enough to also satisfy their needs. Having worked at Binnenbos[7] for multiple years the manager reflected that fencing off the FF in the beginning years would have saved much cost of plant replacement (K. Biesemans-Hoogewijs, personal communication, 29 March 2023). As the *Sterrenbos* is surrounded by forest habitats this could be wise. As the FF should mostly be private, the fencing efforts could be designed to keep humans and animals out.Plant costs and management will be highest in this first planting phase when the FF is still vulnerable. Especially in sandy soils irrigation might be necessary during the establishing years. Trees that grow fruits might need water throughout the summer (Crawford, 2016). Enough funds need to be available to pay for this, starting early with sales and tours can decrease the financial strain.

Continuing from this, at 15 years the FF isfurther hoped to provide high yields.The main income should come from selling the fresh produce and processed foods like jam or pesto. Tours are envisioned to focus more on the design aspect which would be established by then. For the transformation it is therefore important to have good communication strategies as services and products of the FF change over the years. Produce from the FF would likely be known in the estate's network by this point. This can then be used to market other products.The high-end restaurants receiving Zuylestein

[34]Also calledchop and droptechnique

produce are also likely interested in natural and seasonal produce with a story (van Capellen, 2020).From experience there was also a worry that volunteers and staff might lose passion. This could be counteracted by facilitating learning experiences, integration and a community feeling (Wendel et al., 2023). To reach the mature stage at 30 years the stakeholders found the main hurdle to be lower productivity affecting income stability.Facilitating diverse revenue streams through tours and shifting sales more to high value productsare thus crucial toensure financial stability (Albrecht & Wiek, 2021b).

In conclusion, facilitatinga FF transformation is most important in the beginning years, when climate change stress and ecological constraints need addressing. Funds need to be available to pay for plants and management. As the forest matures, ideally resilience continuous to naturally increase while management needs decrease. Focussing on efficient harvesting as well as selling changing products over the years and offering tours suited to the development state of the FF becomes important for the sustainability of the FF project at these stages.Abstracting from Zuylestein, diverse revenue streams, planning for climate change resilience by addressing the ecological starting conditions and aiming for the stakeholders' goals are design principles that could be applied at other locations as well. The local social-ecological context needs to be assessed to create a transformation plan as has been shown for the *Sterrenbos*. Goal setting is crucial to be able to prioritise and identify potential trade-offs. To achieve sustainability, the economic component should be integrated, and investment costs considered. The scenario-building and backcasting method can be useful to apply to reduce complexity.

5.4. Transdisciplinarity and shortcomings

This thesis provided an example of how a transdisciplinary project can create the basis for a context-specific adaptive transformation, which needs to be context specific. The transdisciplinary process was crucial for this process, especially as FF can provide so many different benefits, services and need to be adapted to the local site. System knowledge could have hardly been acquired in a different way and joint goal setting was necessary to narrow down the vision of the FF. Further, the workshop functioned to share acquired knowledge and facilitate an informed discussion of opportunities. In this way, scientific work can have a real-world sustainability impact and benefit stakeholders directly (Daconto& Sherpa, 2010). It further put the agroecological principles of knowledge sharing, especially from FF practitioners' side, and co-creation into practise. However, as the landowner is fully engaged in their estate, not much time was available to co-develop ideas. That tree plantingwas already planned e.g., only became clear at the workshop late in the process. Further, the workshop revealed that their perspective on the FF was more development and business centred, since their priority is the whole estate. This clashed with the practitioner perspectives encountered at the visited FFs. There and in other FF projects around the Netherlands the focus lies more on the ecosystem, sustainability ideals and personal engagement with the land (Wendel et al., 2023). Removing all existing vegetation instead of mulching or attempting to integrate already present components represent this contradiction (compare title page picture).

The important legislative context of FFs could not be explored here further due to time constraints. Policy analysis and general research on restraints or potential subsidies could be useful insights for the landowner. For the same reason the social side of the SES was only explored through the landowner, a stakeholder analysis and their integration in the development process could have offered more perspectives and insights. Furthermore, the ecological assessment could have been extended the soil food web (Allen et al., 2011). Additionally, soils and plants are not only connected linearly, but through feedback mechanisms (Ehrenfeld et al., 2005). Due to the scope, these were not explored.

6. Conclusion

FFs have the similar general properties of undisturbed healthy soils, a well-established nutrient and water cycle and offer high productivity and resilience. They provide an agroecological way of producing food and offer many other benefits for the owner, manager, nature, and local community. FFs can be unique, sustainable projects, shaped around the main purposes. At Zuylestein, a sustainable, climate adaptive FF aims to benefit the environment in the long-term, produce food and be a space for educational tours to provide an income. This represents a transformative adaptation for the estate and contributes to local food sovereignty.Additionally, it should resemble a full forest when it matures. To achieve these goals, particularly the low pH and water holding capacity of the soil should be managed in the face of climate change. Sufficient starting funds are crucial. Most of the area should be closed off to facilitate a productive and resilient system with high biodiversity. It should however still enable efficient harvesting. As the FF matures it goes through different succession phases supporting different kinds of productive plants. An important design principle isadapting food production and tours to the maturity-state of the FF.Produce sales must thus be flexible potentially changing from high to lower volume but to higher-value yields.

To arrive at these results the ecological assessment and close collaboration with the landowner were necessary. The transdisciplinary process required many iterations, as results from the ecological assessment, literature review and stakeholder exchanges shaped and changed the project. The ethnographic FF visits were an important component to get a holistic idea of what FFs can achieve and how unique they are. This transdisciplinary, multi-methodological approach required much flexibility but enabled a holistic exploration of FFs as a concept as well as of the SES Zuylestein, enabling tailored design principles. This thesis demonstrates the usefulness of engaging in a transdisciplinary process from the SES perspective. Itenables the exploration of existing constraints and opportunities and could be useful in further research on agroecological transitions and food sovereignty. Further, this is a contribution to the growing scientific interest in FFs as a climate adaptive,sustainable way of producing food through the literature review and design principles. More research should be conducted quantifying management requisites, associated expenditures, and the identification of economic opportunities. Additionally, investigating sustainable mechanisms to foster transdisciplinary co-creation over extended research durations holds the potential to offer a roadmap for forthcoming projects. These dimensions are crucial to investigate for the sake of making FFs a viable and pragmatic substitute for industrial agricultural practices. This is particularly important in the light of challenges posed by climate change.

7. Bibliography

Adams, W. C. (2015). Conducting Semi-Structured Interviews. In *Handbook of Practical Program Evaluation* (pp. 492–505). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119171386.ch19

Albrecht, S., & Wiek, A. (2021a). Food forests: Their services and sustainability. *Journal of Agriculture, Food Systems, and Community Development*, *10*(3), Article 3. https://doi.org/10.5304/jafscd.2021.103.014

Albrecht, S., & Wiek, A. (2021b). Implementing sustainable food forests: Extracting success factors through a cross-case comparison. *Journal of Agriculture, Food Systems, and Community Development*, *11*(1), Article 1. https://doi.org/10.5304/jafscd.2021.111.019

Allen, D. E., Singh, B. P., & Dalal, R. C. (2011). Soil Health Indicators Under Climate Change: A Review of Current Knowledge. In B. P. Singh, A. L. Cowie, & K. Y. Chan (Eds.), *Soil Health and Climate Change* (pp. 25–45). Springer. https://doi.org/10.1007/978-3-642-20256-8_2

Almers, E., Askerlund, P., &Kjellström, S. (2018). Why forest gardening for children? Swedish forest garden educators' ideas, purposes, and experiences. *The Journal of Environmental Education*, *49*(3), 242–259. https://doi.org/10.1080/00958964.2017.1373619

Altieri, M. A. (2009). Agroecology, Small Farms, and Food Sovereignty. *Monthly Review*. https://monthlyreview.org/2009/07/01/agroecology-small-farms-and-food-sovereignty/

Bazzan, G., Candel, J., & Daugbjerg, C. (2023). *Designing successful agri-environmental schemes: A mechanistic analysis of a collective scheme for eco-system services in the Netherlands*. *146*, 123–132. https://doi.org/10.1016/j.envsci.2023.05.002

Belcher, B., Michon, G., Angelsen, A., Pérez, M. R., &Asbjornsen, H. (2005). The socioeconomic conditions determining the development, persistence, and decline of forest garden systems. *Economic Botany*, *59*(3), 245–253. https://doi.org/10.1663/0013-0001(2005)059[0245:TSCDTD]2.0.CO;2

Biesemans-Hoogewijs, K. (2023, March 29). *Binnenbos food forest participation day in tree planting* [Personal communication].

