FOOD FOREST T. E. A. M.

FINAL REPORT
FOOD FOR THOUGHT

ACT GROUP 2846

The role of wildlife in Dutch food forest systems

APRIL 2022

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FOOD FOREST T.E.A.M.:

Peter van Munnen (Manager)
Fiona Martinez Hofmans (Secretary)
Hannah Ertelt (Controller)
Dion Nugraha Aji
Hanzhe Lin
Rayan Majoor
Tom Bachmann

COMMISSIONER:

Ir. Jeroen Kruit
Wageningen Environmental Research

ACADEMIC ADVISOR

Ir. MJ (Marianne) Groot
Tree Nursery and Fruit Research

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ABSTRACT

Food forests represent a novel branch of modern agroforestry that is in its ascendence. Food forestry increasingly aims to transition into an economically viable agroecological practice. This is done by improving biological diversity, with the end goal of restoring and utilizing ecosystem processes. Faunal diversity, and respective trophic level interactions, may exert impacts on food forest systems. This project aimed to explore, and provide insights into, the ecological challenges currently faced by food forest practitioners in the Netherlands. Additionally, it was investigated whether populations of vertebrate pest species within food forests are naturally regulated by predators, and to what extent these predator-prey interactions may be facilitated through anthropogenic interventions. Geographic information systems (GIS) tools were used to classify food forests in the Netherlands according to two categories: (i) food forest size and (ii) degree of surrounding landscape heterogeneity. This way, a sample size of six suitable food forests was obtained for subsequent data collection. Findings were based on information gained from semi-structured interviews with food forest practitioners, and on additional literature review. A diversity of wildlife species was mentioned to inhabit Dutch food forest systems.

SAMENTVATTING

Voedselbossen zijn een opkomende boslandbouw productie methode. Meer en meer verschuift de doelstelling van voedselbosbouw naar het ontwikkelen van een economisch rendabel agroecologisch systeem. Het vergroten van de biodiversiteit, door gebruik te maken van ecologische processen speelt hierbij een centrale rol. De diversiteit van fauna en de interacties tussen de trophische niveaus, heeft ogenschijnlijk een belangrijke rol in het functioneren van voedselbossen. Tijdens dit project is er in kaart gebracht met welke ecologische uitdagingen Nederlandse voedselbosbouwers te maken hebben. Daarnaast is er onderzocht of de populaties van gewervelde plaagdieren binnen voedselbossysemen op een natuurlijke wijze onder controle worden gehouden door predatoren en op wat voor manieren deze roofdier-prooi interacties kunnen worden gestimuleerd door menselijke interventies. Het geographishe informatie systeem (GIS) is gebruikt om voedselbossen in Nederland te classificeren aan de hand van twee factoren: (i) het formaat van het voedselbos en (ii) de mate van heterogeniteit van de directe omgeving. Aan de hand van deze criteria zijn zes geschikte voedselbossen, voor verdere informatie vergadering geselecteerd. Semi-gestructureerde interviews met de geselecteerde voedselbosbouwers, gecombineerd met een literatuur studie hebben geleid tot de verzameling van resultaten. Verscheidene diersoorten

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INTRODUCTION

A discrepancy exists between the intensification of conventional agriculture to feed a growing global human population and a developing communal awareness of nature's intrinsic value, which raises awareness on the value of functioning natural systems. Although this predicament is visible in many parts of the world, it is perhaps amplified in the Netherlands. During recent decades, the Netherlands has been the second largest producer of food worldwide (Harmsen, 2018). To accommodate such intensive production, a large part of the land (66% in 2019) is attributed to agriculture (Berkhout et al., 2021). Intensive land use practices have resulted in, and continually contribute to, large-scale eutrophication, acidification, and biodiversity loss (van den Burg et al., 2021). Recognizing the unsustainability of the current system catalysed the development of potentially novel, ecologically sustainable food production systems. Transitions in land-use practices emerged which account for constructive practical implications of agroecological principles (Wezel et al., 2020). Modern agroforestry, as a nature-inclusive type of agriculture, is such an agroecological land-use type (Gliessman, 1990; Jose, & Gordon, 2008). Agroforestry systems include a variety of land-use types, with the overall similarity that they integrate trees with agricultural practices. A specific type of agroforestry systems are food forests. In the Netherlands, food forests are in its ascendence as an agroecological system to transform agriculture to a more sustainable, biodiverse system of food production (de Groot & Veen, 2017).

What is a food forest?

According to the definition of the Green Deal Voedselbossen a food forest is:

"A human-designed productive ecosystem, modelled on a natural forest with a high diversity of perennial and/or woody species, whose parts (fruits, seeds, leaves, stems, etc.) serve as food for humans. A 'robust size' is defined by 0.5 hectares in an ecologically rich environment; in a severely impoverished environment, a minimum area of up to 20 hectares is required. It contains:

- a crown layer of taller trees,
- at least 3 of the other niches/ vegetation layers (lower trees, shrubs, herbs, ground covers, underground plants and climbing plants),
- and a rich forest floor life."

According to Huijssoon et al. (2017), food forests designate "a polyculture design that consists of multiple layers of harvestable species, fulfilling ecological, economical, and socio-cultural functions through a practice of inclusive farming and other (economical) activities". Interest in food forests is growing at an accelerating rate in the Netherlands (NPO, 2020). In 2017, the Green Deal Food Forests was conceived as a collaborative strategy by stakeholders within the agricultural sector (government agencies, legislators, research institutions, entrepreneurs) to stimulate implementation and legitimize the scope of this novel agroecological system.