Björklund, J., Eksvärd, K., & Schaffer, C. (2019). Exploring the potential of edible forest gardens: Experiences from a participatory action research project in Sweden. *Agroforestry Systems*, *93*(3), 1107–1118. https://doi.org/10.1007/s10457-018-0208-8

Boulestreau, Y., & van Eck, W. (2016). *DESIGN AND PERFORMANCE EVALUATION OF A 1HA PRODUCTIVE FOOD FOREST MODEL*. WUR.

Bouwmans, E., Cantrijn, J., &Otjens, W. (2022). *Handleidingrekentool 4.0* (p. 19). has Hogeschool.

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., & von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics*, *92*, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008

Breidenbach, J., Dijkgraaf, E., Rooduijn, B., Nijpels-Cieremans, R., &Strijkstra, A. (2017). Voedselbossen van belang voor biodiversiteit. *De LevendeNatuur*, *118*(3), 90–93.

Brolsma, R. J., &Bierkens, M. F. P. (2007). Groundwater–soil water–vegetation dynamics in a temperate forest ecosystem along a slope. *Water Resources Research*, *43*(1). https://doi.org/10.1029/2005WR004696

Buiter, M. (2022). *Wat is eenvoedselbos?* Stichting Voedselbosbouw. https://www.voedselbosbouw.org/media/documents/Artikel_Wat_is_een_voedselbos_FmUQeEN.pdf

Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T. W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J. W., &Brussaard, L. (2018). Soil quality – A critical review. *Soil Biology and Biochemistry*, *120*, 105–125. https://doi.org/10.1016/j.soilbio.2018.01.030

Chapin, F. S., Matson, P. A., &Vitousek, P. M. (2011). Water and Energy Balance. In F. S. Chapin, P. A. Matson, & P. M. Vitousek (Eds.), *Principles of Terrestrial Ecosystem Ecology* (pp. 93–122). Springer. https://doi.org/10.1007/978-1-4419-9504-9_4

Coleman, B. R. W., Thevathasan, N. V., Gordon, A. M., & Nair, P. K. R. (2022). An Agroecological Foundation for Temperate Agroforestry. In H. E. Garrett, S. Jose, & M. A. Gold, *North American agroforestry* (3rd ed). Wiley American society of agronomy.

Collentine, D., & Futter, M. n. (2018). Realising the potential of natural water retention measures in catchment flood management: Trade-offs and matching interests. *Journal of Flood Risk Management*, *11*(1), 76–84. https://doi.org/10.1111/jfr3.12269

Conijn, J. G., &Lesschen, J. P. (2015). *Soil organic matter in the Netherlands: Quantification of stocks and flows in the top soil* (619; p.). Plant Research International. https://library.wur.nl/WebQuery/wurpubs/498774

Crawford, M. (2016). *Creating a forest garden: Working with nature to grow edible crops* (Reprint). Green Books.

Daconto, G., & Sherpa, L. N. (2010). Applying Scenario Planning to Park and Tourism Management in Sagarmatha National Park, Khumbu, Nepal. *Mountain Research and Development*, *30*(2), 103–112. https://doi.org/10.1659/MRD-JOURNAL-D-09-00047.1

Daems, J. (2022). *VOEDSELBOSSEN IN KAART GEBRACHT GEBRUIKTE SOORTEN, SYSTEMEN EN DRIJFVEREN* [Master Thesis]. Universiteit Gent.

Dawson, J. J. C., & Smith, P. (2007). Carbon losses from soil and its consequences for land-use management. *Science of The Total Environment*, *382*(2), 165–190. https://doi.org/10.1016/j.scitotenv.2007.03.023

de Brauwere, J. (2023, April 28). *Landowner Interview about the social context of Zuylestein and the history of the site* [Personal communication].

de Vries, F., Walvoort, D., & Brouwer, F. (2017). *Basis registratie Ondergrond (BRO) Actualisatie-bodemkaart van eenheden met slappekleilagen: Herkartering van de eenheden met slappekleilagen*. Wageningen Environmental Research. https://doi.org/10.18174/423728

Degenaar, J., &Schrama, M. (2023, May 20). *Haarzuilens Food forestoogstdag participation* [Personal communication].

DINOloket. (2023). *DINOloket. Data enInformatie van de Nederlandse Ondergrond*. https://www.dinoloket.nl/

Doomen, R., van Leeuwen, B., &Puhe, L. (2019). *Food Forest business models* [Project Report]. has.

Doran, J. W., & Parkin, T. B. (1994). Defining and Assessing Soil Quality. In J. W. Doran (Ed.), *Defining Soil Quality for a Sustainable Environment* (pp. 1–21). John Wiley & Sons, Ltd. https://doi.org/10.2136/sssaspecpub35.c1

earthwatch Europe. (2023a). *Tiny Forest: Monitoring Report 2022* (p. 24). earthwatch Europe. https://tinyforest.earthwatch.org.uk/images/documents/Tiny-Forest-Monitoring-Report-2022.pdf

earthwatch Europe. (2023b). *Tiny Forest*. https://earthwatch.org.uk/get-involved/tiny-forest

Ehrenfeld, J. G., Ravit, B., & Elgersma, K. (2005). Feedback in the Plant-Soil System. *Annual Review of Environment and Resources*, *30*(1), 75–115. https://doi.org/10.1146/annurev.energy.30.050504.144212

FAO. (2018). *The 10 elements of agroecology: Guiding the transition to sustainable food and agricultural systems*. Food and Agriculture Organization of the United Nations. https://www.fao.org/documents/card/en/c/I9037EN/

FAO. (2019). *Measuring and modelling soil carbon stocks and stock changes in livestock production systems—Guidelines for assessment. Version 1*. FAO. https://www.fao.org/documents/card/es/c/CA2934EN

Farley, K. A., Kelly, E. F., & Hofstede, R. G. M. (2004). Soil Organic Carbon and Water Retention after Conversion of Grasslands to Pine Plantations in the Ecuadorian Andes. *Ecosystems*, *7*(7), 729–739. https://doi.org/10.1007/s10021-004-0047-5

Fedele, G., Donatti, C. I., Harvey, C. A., Hannah, L., & Hole, D. G. (2019). Transformative adaptation to climate change for sustainable social-ecological systems. *Environmental Science & Policy*, *101*, 116–125. https://doi.org/10.1016/j.envsci.2019.07.001

Ferguson, R. S., & Lovell, S. T. (2014). Permaculture for agroecology: Design, movement, practice, and worldview. A review. *Agronomy for Sustainable Development*, *34*(2), 251–274. https://doi.org/10.1007/s13593-013-0181-6

Fleurbaey, M., Kartha, S., Bolwig, S., Chee, Y. L., Chen, Y., Corbera, E., Lecocq, F., Lutz, W., Muylaert, M. S., Norgaard, R. B., Okereke, C., & Sagar, A. (2014). *Sustainable development and equity* (O. Edenhofer, R. Pichs-Madruga, Y. Sokona, J. C. Minx, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, von Stechow, & T. Zwickel, Eds.; pp. 238–350). Cambridge University Press. https://www.ipcc.ch/report/ar5/wg3/

Ford, A., & Nigh, R. (2009). Origins of the Maya Forest Garden: Maya Resource Management. *Journal of Ethnobiology*, *29*(2), 213–236. https://doi.org/10.2993/0278-0771-29.2.213

Fowler, H. J., Lenderink, G., Prein, A. F., Westra, S., Allan, R. P., Ban, N., Barbero, R., Berg, P., Blenkinsop, S., Do, H. X., Guerreiro, S., Haerter, J. O., Kendon, E. J., Lewis, E., Schaer, C., Sharma, A., Villarini, G., Wasko, C., & Zhang, X. (2021). Anthropogenic intensification of short-duration rainfall extremes. *Nature Reviews Earth & Environment*, *2*(2), Article 2. https://doi.org/10.1038/s43017-020-00128-6

GDN. (2023). *Grondwatertools*. Geologische Dienst Nederland. https://www.grondwatertools.nl/

greendealvoedselbossen. (2023). Ketelbroek. *Green Deal Voedselbossen*. https://greendealvoedselbossen.nl/koplopers/ketelbroek/

Guerry, A. D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G. C., Griffin, R., Ruckelshaus, M., Bateman, I. J., Duraiappah, A., Elmqvist, T., Feldman, M. W., Folke, C., Hoekstra, J., Kareiva, P. M., Keeler, B. L., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., … Vira, B. (2015). Natural capital and ecosystem services informing decisions: From promise to practice. *Proceedings of the National Academy of Sciences*, *112*(24), 7348–7355. https://doi.org/10.1073/pnas.1503751112

Guignard, M. S., Leitch, A. R., Acquisti, C., Eizaguirre, C., Elser, J. J., Hessen, D. O., Jeyasingh, P. D., Neiman, M., Richardson, A. E., Soltis, P. S., Soltis, D. E., Stevens, C. J., Trimmer, M., Weider, L. J., Woodward, G., & Leitch, I. J. (2017). Impacts of Nitrogen and Phosphorus: From Genomes to Natural Ecosystems and Agriculture. *Frontiers in Ecology and Evolution*, *5*. https://www.frontiersin.org/articles/10.3389/fevo.2017.00070

Hammarsten, M., Askerlund, P., Almers, E., Avery, H., & Samuelsson, T. (2019). Developing ecological literacy in a forest garden: Children's perspectives. *Journal of Adventure Education and Outdoor Learning*, *19*(3), 227–241. https://doi.org/10.1080/14729679.2018.1517371

Hart, R. (1996). *Forest Gardening: Cultivating an Edible Landscape, 2nd Edition*. Chelsea Green Publishing.

Hartemink, A. E., & Barrow, N. J. (2023). Soil pH - nutrient relationships: The diagram. *Plant and Soil*, *486*(1), 209–215. https://doi.org/10.1007/s11104-022-05861-z

Heaton, L., Fullen, M., & Bhattacharyya, R. (2016). Critical Analysis of the van Bemmelen Conversion Factor used to Convert Soil Organic Matter Data to Soil Organic Carbon Data: Comparative Analyses in a UK Loamy Sand Soil. *Espaço Aberto*, *6*, 35–44. https://doi.org/10.36403/espacoaberto.2016.5244

Henrichs, T., Zurek, M., Eickhout, B., Kok, K., Raudsepp-Hearne, C., Ribeiro, T., van Vuuren, D., &Volkery, A. (2010). Scenario Development and Analysis for Forward-looking Ecosystem Assessments. In United Nations Environment Programme World Conservation Monitoring Centre, *Ecosystems and Human Wellbeing: A Manual for Assessment Practitioners*. Island Press. https://wedocs.unep.org/20.500.11822/8949

Holmgren, D. (2012). *A summary of permaculture concepts and principles taken from 'Permaculture Principles & Pathways Beyond Sustainability'*.

Horcea-Milcu, A.-I., Leventon, J., & Lang, D. J. (2022). Making transdisciplinarity happen: Phase 0, or before the beginning. *Environmental Science & Policy*, *136*, 187–197. https://doi.org/10.1016/j.envsci.2022.05.019

Hotel Haferland. (2023). *BiolandHotelgarten – Hotel Haferland*. https://hotelhaferland.de/bioland-hotelgarten/

IPBES. (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services* (summary for policy makers). Zenodo. https://doi.org/10.5281/ZENODO.3553579

IPCC. (2019). *Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*.

Jacke, D., & Toensmeier, E. (2005a). *Edible forest gardens. Volume 1: Ecological vison and theory for temperate-climate permaculture*. Chelsea Green Publishing.

Jacke, D., & Toensmeier, E. (2005b). *Edible forest gardens. Volume 2: Ecological design and practice for temperate-climate permaculture*. Chelsea Green Publishing.

Janssen, M., Bodin, Ö., Anderies, J., Elmqvist, T., Ernstson, H., McAllister, R. R. J., Olsson, P., & Ryan, P. (2006). Toward a Network Perspective of the Study of Resilience in Social-Ecological Systems. *Ecology and Society*, *11*(1). https://doi.org/10.5751/ES-01462-110115

Jin, S., Tian, X., & Wang, H. (2018). Hierarchical responses of soil organic and inorganic carbon dynamics to soil acidification in a dryland agroecosystem, China. *Journal of Arid Land*, *10*(5), 726–736. https://doi.org/10.1007/s40333-018-0066-2

Jose, S., Garrett, H. E., Gold, M. A., Lassoie, J. P., Buck, L. E., & Current, D. (2022). Agroforestry as an Integrated, Multifunctional Land Use Management Strategy. In H. E. Garrett, S. Jose, & M. A. Gold, *North American agroforestry* (3rd ed). Wiley American society of agronomy.

Kettler, T. a., Doran, J. w., & Gilbert, T. l. (2001). Simplified Method for Soil Particle-Size Determination to Accompany Soil-Quality Analyses. *Soil Science Society of America Journal*, *65*(3), 849–852. https://doi.org/10.2136/sssaj2001.653849x

Klimaatportaal. (2023). *Klimaat in de provincie Utrecht*. Drogte, Hitte, Overstromingen. https://experience.arcgis.com/experience/7ce581cbafbd4821a531aea13663fe01/page/Droogte/

KNMI. (2021). *KNMI Klimaatsignaal '21: Hoe het klimaat in Nederland snelverandert* (p. 72). KNMI.

KNMI. (2023). *Klimaat van Nederland*. https://www.knmi.nl/klimaat

Lal, R. (2020). Soil organic matter and water retention. *Agronomy Journal*, *112*(5), 3265–3277. https://doi.org/10.1002/agj2.20282

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, *7*(1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Lehmann, L. M., Lysák, M., Schafer, L., & Henriksen, C. B. (2019). Quantification of the understorey contribution to carbon storage in a peri-urban temperate food forest. *Urban Forestry & Urban Greening*, *45*, 126359. https://doi.org/10.1016/j.ufug.2019.06.002

Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., &Schellnhuber, H. J. (2019). Climate tipping points—Too risky to bet against. *Nature*, *575*(7784), 592–595. https://doi.org/10.1038/d41586-019-03595-0

Lerch, G. (1972). Pflanzenökologie. In *Pflanzenökologie*. De Gruyter. https://doi.org/10.1515/9783112643747

Lokin, M., & Ramaker, M. (2023, April 1). *Den Food Bosch food forest tour and conversation* [Personal communication].