Food forest systems rely and thrive on a high abundance of intact natural processes (Limareva, 2015). System design of food forests aims to enable successive growth of the system to reach a state of biological self-sustainability and minimize dependency on human intervention. As food forests are open systems, they are receptive to a wide and continuously evolving array of animal-plant interactions. High faunal diversity has been shown to contribute to ecosystem stability and pest resistance (Limareva, 2014). Furthermore, complex interactions create a facilitative network, which can stimulate growth, neutralize disease vectors, and counteract antagonistic growth factors (Limareva, 2014). Functionally biodiverse communities within food forest systems conceivably develop through the natural process of niche differentiation; diet separation and the spatiotemporal alternation of both activity periods and foraging locations (Buckley, 2003). When circumstances and resource supply in the habitat are relatively constant, interspecific competition can balance out into either the dominance of a single species, or a stable coexistence of multiple species (Begon et al., 2014). The prevailing population dynamics theory elucidates the potential for rapid growth of herbivore populations in the absence of either top-down or bottom-up control (Begon et al., 2014). Such large populations can have a major influence on the production output of forested ecosystems (Schowalter et al., 1986). Within contemporary forestry practices, bottom-up control aims to release browsing pressure by establishing dense natural regeneration, fodder crops, or seeding browse tolerant species. At the same time, top-down control is facilitated by the presence of predators which naturally limits the size of prey populations (Löf et al., 2019). The degree to which apex predator populations are supported depends on a variety of biotic and abiotic factors.

Availability of suitable habitats and prey population sizes are key factors that determine the potential presence of predator species (Krebs, 1978). The density of the prey species, and the landscape which constitutes the foraging area, determine the carrying capacity of a system. The degree to which predators are specialized to hunt specific prey species differs greatly. In Dutch ecosystems, mammalian predators are represented by members of the taxonomic families of canids, felids, and mustelids (IJsseling & Scheygrond, 1943). Common birds of prey belong to the orders of Falconiformes and Strigiformes (Génsbøl et al., 2007). Many species within these groups can potentially find suitable prey withing food forest systems as their prey consists largely of small rodents and birds, which are oftentimes common in these systems. The presence of predator species in environments of early succession stages, as many Dutch food forests are in, does not only depend on habitat suitability of the patch, but also on the diversity of the wider landscape and the specific dispersal potential of predators.

Herbivores, as well as carnivores, influence ecosystems as system regulators (Holtmeier, 2014; Chew, 1994). Their dispersal however is determined largely by the character and heterogeneity of the surrounding landscape (Begon et al., 2014). In turn, landscape spatial patterns and functional roles are shaped by land-use practices, which often depend on economic and political conditions (Holtmeier, 2014). Cultural landscapes consisting of patchy habitat mosaics offer an abundance of forage within the current European context (Holtmeier, 2014). For instance, distribution of selective browsers like roe deer (*Capreolus capreolus*) is determined by the availability of energy-rich, digestible browse across the landscape. Herbs and flowers may be consumed on meadows, whereas forests might provide an array of young shoots and shrubs, as well as acorns, chestnuts and the berries of *Sorbus aucuparia* and *S. torminalis* (Hofmann, 1977; Hofmann 1978). Spatiotemporal grazing patterns of many herbivores influence vegetation distribution, which is intricately linked to topography (Holtmeier, 2014). The impacts of yellow-necked field mice (*Apodemus flavicollus*) and bank voles (*Clethrionomys glareolus*) on stands of beech, fir, spruce, and maple trees is well documented (Ashby, 1967). Seed consumption and destruction of plantules results in overaging of forests and changes in stand structure. However, zoochory by these two species contributes to the modification of habitat conditions by sustainably influencing composition, succession, and plant cover structure (Holtmeier, 2014). It is thus apparent that faunal species, through their regulative impacts, may express varying effects within a system, dependent on factors related to the system complexity, succession stage and the landscape heterogeneity.

The Dutch landscape has a long history of human intervention. The degree to which the land has been altered is so significant that it is debatable whether one can still speak of “natural areas”. Anthroposophical influence has surely resulted in a loss of biodiversity during certain eras. Most influential is the extirpation of many large carnivorous species (Crees et al., 2016; van Zanden et al., 2021). At the same time, it can be argued that the conversion of forest and swamps into extensive agricultural systems, combined with the mostly unintentional introduction of non-native species, has also created novel, biodiverse and precious ecosystems (van Zanden et al., 2021). The intensification of agriculture during the past century has resulted in heavy fragmentation of the Dutch landscape, especially of nature areas. One consequence of this is that several ecosystems are considered to be no longer complete (Stanturf, 2021). Often this means that apex predator species are no longer present. When the growth of herbivore populations is not limited by predators, their numbers can grow rapidly. This can result in the degradation of habitat and a reduction of the system's carrying capacity (Terborgh & Estes, 2010). In these incomplete systems, control of herbivorous animals is often heavily dependent on human intervention.

In intensely cultivated landscapes of the Netherlands, sustainable management of fallow land by use of large herbivores or other top-down control factors is dependent upon a myriad of socioeconomic and political conditions, as well as public interest; biodiversity conservation and preservation of landscape diversity may often be given priority (Holtmeier, 2014). Despite numerous attempts of rewilding in the Netherlands, management implications inhibit natural succession to 'near-natural' woodland systems by keeping fallow land open (e.g. grasslands). Exploring the potential of novel agroecological systems has the potential to integrate current land management practices with production systems.

Although ecological knowledge on predator-prey interactions has been applied extensively to affect the dynamics of natural systems, it remains unclear whether the current ecological state of the Netherlands can facilitate top-down control approaches of herbivorous vertebrate pest species within food forests. This study aims to highlight the role of food forest size and landscape heterogeneity in relation to the degree of anthropogenic intervention within the food forest, as prescribed by naturally facilitated top-down control factors. Depending on stakeholder's needs and local abiotic factors (soil, water, and microclimate) the ecological functioning of food forests, as mediated by biotic interactions, might cater to an agricultural output that is both ecologically sound and economically viable (Batish, 2008; Blok, & Veluw, 2019; Breidenbach, Dijkgraaf, Rooduijn, Nijpels-Cieremans, & Strijkstra, 2017).

By compiling relevant information on the Dutch forested foodscape, and exploring current issues through interviews with food forest practitioners, the obstacles and challenges regarding the functionality of food forest within the ecological context of their surroundings were compiled and analysed. Relevant topics that were found to be insufficiently studied have been outlined so as to provide orientation for potential future research programmes. This report aims to provide food forest owners and other interested parties with a documented inventory of practical considerations, management tools, and guidelines to advance the contrivance of food forest systems.