Loorbach, D., &Rotmans, J. (2006). Managing transitions for sustainable development. In X. Olshoorn, Wieczorek, & A. J. Dordrecht, *Understanding Industrial Transformation*. Springer.

Lou, Y., Xu, M., Chen, X., He, X., & Zhao, K. (2012). Stratification of soil organic C, N and C:N ratio as affected by conservation tillage in two maize fields of China. *CATENA*, *95*, 124–130. https://doi.org/10.1016/j.catena.2012.02.009

Margesin, R., & Schinner, F. (2005). *Manual for soil analysis: Monitoring and assessing soil bioremediation*. Springer.

McKay, B. M., &Veltmeyer, H. (2021). Industrial agriculture and agrarian extractivism. In A. H. Akram-Lodhi, K. Dietz, B. Engels, & B. M. McKay (Eds.), *Handbook of Critical Agrarian Studies*. Edward Elgar Publishing. https://doi.org/10.4337/9781788972468.00065

Munsell, J. F., Bukowski, C. J., Yanez, M., & Allen, J. A. (2022). Urban Food Forests and Community Agroforestry Systems. In H. E. Garrett, S. Jose, & M. A. Gold, *North American agroforestry* (3rd ed). Wiley American society of agronomy.

Nabisubi, B., Frenquellucci, C., Lukács, D., &Bridault, V. (2020). *Financing food forests* [Student training & consultancy report, has]. https://www.has.nl/media/25gjudp2/financing-food-forests.pdf

Nelson, D. W., & Sommers, L. E. (1996). Total Carbon, Organic Carbon, and Organic Matter. In *Methods of Soil Analysis* (pp. 961–1010). John Wiley & Sons, Ltd. https://doi.org/10.2136/sssabookser5.3.c34

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., Bednarek, A. T., Bennett, E. M., Biggs, R., de Bremond, A., Campbell, B. M., Canadell, J. G., Carpenter, S. R., Folke, C., Fulton, E. A., Gaffney, O., Gelcich, S., Jouffray, J.-B., Leach, M., … Österblom, H. (2020). Principles for knowledge co-production in sustainability research. *Nature Sustainability*, *3*(3), Article 3. https://doi.org/10.1038/s41893-019-0448-2

NPUH. (2020). *Blauwe Agenda*. Stichting Nationaal Park Utrechtse Heuvelrug. https://www.np-utrechtseheuvelrug.nl/stichting-npuh/blauwe-agenda/, https://www.np-utrechtseheuvelrug.nl/stichting-npuh/blauwe-agenda/

Nurani, L. M. (2008). Critical Review Of Ethnographic Approach. *JurnalSosioteknologi*, *7*(14), 441–447.

Nytofte, J. L. S., & Henriksen, C. B. (2019). Sustainable food production in a temperate climate – a case study analysis of the nutritional yield in a peri-urban food forest. *Urban Forestry & Urban Greening*, *45*, 126326. https://doi.org/10.1016/j.ufug.2019.04.009

Park, H., & Higgs, E. (2018). A criteria and indicators monitoring framework for food forestry embedded in the principles of ecological restoration. *Environmental Monitoring and Assessment*, *190*(3), 113. https://doi.org/10.1007/s10661-018-6494-9

Park, H., Turner, N., & Higgs, E. (2018). Exploring the potential of food forestry to assist in ecological restoration in North America and beyond: Food forestry and ecological restoration. *Restoration Ecology*, *26*(2), 284–293. https://doi.org/10.1111/rec.12576

Patel, R. (2009). Food sovereignty. *The Journal of Peasant Studies*, *36*(3), 663–706. https://doi.org/10.1080/03066150903143079

Penn, C. J., &Camberato, J. J. (2019). A Critical Review on Soil Chemical Processes that Control How Soil pH Affects Phosphorus Availability to Plants. *Agriculture*, *9*(6), Article 6. https://doi.org/10.3390/agriculture9060120

Pepels, N. (2019). *Do food forests need fertiliser?* [Internship report]. WUR.

Pereira, L. M., Hichert, T., Hamann, M., Preiser, R., & Biggs, R. (2018). Using futures methods to create transformative spaces: Visions of a good Anthropocene in southern Africa. *Ecology and Society*, *23*(1). https://www.jstor.org/stable/26799045

Philip, S. Y., Kew, S. F., Wiel, K. van der, Wanders, N., &Oldenborgh, G. J. van. (2020). Regional differentiation in climate change induced drought trends in the Netherlands. *Environmental Research Letters*, *15*(9), 094081. https://doi.org/10.1088/1748-9326/ab97ca

Pilgrim, E. S., Osborne, J., & Winter, M. (2018). Evaluating the multiple benefits of multi-layered agroforestry systems. *International Journal of Agricultural Management*, *7*, 4–16. https://doi.org/10.5836/ijam/2018-07-04

Ponton, K., &Remiarz, T. (2022). *Ten Year Forest Garden Trial. Final Report (2011—2021)*. Permaculture Association UK. https://www.permaculture.org.uk/sites/default/files/ten_year_forest_garden_trial_final_report.pdf

Queirós, A., Faria, D., & Almeida, F. (2017). Strengths and limitations of qualitative and quantitative research methods. *European Journal of Education Studies*, *0*, Article 0. https://doi.org/10.46827/ejes.v0i0.1017

Rawls, W. J., Pachepsky, Y. A., Ritchie, J. C., Sobecki, T. M., & Bloodworth, H. (2003). Effect of soil organic carbon on soil water retention. *Geoderma*, *116*(1), 61–76. https://doi.org/10.1016/S0016-7061(03)00094-6

Raza, S., Zamanian, K., Ullah, S., Kuzyakov, Y., Virto, I., & Zhou, J. (2021). Inorganic carbon losses by soil acidification jeopardize global efforts on carbon sequestration and climate change mitigation. *Journal of Cleaner Production*, *315*, 128036. https://doi.org/10.1016/j.jclepro.2021.128036

Runhaar, J., Bartholomeus, R. P., & Cirkel, D. G. (2010). *Invloedgrondwaterstanden op standplaatsconditiesenvegetatie | Hydrotheek*. WUR. https://library.wur.nl/WebQuery/hydrotheek/1972322

Sabareeshwari, V., Baskar, M., Balasubramaniam, P., Geethalakshmi, V., & K., S. (2018). Assessment of Water Holding Capacity of Major Soil Series of Ponnaniyar Reservoir Basin, Manapparai, Trichy, Tamil Nadu, India. *Research Journal of Agricultural Sciences*, *9*(6).