Research Questions:

1. What is the current understanding of ecological processes concerning dynamics between vertebrate pests and predators in relation to the ecological sustainability of Dutch food forests?

2. a. What are the effects of both the size of a food forest system and the degree of heterogeneity of the surrounding landscape on the ecological dynamics of vertebrate prey (pest) and predator species?

2. b. To what extent can human intervention levels manipulate predator-prey interactions as to promote a functioning agroecological production system?

METHODOLOGY

1. Preliminary literature review

To establish a current state of affairs, it is necessary to have an up-to-date image of the actual problems faced by food forest practitioners. Background research was done at the initial phase of the project to design the interviews and select suitable interviewees. Relevant search terms and queries were compiled and used to find information on ecological principles related to "trophic levels", "food webs", "incomplete systems", "macro pest", "top-down", "animal-plant interaction", and "functional guild". As food forests are a novel agriculture system in the Netherlands and information is limited, the background research aimed to incorporate a variety of literary sources. This included peer reviewed scientific literature as well as others MSc theses, PhD papers, organizational and/or annual reports, informative books, and popular science articles.

2. Selection of interview partner via ArcGIS's

a. Criteria of categories and sources

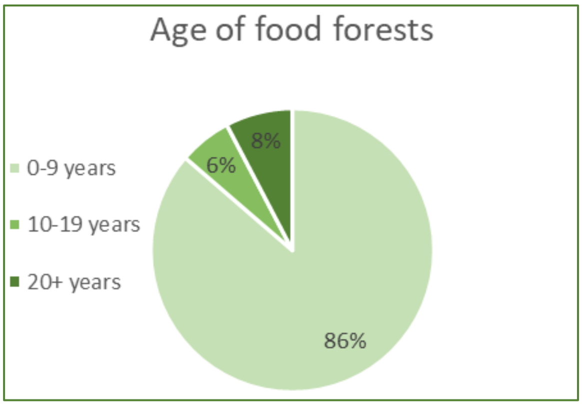

Figure 1. Age composition of Dutch food forests

In order to compare ecological dynamics across a variety of landscapes, and at varying spatial scales, food forests were categorized according to two criteria: the size of an individual food forest and the heterogeneity of its surrounding landscape. Age as a category was not established as, due to the young age of the movement in the Netherlands, most of the food forest are under 5 years old. An analysis of the data provided on the Green Deal Voedselbossen website revealed that 86% of the food forests in 2022 are under 10 years old (Figure 1).

For the size criterium, the definition of the Green Deal Voedselbossen was used to establish two categories: "small", which includes all systems smaller than 5 hectares (ha), and "large", which includes food forests of an area equal to or exceeding 5 ha (Green Deal Voedselbossen, 2020). Although the size category "large" makes up only a small proportion of Dutch food forests (11 in total), the size of a food forest was considered a relevant factor for the analysis. The dimensions of the area in which a predator can forage is an important factor in determining its survival potential. Landscape heterogeneity was divided into three categories, following Kleijn et al. (2011).

Landscapes classified as "low heterogeneity" (<2% semi-natural vegetation), "medium heterogeneity" (between 2-20% semi-natural vegetation) or "high heterogeneity" (>20% semi-natural vegetation). Delineation of food forest spatial extent allows one to investigate the potential as wildlife refugia and/or corridors. Furthermore, defining an axis for landscape heterogeneity aims to address the influence of surrounding land-management practices on the dispersal and colonization events of vertebrate pest species across the Dutch food forested landscape. Therefore, in total, six categories were established based on the combination of landscape complexity and food forest size, forming the basis for both interviews and subsequent analysis of acquired data.

A map of existing food forests in the Netherlands is available on the Green Deal 'Voedselbossen' website, including the size and contact information of the food forests. The food forest spots data in the Netherlands was used, provided by the same author. All food forests mentioned in this source meet the definition for food forests provided by the Green Deal as stated in the introduction.

To define the "landscape heterogeneity" for the purpose of selecting interviewees, spatial data from protected nature reserves (Natura 2000 areas) in the Netherlands and a map of different land cover types was considered (Figure 2). Natura 2000 areas are part of one of the largest coordinated networks of protected areas worldwide and were established by the European Commission to ensure the survival of vulnerable and threatened species and habitats (EU Commission, 2022). Based on this definition, the assumption is that a food forest close to a Natura 2000 area is surrounded by a heterogenic landscape that provides functioning ecosystem services and habitat for wildlife. This could support stronger interactions or abundance of wildlife, which will be investigated during the interviews with the food forest practitioners.

This layer displays a global map of land use/land cover (LULC) in 2021 derived from ESA Sentinel-2 imagery at 10m resolution. To extract the area of the Netherlands for the analysis, *Analysis Tools - Extract – Clip* was used. In line with the research plan, the land cover types were divided into semi-natural area (Flooded Vegetation, Trees and Water) and artificial area (Bare Ground, Built Area, Crops and Rangeland). Based on this data, the heterogeneity of a landscape is defined by the number of land cover types that appear in the buffer zone (500m radius) of each food forest, to show the proportion of natural habitat surrounding it and categorize them into "cleared (0 - 2%), simple (2 - 20%) and complex (20 +%)".

Table 1. Overview of data sources for ArcGIS analysis; the datasets are from ArcGIS online database- permissions provided by WUR.

Layer	Source	Author	Content	Source
Food forests	ArcGIS online	SijtseJan Roeters	Food forests according to the definition of the *Green Deal Voedselbossen*.	https://wur-girs.maps.arcgis.com/home/item.html?id=4493e50788014e718d367f7fd59453af
Natura 2000	ArcGIS online	mcca004_WUR_GIRS	Natura 2000 areas in the Netherlands.	https://wur-girs.maps.arcgis.com/home/item.html?id=8e3932a5307344679a0a7bde85be80a5
Sentinel-2 10m land cover (2021)	ArcGIS online	Esri	After limiting the range to the Netherlands, the classes left are Bare Ground, Built Area, Clouds*, Crops, Flooded Vegetation, Rangeland, Trees and Water.	https://wur-girs.maps.arcgis.com/home/item.html?id=d3da5dd386d140cf93fc9ecbf8da5e31

* No land cover information due to persistent cloud cover.

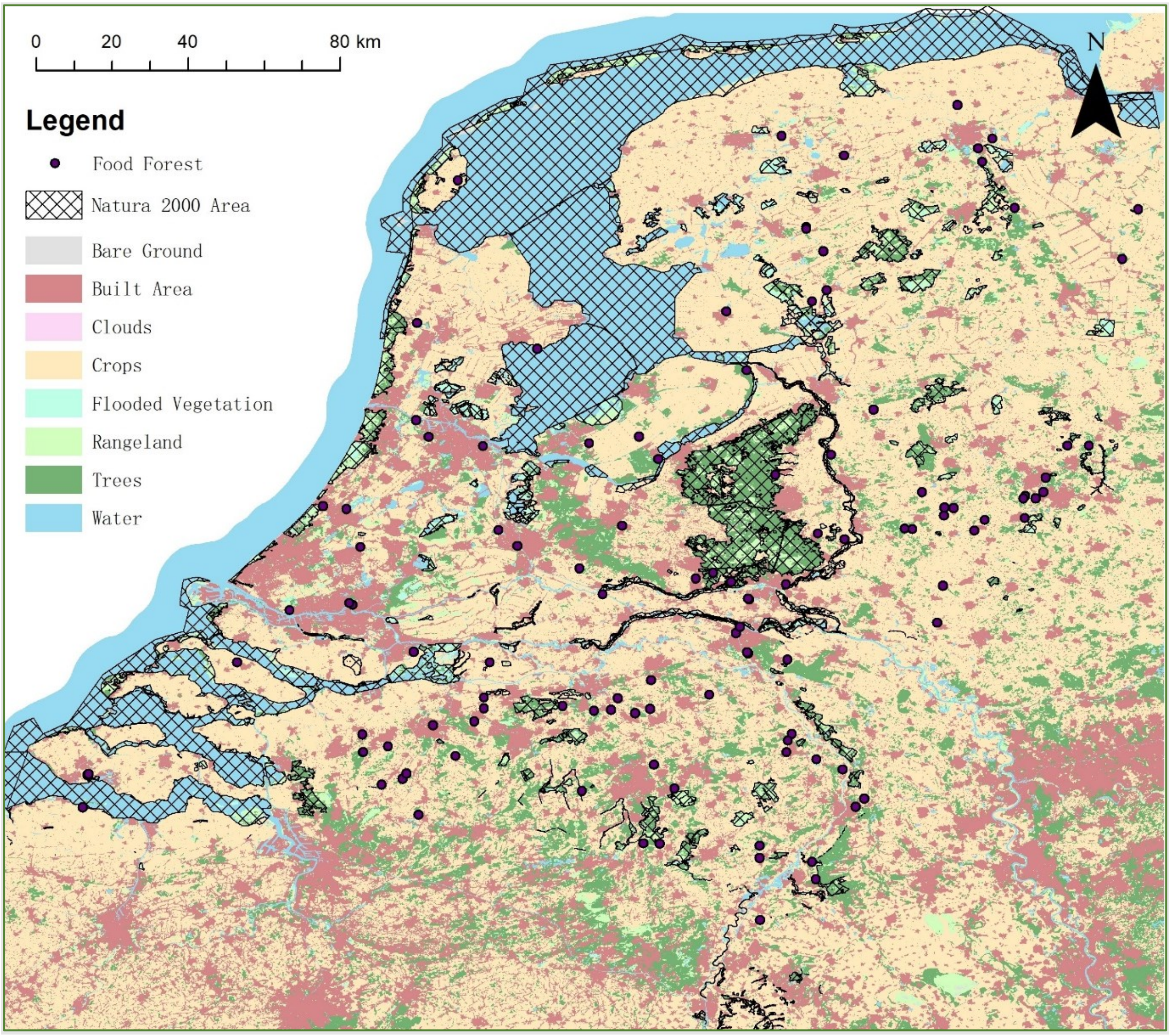

Figure 2. Overview of Natura 2000 areas, land cover and current food forest locations in the Netherlands via ArcGIS.

b. ArcGIS analysis

Our geographic analysis is based on *ArcGIS Pro*. After all the layers mentioned above were added, *Analysis Tools - Proximity - Buffer* was used to process the landscape complexity analysis in a buffer with a 500 meters radius around the food forest (point file). This radius is based on the buffer zone sizes that are often used in nature conservation management. Pests such as bark beetles stay in a circle of 300 meters around the hotspot, which is why in Germany buffer zones of 500 meters around conservation areas are maintained to prevent spreading (LWF, 2015). According to buffer zone regulations in the Netherlands, a 250 meter radius needs to be considered around nature conservation areas (Kuneman et al, 2008). Therefore, it is assumed that most interaction a food forest and its surrounding landscape will occur within the buffer zone of 500 meters, and influences from further away will be minimal.

To analyse the land cover in the buffer, *Analysis Tools - Overlay - Intersect* was used to get the overlapping area of buffer and land-use type. The resulting layer contained specific size of each land-use type in each food forest buffer. After using *Conversion Tools - Excel - Table to Excel* to export the attribute sheet, the proportion of each land cover type was calculated and each buffer was divided into the three complexity types. The same method is used for the Natura 2000 area to analyse whether the food forest overlaps with a Natura 2000 area.

The resulting Excel sheet contains details of 118 food forests, of which only 107 food forests were used for the analysis. For the other 11 food forest, no data for the size was available. The *Pivot Table* function in Excel was used to classify the food forests into different complexity and scale levels. When selecting food forests of a specific category, firstly their homepage and effort on public awareness were checked as to estimate willingness to be interviewed. Thereafter, the description of the food forest, as well as recent activities, were checked to assess its value for the interview. Distance is considered for practical reasons, as time and budget were limited.