Sala, O. E., Stuart Chapin, F., III, Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. M., Mooney, H. A., Oesterheld, M., Poff, N. L., Sykes, M. T., Walker, B. H., Walker, M., & Wall, D. H. (2000). Global Biodiversity Scenarios for the Year 2100. *Science*, *287*(5459), 1770–1774. https://doi.org/10.1126/science.287.5459.1770

Salgueiro-Otero, D., Barnes, M. L., & Ojea, E. (2022). Climate adaptation pathways and the role of social-ecological networks in small-scale fisheries. *Scientific Reports*, *12*(1), Article 1. https://doi.org/10.1038/s41598-022-18668-w

Salzman, J., Bennett, G., Carroll, N., Goldstein, A., & Jenkins, M. (2018). The global status and trends of Payments for Ecosystem Services. *Nature Sustainability*, *1*(3), Article 3. https://doi.org/10.1038/s41893-018-0033-0

Sangaramoorthy, T., & Kroeger, K. A. (2020). *Rapid Ethnographic Assessments: A Practical Approach and Toolkit For Collaborative Community Research* (1st ed.). Routledge. https://doi.org/10.4324/9780429286650

Schafer, L. J., Lysák, M., & Henriksen, C. B. (2019). Tree layer carbon stock quantification in a temperate food forest: A peri-urban polyculture case study. *Urban Forestry & Urban Greening*, *45*, 126466. https://doi.org/10.1016/j.ufug.2019.126466

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), Article 13. https://doi.org/10.3390/su11133522

Scheffer, M., Carpenter, S. R., Lenton, T. M., Bascompte, J., Brock, W., Dakos, V., van de Koppel, J., van de Leemput, I. A., Levin, S. A., van Nes, E. H., Pascual, M., & Vandermeer, J. (2012). Anticipating Critical Transitions. *Science*, *338*(6105), 344–348. https://doi.org/10.1126/science.1225244

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., … Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, *562*(7728), Article 7728. https://doi.org/10.1038/s41586-018-0594-0

Stichting Voedselbosbouw. (2023a). *Voedselbossen in Nederland*. https://www.voedselbosbouw.org/voedselbosbouw-link/voedselbossen-in-nederland/

Stichting Voedselbosbouw. (2023b). *Voedselbossen: Van waardenaar geld - Stichting Voedselbosbouw*. https://www.voedselbosbouw.org/nieuws/voedselbossen-van-waarde-naar-geld/

Stichting Voedselbosbouw Nederland. (2018). *RekenmodellenAanlegenExploitatieVoedselbossen Welna*.

Swart, F. (2022). *Food forest case study: From forest to table* [Internship Report]. HAS university of applied sciences.

TEEB. (2010). *Quick Guide to The Economics of Ecosystems and Biodiversity for Local and Regional Policy Makers*. https://www.teebweb.org/media/2010/09/TEEB-D2-Local-and-Regional-quick-guide_English.pdf

Toensmeier, E. (2016). *The Carbon Farming Solution: A Global Toolkit of Perennial Crops and Regenerative Agriculture Practices for Climate Change Mitigation and Food Security*. Chelsea Green Publishing.

Toensmeier, E., Ferguson, R., & Mehra, M. (2020). Perennial vegetables: A neglected resource for biodiversity, carbon sequestration, and nutrition. *PLOS ONE*, *15*(7), e0234611. https://doi.org/10.1371/journal.pone.0234611

Tomich, T., Brodt, S., Ferris, H., Galt, R., Horwath, W., Kebreab, E., Leveau, J., Liptzin, D., Lubell, M., Merel, P., Michelmore, R., Rosenstock, T., Scow, K., Six, J., Williams, N., & Yan, L. (2011). Agroecology: A Review from a Global-Change Perspective. *Annual Review of Environment and Resources*, *36*. https://doi.org/10.1146/annurev-environ-012110-121302

Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G., &Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment*, *230*, 150–161. https://doi.org/10.1016/j.agee.2016.06.002

Trivedi, P., Singh, B. P., & Singh, B. K. (2018). Chapter 1 - Soil Carbon: Introduction, Importance, Status, Threat, and Mitigation. In B. K. Singh (Ed.), *Soil Carbon Storage* (pp. 1–28). Academic Press. https://doi.org/10.1016/B978-0-12-812766-7.00001-9

USDA. (2011). *Carbon to Nitrogen Ratios in Cropping Systems*. USDA Natural Resources Conservation Service. https://marionswcd.org/wp-content/uploads/C_N_ratios_cropping_systems.pdf

van Capellen, F. (2020). *An explorative study into potential partnerships between restaurants and food forests in The Netherlands* [Internship report, has]. https://www.has.nl/media/rrecq25v/report_the_potential_of_partnerships_between_restaurants_-and_foodforests_fienvancappellen_has.pdf

van de Kerkhof, M. (2006). A dialogue approach to enhance learning for sustainability. An Dutch experiment with two participatory methods in the field of climate change. *Integrated Assessment Journal*, *6*(4), Article 4. https://journals.lib.sfu.ca/index.php/iaj/article/view/2724

van Gent, T. (2019). *FOOD FOREST BUSINESS MODELS IN THE NETHERLANDS: CHALLENGES AND OPPORTUNITIES FOR SCALING* [Master Thesis]. Utrecht University.

van Ginhoven, S., Gerrits, J., Hartog, A., Sparreboom, J., Warmerdam, D., van Zon, L., &Zwerver, D. (2022). *Implementing climate adaptation strategies for the agricultural and natural transition*. Utrecht University, NPUH.

van Vliet, M., & Kok, K. (2013). Combining backcasting and exploratory scenarios to develop robust water strategies in face of uncertain futures. *Mitigation and Adaptation Strategies for Global Change*, *20*. https://doi.org/10.1007/s11027-013-9479-6

Voedseluit het bos. (2022a). *Food forest recipes: Dorskamp—Visitors welcome!* Food From The Forest. https://voedseluithetbos.nl/en/voedselbosrecepten/?recept=27280&grondsoort=Zandgrond&grondwaterstand=60-120+centimeter+onder+het+maaiveld

Voedseluit het bos. (2022b). *Food forest recipes: Welna—Future-proof (food) forest in production forest*. Food From The Forest. https://voedseluithetbos.nl/en/voedselbosrecepten/

Voedseluit het bos. (2022c, April 14). *Four food forest themes and their rationale*. Food From The Forest. https://voedseluithetbos.nl/en/kennis/vier-voedselbosthemas/

Voedseluit het bos. (2023). *Course calendar*. Food From The Forest. https://voedseluithetbos.nl/en/cursussen/

Vos, A. de, Maciejewski, K., Bodin, Ö., Norström, A., Schlüter, M., &Tengö, M. (2021). The practice and design of social-ecological systems research. In *The Routledge Handbook of Research Methods for Social-Ecological Systems*. Routledge.

Wartman, P., Van Acker, R., & Martin, R. C. (2018). Temperate Agroforestry: How Forest Garden Systems Combined with People-Based Ethics Can Transform Culture. *Sustainability*, *10*(7), Article 7. https://doi.org/10.3390/su10072246

Wendel, B., Rooduijn, B., &Disselhorst, E. (2023). *Voedselbossen: Bodem, biodiversiteit, biomassa, business &beweging*. NationaalMonitoringsprogrammaVoedselbossen. https://www.voedselbosbouw.org/media/documents/Rapport_NMVB_Drie_Jaar_Voedselbossen_w2kOT2O.pdf

Wezel, A., Herren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., & Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, *40*(6), 40. https://doi.org/10.1007/s13593-020-00646-z

Wiersum, K. F. (2004). Forest gardens as an 'intermediate' land-use system in the nature-culture continuum: Characteristics and future potential. In P. K. R. Nair, M. R. Rao, & L. E. Buck (Eds.), *New Vistas in Agroforestry: A Compendium for 1st World Congress of Agroforestry, 2004* (pp. 123–134). Springer Netherlands. https://doi.org/10.1007/978-94-017-2424-1_9

Wigboldus, S., Leeuwen, S. van, Schoutsen, M., Vijn, M., & Kruit, J. (2022). *Agroforestry kansrijk(er) maken in Nederland: Hoe rekenen, waarmeerekeninghouden, enwaaraanwerken?* https://doi.org/10.18174/585185

Willis, K. J., Jeffers, E. S., & Tovar, C. (2018). What makes a terrestrial ecosystem resilient? *Science*, *359*(6379), 988–989. https://doi.org/10.1126/science.aar5439