In the end, six food forests were selected for interviews, covering all the different complexity and size categories. For some categories, one or two additional interview candidates were selected in case there would not be a timely response. Eventually, successful contact was established with food forests in five of the categories (Figure 3). For the large food forests in a complex landscape, three of all five eligible food forest were reached out to, but none responded within due time. An overview of characteristics for the visited food forests is given in table 2.

Table 2. Overview the general characteristics of selected food forests, such as age, and respective categories according to size and landscape heterogeneity. Sorted by interview date.

Name	**Year of establishment**	**Artificial Land (%)**	**Semi-natural Land (%)**	**Heterogeneity category**	**Area (ha)**	**Size category**	**Natura 2000 Area**
1. *Food Forest Benthuizen*	2014	100	0	Cleared	1.2	Small	No
2. *Food Forest d'Ekkers* (Berlicum)	2020	100	0	Cleared (under transformation)	1.8	Small	No
3. *Food Forest Leuker1818* (Baexem)	2019	100	0	Cleared	5	Large	No
4. *Food Forest Het Voedselrijk* (Bennekom)	2019	13.3	86.7	Complex	3.4	Small	Yes
5. *Nij Boelens* (Boelenslaan)	1994	93	7	Simple	5	Large	No
6. *Food Forest Ware Natuur* (Enschede)	2015	89.7	10.3	Simple	0.14	Small	No

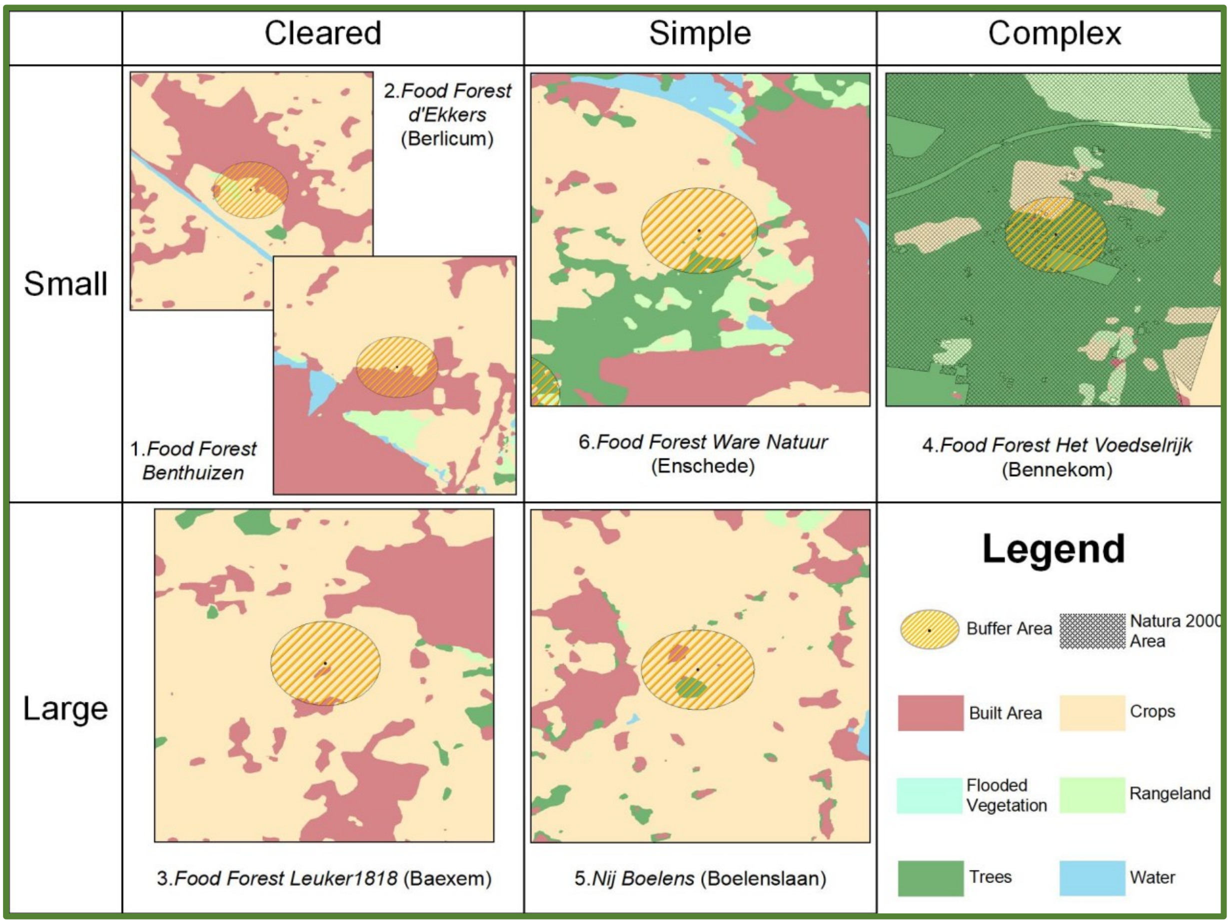

Figure 3. Visualisation of the surrounding landscape of each food forest via ArcGIS, including all layers from Figure 2.

3. Preparation of interview

The aim of the semi-structured interviews was to establish a picture of the current state of affairs at the grass roots level. Interviews were conducted with food forest practitioners to get an overview of challenges and knowledge gaps that appear in practice, as well as to derive relevant information to the scope of our investigative approach. Interviews served the purpose of an indicator to steer further literary review and come up with potential interventions, or to provide insights that may contribute to prospective research agendas. In more detail, this involved the assessment of insights concerning practical experiences with different mammal species and their effects on ecosystem dynamics and productivity, the effects of (un)successful interventions, and the perceived effects of size and surrounding landscape on the food forest.

The preliminary literature research provided the foundation from where the design of the interview was constructed. Questions were divided into different sections, starting with introductory questions regarding specifics of the food forest were addressed. Subsequently, questions regarding the landscape and observed predator-prey interactions in the food forest followed. Lastly, there was room for additional questions in which input for the formation of a research agenda was discussed. The complete list of interview questions can be found in Appendix I. As this concerns a semi-structured interview, the order in which these questions were addressed were not set in stone. Furthermore, novel or follow-up questions were brought forth when this was considered relevant.

4. Conduction of interview

The selected food forest practitioners were contacted via email during the first weeks of April, and informed about the topic and purpose of the research. About one hour was scheduled for each interview, which was conducted in the respective food forest. This enabled direct observations of the surrounding landscape and possible damages caused by animals in the food forest, as well as an analyzation of the status quo of the food forest. The semi-structured form of the interview allowed room for both questions that were written in advance, as well as for follow-up questions to gain a deeper insight into individual experiences.

To gain prior informed consent, the interviewee was informed about the projects purpose, the processing of the data from the interview, and the anonymity regarding their names in the outputs. A consent form was signed by each participant beforehand, a copy was stored safely until the finalization of this project. For analysis purposes the interviews were recorded, and the recordings were only made accessible for team members of the project.

Interview topics:

1. General characteristics such as size and age, as to verify and specify the data obtained from the internet.

2. Food Forest **practitioner's motivation** as to get an insight of the food forest's purpose and philosophy behind.

3. Heterogeneity of the surrounding landscape as to address RQ2 about interactions between landscape, size and food forests functionality and to verify the landscape categorisation used in this project.

4. Different **pests and wildlife experiences** as to get an idea of importance but also the variety of pest and wildlife issues in food forests.

5. Different **potential human interventions** as to obtain an overview of currently practised ecological solutions, but also to identify knowledge gaps and research opportunities.

5. Analysis of Interview

The analysis of interviews followed the purpose to collect qualitative data to answer the research questions. As the purpose of these interviews was to investigate the current state and to steer further research and the recommendations of the project, no analytical programmes were used to analyse the interviews themselves. The recording and a typed transcript were used to create a summarising Excel table containing information such as size, age and purpose of the food forest. Additionally, qualitative data about the surrounding landscape and species abundance, and their impact on the food forest system, as well as management strategies, human intervention level, and the philosophy behind the food forest were included. To gain a quantitative overview of species abundance in the selected food forests, a list of all species was created. This list includes the species mentioned during the interviews, as well as the species that were identified in the National Monitoring Programme Food Forests (*Nationaal Monitoringsprogramma Voedselbossen*, NMVB), as provided by the food forest practitioners themselves.

RESULTS

1. Results from the interviews

As to provide a clear overview, numbers are used in this section for the food forests (1-6), according to table 2.

a. General characteristics

According to the definition of the Green Deal Voedselbossen (2018), 0.5 ha in a complex and up to 20 ha in a cleared landscape are the minimum size necessary to create a "robust system" for a food forest to be able to provide all ecosystem functions (Green Deal, 2020).

The majority of selected food forests were between two and eight years old, only a 2 ha large subsection within food forest number 5 was established 28 years ago. Food forest sizes ranged from 0.3 to 5 ha. Categories for landscape selection based on heterogeneity could be verified by the interviewee or by personal observations. An exception is provided by food forest number 2, which was categorised into a cleared landscape, whereas on sight analysis revealed the surrounding to be transformed into a nature area and laid fallow. An adjacent stream contained a variety of hedges, trees, and grassland, characterising the food forest into the prospective complex category, as opposed to the current simple category (see table 2). All food forests were characterised by a highly divers species composition of trees and shrubs, some did include herbs and annuals as well.

b. Food forest philosophy/ purpose

For most food forests visited (2,4,5,6), generating a monetary income is not the main priority, although plans exist to develop food forest 5 into a commercial entity with economic viability. Other purposes that were mentioned by the interviewees are education and awareness about nature and food production, ecosystem regeneration, own consumption, and connection and collaboration with nature. The practitioners of food forest 1 and 3 rely financially on the food forest but both systems are still in an early stage and production levels are yet to grow to a commercially viable level. All interviewed food forest practitioners adhere to a clear nature-inclusive ecosystem approach as they seek to promote the balance of nature. Some of these food forests view humans as an equal part of the ecosystem (1,2,3,6). This philosophy does not acknowledge the existence of pests, as all animals have a place within the ecosystem and humans do not stand above other organisms (1). Over time, nature will establish a balanced ecosystem where damage from a specific animal is unlikely to pertain over a longer period of time (3,5). Half of the food forest practitioners believe that sharing the available food reduces conflict with wildlife (1,2,3). As one of the practitioners formulated it:

> *"The upper 3rd part of the tree belongs to the birds, the middle part to humans and the lower part to animals from the ground such as deer or badgers..."* (2)

As a future perspective, all the interviewees were convinced that food forests can be a solution to many problems that are faced by farmers nowadays. Food forests will reduce nitrogen emission, are less sensitive to water and fertilizer shortage, enhance the quality of nature, promote biodiversity, and overall lower the ecological footprint of agriculture. Often, dissatisfaction with the current farming system and its effects on nature were mentioned as major drivers in starting up a food forest (2,3,4).

c. Surrounding landscape and impact on food forest system

Originally, two food forests were to be interviewed for each of the landscape complexity levels. Due to lack of response however, only one food forest was interviewed for the complex landscape, and three for the cleared landscape.

Cleared landscapes were characterised by grassland, meadows, and fields of conventional monoculture farmers. Consequently, a low level of biodiversity was found in the surroundings of these food forests. In some cases, neighbouring farmers were mentioned to use fertilisers and pesticides (1), and actively combat mice and moles using traps or poison (1,2,3). In one case hunters are actively hunting hares and foxes in the surroundings, thus reducing their population with the highest possible intervention (1). In the cleared landscape the food forest is experienced as a niche or shelter for wildlife such as hares, hedgehogs, mice, foxes, birds, and butterflies, which migrates into the food forest during different seasons, creating a large contrast to the conventional farmland. Hunting and traps in the surrounding, as well as the absence of close-by forests, reduces the presence of the larger invertebrate wildlife such as deer, hares, foxes (1), boar (the last of which were not mentioned at all).

Simple landscapes were characterised by plain agricultural land, but also included some biodiverse patches of (semi-)natural land such as hedges, forests, or rivers. These patches are within migrating distance for wildlife, which puts the food forest in a 'stepstone' position. Use of fertilisers, pesticides (5) and mole traps by neighbouring farmers (6), and activity of hunters (6), were mentioned as factors affecting wildlife (Figure 4). For food forest 5, forest areas were thus isolated in the region that squirrels do not occur there.