World Bank. (2023a). *State and Trends of Carbon Pricing 2023*. https://doi.org/10.1596/39796

World Bank. (2023b). *Climate Change Knowledge Portal*. https://climateknowledgeportal.worldbank.org/

Wosten, J. H. M., Groenendijk, P., Veraart, J. A., &Lugt, L. M. van der. (2019). *Soil Organic Matter and its Importance for Water Management*. https://research.wur.nl/en/publications/soil-organic-matter-and-its-importance-for-water-management

WUR. (n.d.). *Hoogtekaart Nederland* [Map]. http://www.geo-informatie.nl/geodesk/hgt-300dpi.pdf

Young, K. J. (2017). Mimicking Nature: A Review of Successional Agroforestry Systems as an Analogue to Natural Regeneration of Secondary Forest Stands. In F. Montagnini (Ed.), *Integrating Landscapes: Agroforestry for Biodiversity Conservation and Food Sovereignty* (pp. 179–209). Springer International Publishing. https://doi.org/10.1007/978-3-319-69371-2_8

Acknowledgements

First and foremost, I would like to thank my supervisor Brian Dermody for the continuous scientific and practical support and encouragement to take a less conventional approach to a thesis. Thank you also to Victor Trouw and Andrea Rujas for making the lab assessments possible. Further, I would like to acknowledge the food forest practitioners for inviting me into their food forests and so openly sharing their knowledge and experiences. Also, thank you to Eline van Remortel and Victor Beumer from earthwatch for lending me the equipment for the ecological assessments. Last but not least, thank you Jemima for this collaboration, your time and engagement. I hope the food forest will be a great addition to your estate for many years to come!

Appendix A


Legenda
Paden van halfverharding
Bestaande bosvakken
Bestaande bomen
Nieuwe beukenlaan maat 10/12
Bosvak (iep, linde, beuk, eik, hazelaar, lijsterbos, tamme kastanje, vlier)
Grondwal/geul
Vijvers & sloten
0 10 20 30 40 50
N
Landgoed Zuylestein, Leersum
A3
Projectnr. 2012-0066
Definitief Ontwerp Sterrenbos
1:1000
Datum tekening 8-11-2021
M.Lijding
DO
DEBIE & VERKUIJL
tuin | park | landschap
Dorpsstraat 5, 3927 BA Renswoude
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Appendix B

Impression of the site. On the left: View from the centre of the Sterrenbos over the destroyed area. On the right: View from the moestuin along the central line of the Sterrenbos with FF site to the right. (Own photographs from December 2022)

Appendix C

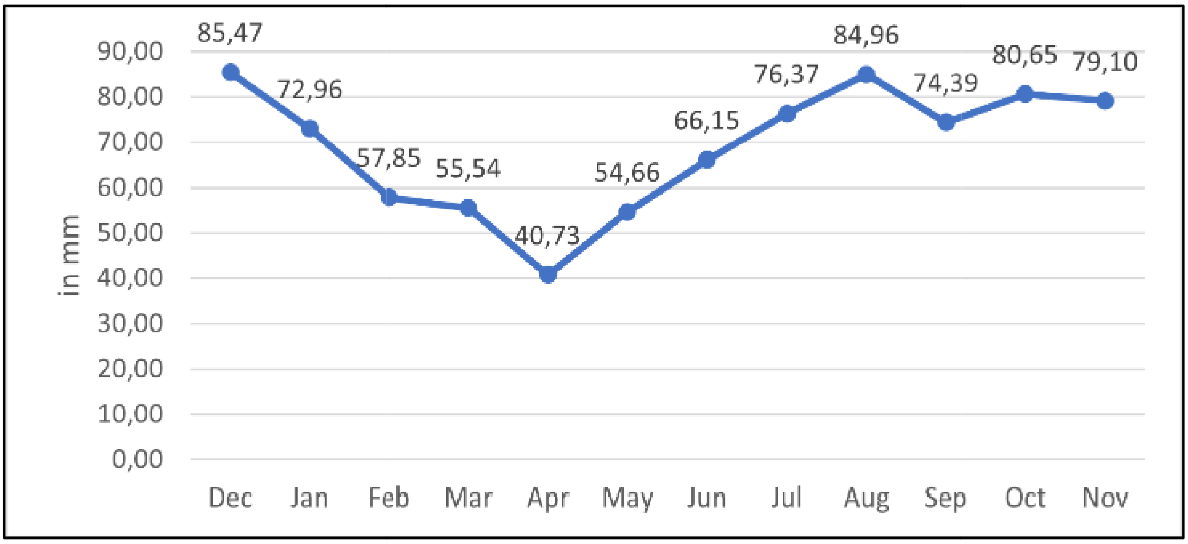
Table 5

Climate data for the Netherlands (1991-2020). (own representation) (World Bank, 2023b)

Season	Average Minimum Temperature (in °C)	Mean-Temperature (in °C)	Average Maximum Temperature (in °C)	Average Total Pre-cipitation (in mm)
Winter (DJF)	1,35	3,98	6,66	216,28
Spring (MAM)	5,15	9,73	14,34	150,93
Summer (JJA)	12,53	17,33	22,19	227,48
Autumn (SON)	7,26	10,90	14,60	234,14
Annual	**6,57**	**10,48**	**14,47**	**828,83**

Figure 11

Monthly average precipitation for province of Utrecht per month (1991-2020), (own representation) (World Bank, 2023b)



Appendix D
Binnenbos

Research format	Participated in apple tree planting on 29th March (10am-3pm)
Contact	Food forest manager/gardener "voedselboswachter" (Apprenticeship as gardener and 1 year workshops specifically for food forests
Size	Ca 4 ha
Location	Langbroek (Heuvelrug)
Conditions	Soil: mostly clay Area crossed by and sourrounded by ditches (sloten) Ditches along the polders for water retention (used to be deepened every year but not anymore) Oak forest on the side
Site before food forest	Pasture land (sheep)
Design	By professional landscape designer with food forest experience
Time planned to complete set up	5-6 years
Established	Started in November 2021 (originally February but legal objection → delay)
Aim	Creating a showcase model to inspire farmers to implement some agroforestry practices
Business model	None (finances stable due to stichting)
Involved actors	Stichting Voedselbosbouw

Design

- Diverse as possible for pollinators

Plants

- Comfrey and distel as transport plants
  (transport of water and nutrients up from below and distribution – mainly by cutting and using as mulch; soil loosener)
- Nitrogen fixators due to stickstof crisis not really necessary but implemented to address all aspects of a functioning system (in theory)
- Species chosen according to water tables
- Umbelata plant species attracts hover flies -> eat larvae pf other animals
- Elders died (maybe too much environmental stress since usually in grown forests)

Management/setup/implementation/hurdles

- Deer damage young plants by rubbing their developing antlers on them
  Recommendation: for new food forest to bild fence until a bit matured, otherwise individual protection but that is very time intensive
- Mice love roots and habitat under mulch → try to avoid that

Costs

- Apple tree 15-20€
- Nut trees 60-200€

Climate adaptation

- Not addressed specifically in design but implicitly:
    - Sowing instead of cloning to create biodiversity →resilience
    - Windbreaking hedges to address increasing storm intensity

Water management

- Polders with stable water realised by waterschapen→ currently no worries about too low groundwater
- Trying to increase water retention on the area so it is not transported away (e.g. letting the ditches' vegetation grow → infiltration