Figure 4. Deer stands next to the food forest.

The complex landscape was (partly) within a natura 2000 area and therefore consisted of more than 20% semi-natural area, according to the definition used in this project. This type of landscape can provide more habitats for large wildlife such as deer, badger, wild boar, bird of prey, and squirrel. Fragmentation can still occur through infrastructure, as was the case in food forest 4 which was separated from the wild boar populations by a highway. However, as the surroundings are mostly forest and within the Natura 2000 area, forest 4 does not suffer from some of the disturbances in the surroundings that other food forests in less complex landscapes may experience. In contrast to the cleared landscape, complex landscapes do not put the forest on a pedestal as shelter for wildlife but instead incorporate the food forest as a part of the natural landscape within which wildlife wanders.

d. Species abundance and impact on the food forest system

Hares were present in most of the food forests (1,2,3,6) and were mentioned as the most (economically) damaging species. They can cause severe damage on young bushes and trees. Also, when in abundant supply of other food sources, hares might feed on the bark of tree stems (Figure 5). The hares in forest 4 were mentioned to have gone extinct due to myxomatosis a number of years ago; a severe and usually fatal disease in European rabbits, but also sometimes infecting hares (García-Bocanegra et al., 2019). Only in the 25 years old food forest (5), hares were not mentioned as an impactful issue as the trees are already grown up.

Figure 5. Hare damage: the bark is stripped off the tree, up to a height of around 0.5 meters.

Roe deer come second, after hares, as most damaging animals mentioned in the interviews. As mentioned by one practitioner, roe deer only target single trees at a time and usually remain at the edge of a parcel (3). However, roe deer can reach higher parts of the trees than hares and might therefore still damage trees at a 2-5 year age of a food forest (Figure 8). Although heavily damaged trees can regrow from the roots, a delay in development and time of maturity may be caused by roe deer damage (Figure 9). Roe deer need at least a small forest as a refuge, from which they can migrate to feeding areas as they generally stay within 1 km distance of these forests. Young food forests will therefore not have roe deer around unless there is a forest nearby (1,4), but older food forests can serve as a refuge for roe deer (6). High fences around the food forest, or single tree browsing protection, provide an efficient barrier to prevent damage by roe deer (5), thus reducing the urgency for alternative solutions against roe deer at the current stage.


Figure 9. Damaged tree that resprouted from the roots.

Weasel, marten, and fox are the large predators that were regularly mentioned by food forest practitioners. They were not perceived as issue for the food forests itself, as they do not damage the trees or bushes. In case poultry are kept nearby, damage can occur by martens or foxes (1,6). Weasels however were mentioned to not significantly affect the hare population yet but might do so over time if the weasel population is allowed to grow. Despite the absence of livestock in food forests, livestock may be kept adjacent to food forests or integrated in other forms of husbandry.

Badgers, in contrast to the other predators, are social animals that build large setts. They mainly hunt on humus building larvae and earth worms, thereby affecting the soil system (IJsseling, & Scheygrond, 1943). The production level of the food forests that had badgers in the area was still too low to identify damage of badgers on fruit yields. As badger populations were visibly growing in food forest 2, it was remarked that their fruit consumption might become a problem in the future. Badgers in young food forest usually have their setts outside the food forest and only visit the food forest to forage. This is especially the case when the food forest is situated in the complex landscape category (4). In some cases, badger setts might already be present within the food forest itself (2). This can easily be observed by the entrance holes to the sett, and by walking trails dispersing from the sett (Figure 6). There is no observation of damage to plants, as inflicted by badgers, a since their foraging behaviour normally only consists of searching the upper soil layers for invertebrate prey.

 

Figure 6. Badger trail and one of the entrances to the sett.

Owls, falcons, and buzzards are the birds of prey that were observed in, or close to, all the food forests and were mentioned to make active use of provided nesting boxes. These birds of prey have a value as natural control agents of mice and voles, and attack smaller fruit eating bird species. Day-active birds of prey, in special large species like buzzards, need an open area for hunting and will therefore disappear from the food forest as it matures (5,6). However, they might remain present in the surrounding landscape and thereby indirectly influence the wildlife populations in the food forest. Other birds of prey include herons and egrets, which were mentioned as active predators of mice in food forest 3. However, they are bound to habitats but were not specifically mentioned by all the food forests.

Mice and voles were identified as damaging by all the food forest owners, except the older food forest (5). On the lower level in the food forest, they damage the young trees and eat berries or strawberries from the bushes. However, this damage is accepted in all the interviewed food forests, and food forest 2 promotes the presence of mice by creating straw mounds as a habitat and nesting place for mice.

Moles were present in all food forests, but were welcomed as they are responsible for bioturbation, meaning aeration and loosening the soil, as well as for insect control (5,6). However, the molehills are perceived as a nuisance by neighbouring farmers (Figure 7), where they might unroot crops or hinder machines. Farmers often actively respond to this by making interventions against moles (1,4,6).

Figure 7. Molehills in the food forest.

Blackbirds were mentioned as yield reducing species as they eat fruits. They are, however, also observed to create 'insect factories' by picking a hole in the fruit to attract prey insects. Some birds of prey might hunt (young) blackbirds and thereby either reduce the number of blackbirds or alter their behaviour. Together with other insectivorous or herbivorous birds, blackbirds play an important role in the ecosystem as a control agent of insects, including species like the oak processionary caterpillar.

Figure 8. Roe deer damage to a young tree.

Wild boars and squirrels were not mentioned in any of the food forests, even though they might play an important role if present. It was proposed that the lack of these animals could be caused by a clear surrounding landscape that does not promote their presence (5).

e. Management strategies / human intervention

Several intervention strategies were named among the interviewees. These interventions can be classified as either facilitative or protective.