Extra Information

- Read martin crawford
- Difference of approaches: Crawford: well planned, established in one, Wouter van Eck: very slow "let the land do its thing" (Kats opinion: no time anymore to let the land do its thing, Wouters project had less extreme summers and winters, this is not the case anymore)
- Topotijdreis.nl = maps the last 200 years
- Bastiaan Rooduijn (did monitoring and now has own food forest advising business)
- https://voedseluithetbos.nl/en/→ explore voedselbossen

Den Food Bosch

Research format	Participating in their monthly tour on 1st April and asking questions after
Contact	In person with 3 "beheerders" – managers E-Mail with Marente
Size	0.8ha
Location	Sint Michielgestel
Conditions	Sandy Soil High groundwater table
Site before food forest	cornfield
Design	Originated from student thesis with idea of syntropic farming (Ernst Götsch)
Time planned to complete set up	Built to provide harvest from the beginning (includes succession thinking)
Established	Winter 2017/18 (5,5 years)
Aim	Being n example of what food production can look like
Business model	Originally to sell produce, changed with change of managers and workers to a foundation model, now starting to set up delivery to Michelin Restaurant in Den Bosch
Involved actors	DFB foundation (Den food bosch)

Design

- Designed for high maintenance to create fast yield
- Planned for space &time
- Diverse as possible for pollinators
- Extending flowering thesis for as long as possible to sustain pollinators (especially in July and August usually not much available for them)
- Includes wooden structures for grape vines for shadow that are planned to rot and fall when the other trees are becoming big enough
- Half circle design to provide sun everywhere
  Smaller half circles of fast yielding shrubs should grow together with larger circles to form wider rows as forest matures
- Using pioneer trees around perennials to create shadow/forest ecosystem before these are big enough

Plants

- General idea**: flowering for as long as possible to support insects and to include as many symbiotic relationships as possible but often difficult or impossible to research**
- Many foreign plants
- Includes row of different raspberry species to show diversity and making harvesting over longer time period possible
- Willow trees for fast biomass
- Pioneer plants to loosen soil, generate biomass and create a forest ecosystem (→ shade) (birch, elder
- Wind protecting hedges (willow, pioneersmut)
- Pear
- Hazelnut (starts as shrub but grows into almost a tree)
- Cassis
- Mint can sustain half shadow
- Glechoma hederacea (Hondsdraf) as ground cover
- Planting lupin on pathways to cut and drop later
- Gooseberry – likes shadow
- Ground layer:
  - Sage
  - Rosmary
  - Lavender
- European dwarf cherry (struikkers)
- For protein:
  - Nuts
  - Erwtenstruikje (=Siberian peashrub) (also N fixator)
- Kardinalsmut (=spindle tree) as hedge:
  Poisonous but attracts lice that attract predators such as wasps → support pest defence
- Pine tree can stand in shade for 10 years and grow large afterwards
- Wild garlic for shade

Management/setup/implementation/hurdles

- Built fence around it to prevent too much damage in setup phase
- Pioneer trees to generate biomass (very low SOM content after use as monoculture) → chop and drop
- In the style the food forest was setup much management is included
  - Watering the plants in the beginning as almost everything was planted at once
  - Using pioneer trees to generate much biomass → cutting back to stimulate more growth and to generate biomass on the ground

- Felling of pioneering trees that do not provide harvest at some point
- Tree species and race choices: **dependant on what local grower has available**
- Many different species (e.g. apple trees) make harvest more complex and require detailed knowledge
- Creating the ground layer difficult: much competition with grass etc, could be smart to introduce things like mint and rosemary later when balance has established
(otherwise grass needs to be actively removed)
- Hurdle: produce is constantly harvested: what to do then!? → distribution system must be well thought out

Costs

- Estimated setup costs for them: 10.000€-20.000€
- Recommendation: https://meerbomen.nu/over-de-actie/planten/

Climate adaptation

- Only implicitly addressed because design was done by someone else (biodiversity → resilience)
- Main focus on droughts → increasing water holding capacity

Water management

- Increasing organic soil content as much as possible to increase soil water holding capacity (per % of SOM 16l more water in soil according to Marente
- (already raised their SOM for 4%)

Extra Information

- Great idea: create monthly harvest rows (August etc. → people can come and harvest)
- Older species like peatree does not produce tastes we are used to today → harder, bitterer, less sweet
- Idea of manager: open source document for beginners of food forests, simple language and accessible
- My idea: what food forest suits you?
- Personal connection/character of care taker/personality comes in: if one caretaker does not like a certain plant they will take less care of it

Info for further research:

VoedesbosSchijndel (one has 4ha and one 16ha)

Martijn Allbrecht (potential expert interview)

Plant inspiration from Voedselbosrecipes: https://www.devoedselboss.nl/recepten-uit-het-voedselbos/

Haarzuilens

Research format	Joined the subscription group in harvesting and cooking sirup 20.5.2023
Contact	Voedselbosbeheerders Jan en Marten
Size	5 ha
Location	Utrecht Haarzuilen
Conditions	Soil: heavy clay groud, neutral ph Area crossed by and sourrounded by ditches (sloten) Different food forest areas on different polders (e.g one with mainly exotic

	species)
Site before food forest	Nature area
Design	Through Jan and Marten (biologists) But no info on how exactly
Time planned to complete set up	Continuous project with no defined equilibrium target state
Established	Oldest part: 2016, newer parts since 2020
Aim	Not loose any money, show what is possible, experiment
Business model	Multiple streams of income but as they are part of the lekkerlandgoedstichting there is no need to be independently financially stable
Involved actors	Stichting Voedselbosbouw

Design

- Aesthetically pleasing
- Adventurous layout to make it into an experience
- Divided into different sections on different islands
- Trees stand closer to the sloten grow better but probably due to clay ground, where water levels in the sloten does not affect growing area water levels much
- Martin Crawford inspired (no scientific approach at all)

Plants

- Old dutch species (old spinach): brave Hendrik
- Winterlinde: leaves for salad
- Walnuts and hazelnuts
- Fruit trees: raspberry, gooseberry (had partial mildew mold)
- Mint but has hard competition with nettles
- Witte moorbij (mulberry, leaves as salad and berries)
- Mispel (medlar, fruits and wijn/cider can be made from it)
- Judas tree (judas boom, for beautiful tasty salad flowers
- Elderberry (vlierbloessem)
- Loorbeer (eat young shoots, have as spice leave)
- Roomsekervel (SCHADUWPLANT) tastes like anis
- Sorrel (zuring) to
- Honingbes&wildehoningbes (first berry of the year)
- Groundivy (hondsdraf) from mint family and nice groundcover, (restaurant Herold harvests a lot every week)
- Pimpernoot (European bladdernut) eadible young leaves and flowers – taste very nutty
- Akelei (Aquilegia), eadible flowers blue
- Fenkel
- Uiensoep boom

Management/setup/implementation/hurdles

- Trees that grow large can grow up well in the shadows
- Stinging nettles come from nitrate ground and mostly affect other plants by shadowing them and creating a wet climate and climbing opportunities for snails which eat the other plants first, also little bit of water competitione
- Two people (jan and Marten) that each work 1 to 2 days per week there to e.g. keep paths clear, do necessary maintenance

- Young trees have it difficult in wet winter soils, long lasting night frosts into spring and then warm summers
- 10 years should be given to the forest to allow actual revenue

Costs

- Invested 100.000€

Jaarrekening lekker landgoed 2020

Baten	2020	2019
Inkomsten uit voedselproducie	€ 2.185,56	-
Inkomsten uit donaties	€ 3.350,00	€ 1.281,50
Inkomsten uit aangeschreven fondsen	€ 4.000,00	-
Totaal baten	€ 9.535,56	€ 1.281,50
Lasten		
Aanschaf plantgoed en zaaigoed	€ 1.785,49	€ 1.932,87
Transport en materiaalkosten	€ 1.135,69	€ 13.953,96
Graafwerkzaamheden	€ 139,15	€ 79,86
Kennis en onderzoek	-	€ 70,95
Kosten vrijwilligersactiviteiten	€ 20,00	€ 90,89
Kosten vergoeding (zakgeld JD)	€ 2.000,00	-
Vaste lasten; kosten KvK, website, bankrekening	€ 186,50	€ 150,05
Kosten vergunning schuurtje	-	€ 517,20
Afschrijving schuurtje	€ 1.000,00	-
Totaal lasten	€ 6.266,83	€ 16.795,78
Resultaat	€ 3.268,73	€ -15.514,28

Climate adaptation

- Not considered really in the design
- Many plants from all over the world – so could be seen as some kind of adaptation

Water management

extremely wet in winter, 1-2- meters deep in summer → very variable

Business model

- Subscriptions of self harvesters (150€/year)
- Restaurants (Héron, Landhuis in de Stad, eneenenkelekeerGasterij Wielrevelt)
- VOKO
- Donations
- Grants

See their year afrekening: http://www.lekkerlandgoed.nl/wp-content/uploads/2021/02/2020_Jaarverslag-Lekker-Landgoed-1.pdf

Other Information:

Read martin crawford

- Article about them: https://christiansson.nl/eetbaar/toekomstboeren-jan-en-maarten-op-lekker-landgoed/

Appendix F

Figure 12

Map representing the location of the borehole (screenshot from DINOloket) (DINOloket, 2023)

Appendix E
Practitioner Participation Consent Form

Contact

Pia Winckler

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p.c.winckler@students.uu.nl

Information on the research

Name of Researcher	Pia Winckler
Project Type	Master thesis research
Institution	Utrecht University
Faculty	Faculty of Geosciences
Study Program	Sustainable Development – Environmental Change and Ecosystems
Title	Designing a food forest at the Utrechtse Heuvelrug: A case study at estate Zuylestein
Research Question	What are sustainable design principles for a climate adaptive food forest in the cultural landscape of Zuylestein estate within the Utrechtse Heuvelrug National Park?

The goal of this research is to identify promising design principles for a food forest at the estate Zuylestein. For this purpose, I am interested in learning about successful or promising food forest projects and practices. I would like to learn about how and what plants and designs were chosen for your specific site, which plants and design principles are (not) successful in your food forest if you have experience with or plan for climate adaptation and what business models you pursue to sustain your project. In short, I am curious to learn about your experiences, successes and failures with the food forest.

Form of the research

The form of research is agreed upon before and can range from a tour of your food forest or telling me about it to me actively participating in the maintenance. Any information and knowledge you would like to share during or after is welcome. I will take notes during and after to store the information.

Use of your data

The information you share with me will be handled confidentially and used in my master thesis. Your name will not be mentioned, however the food forest you are involved with and your relation to/position within it will be included. This is necessary due to food forests' unique site conditions. If the knowledge you share might be utilized in any other project or publication (such as an openly accessible best-practice guide), you will be asked for your consent again.

Right to withdraw

You have the right to withdraw your consent to participate at any point.

Declaration

Food forest: ______________________________

I confirm that:

- I am satisfied with the received information about the research;
- I have no further questions about the research at this moment;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes;

I understand that:

- I have the right to withdraw my consent to use the data as long as they can be identified;
- I have the right to see the research report afterwards.

I have read the explanations of the participation consent form and agree to participate in the research:

O yes **O** no

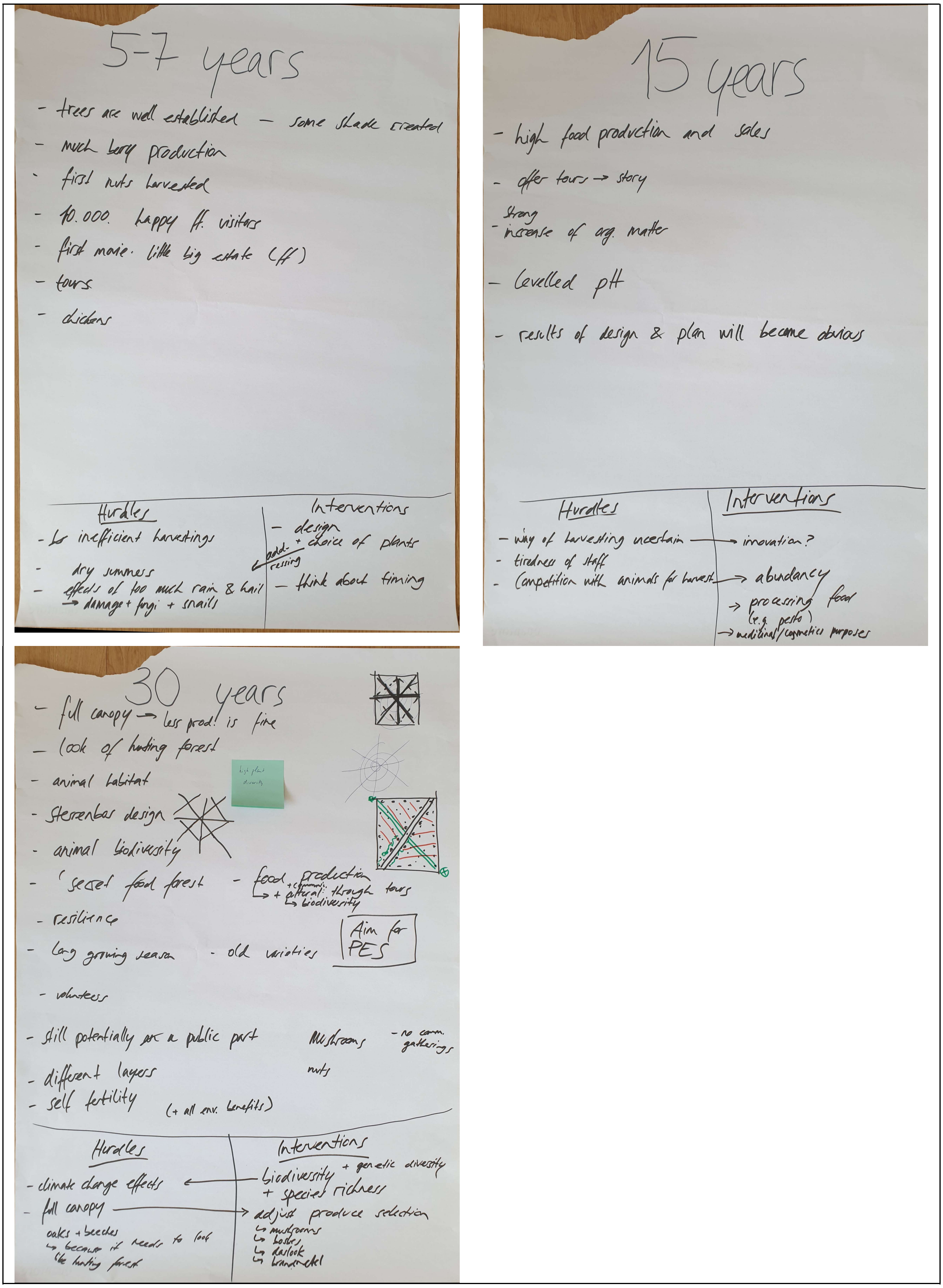
Appendix G

Recreational (using turquoise post-its), Communal (yellow), Experimental (pink) and Productional (purple)

Appendix H

Figure 13

Posters collecting the results of the scenario and backcasting workshop



Note. Starting from the top-left for 5-7 years, 15 years on the top-right and 30 years on the bottom.