The most commonly mentioned facilitative intervention was the installation of nesting boxes for birds of prey (Figure 10). By promoting the presence of birds of prey, populations of damaging wildlife like mice and frugivorous birds can be naturally controlled. Some birds, like the tawny owl, are mentioned to fiercely protect their nests (6). This should be taken into consideration when placing nest boxes to facilitate tawny owl nesting. Two food forest owners, with an older food forest or located in a complex landscape respectively, also considered facilitating bat populations in the food forests to reduce insect herbivory pressure (4,5).

Figure 10. Nesting boxes for owl and falcon respectively.

Sandbanks were made to create a more gradual transition from water to land, allowing a larger diversity of microclimates and facilitating movement of semi-aquatic animals (1). Additionally, sand banks create nesting opportunities for solitary bee species. This improves the pollination activity in the food forest and thereby decreases the dependence of the food forest on the surrounding area.

A final facilitative intervention is the general creation of habitat. Examples of this are the creation of straw mounds for mice (2) (Figure 11) and a 'sloppy corner' for weasels (3). Similar interventions can be made to promote hedgehogs (1).

Figure 11. Example of a straw mound for mice.

Protective measurements can be either direct or indirect. Examples of direct protective measurements that were mentioned are fences around (part of) the food forest (Figure 12), and placement of browsing protection (chicken wire or plastic tubes) around young trees (Figure 13). While high fences around the food forests can be tunnelled by hares, they provide an efficient barrier to specifically keep out roe deer (5), which reduces the urgency for alternative solutions against roe deer damage at the current stage. Indirect protective measurements include planting trap crops such as berries, bushes, or young trees that are preferred by birds, hares and mice, over the harvested shrubs and trees (1,2,3). This way, herbivory pressure could be shifted.

(a) (b)

Figure 12. (a) Fence around the food forest. The lower part of the fence has lower holes to keep out smaller animals. (b) Fence to keep out poultry such as peacocks and turkeys.

Figure 13. Several examples of browsing protection for young trees.

Compared to conventional, high-intervention agriculture practices, food forests are characterised by the intention to let nature “do the work”. This means that disruptive interventions like mowing and the use of heavy machinery are not used, harvest is performed mostly manually, and specific walking paths are designed to assure calmer and less interrupted areas (1,4,5,6). However, some level of intervention might be necessary in building up the desired ecosystem at the beginning of the establishment of a food forest.

2. Results of literature review

The body of knowledge regarding a multitude of aspects that are relevant to the functionality of food forest is ever expending. As mentioned before, however, food forest systems are a relatively new phenomenon. Consequently, relatively few scientific studies have been conducted on the workings of ecological processes within food forest systems. However, food forests share many characteristics with both natural and more conventional agricultural systems. Therefore, studies within natural and agricultural systems oftentimes provide a foundation for understanding processes in food forests. Even though currently available literature can be used to promote the functionality of food forest to a certain degree, knowledge gaps prevent us from reaching a holistic understanding of these systems. To provide a starting point for the improvement of food forests, several uncovered knowledge gaps are pointed out in the following literature review section. This literature review incorporates different focus points, uncovered from the interviews. Especially rodents, roe deer and birds have been mentioned as pests, or yield-reducing species. An overview of possibly important wildlife species/groups and some additional information can be found in Appendix II. The following text highlights current trends in research on management concerning these animals in relation to food forest systems.

f. Rodent exclusion from areas

One way to reduce the number of animals that damage trees within the system, is to completely exclude them altogether. This approach has the appeal of being non-lethal and provides the possibility of potentially providing a permanent solution. Exclusion methods can be physical barriers such as fencing, chicken wire, sheet metal, or electric wires (Buckle & Smith, 2015). It is notoriously difficult to stop rodents from accessing an area they want to enter. They are capable of getting over, around, though, or under virtually any type of barrier that is put in their way. Rodents are generally small, flexible and agile, with a chewing capability which makes them particularly adaptable. Detailed guides are available on how to exclude rodents from buildings (Corrigan, 2001; Hygnstrom et al., 1994). However, positive results are only achieved with much effort, expense, diligence, and maintenance. In agricultural settings such as fields or orchards, the task of rodent exclusion is much more difficult, and the chances of success are significantly reduced.

Besides exclusion, common orchards apply habitat destruction, reduction of food availability, facilitation of predators, or usage of rodenticides as effective rodent-reducing practices (Jacob & Tkadlec, 2010). These are not all in line with a food forest approach, as in food forests it is assumed that all animals will have their role to provide a productive system, once the balance of the ecosystem is restored and reached. The facilitation of predators as a management approach for rodents mainly involves nest boxes and perches for predatory birds (Olson et al., 2017). Especially for agroecosystems, birds of prey such as owls and hawks are used as intervention strategy due to their preference for hunting in large, open areas with some trees in them. That being said, research in this area continues, in order to find non-disruptive exclusion methods which are both effective and easy to apply. The allure of finding such methods to permanently solve rodent issues remains great.

(Rodent) IPM

Integrated pest management (IPM) can be described as a sustainable, science-based, decision-making process that combines biological, cultural, physical and chemical tools to identify, manage and reduce risk from pests and pest management tools and strategies in a way that minimizes overall economic, health, and environmental risks (Witmer, 2007). Obviously, it does not fit the ideology of food forests perfectly, as there is no focus on maintaining (semi-)natural ecosystems and use of chemical interventions are not desired in food forests. However, a large emphasis of IPM is on the use of the biology and ecological characteristics of the pest species in biological control. Biological control in this instance means that a pest is managed by the introduction of a natural enemy or predator. Therefore, it is worth looking at the methodology of IPM in relation to pests that can cause issues for food forests.

As for all IPM strategies, development of rodent IPM strategies requires the consideration of many factors. First, the rodent species must be correctly identified, after which monitoring of the population and damage status comes into effect. The questions that should be answered by this are: “Is the rodent abundance correlated to the level of damage that has occurred?” and, “Can a threshold be established for when action should be taken?”. The following step is considering the biology and ecological niche of the species in the environment where the damage is occurring. To this end, it is important to have knowledge on how the animal uses its habitat and how it interacts with other species. In the context of food forests, this knowledge is especially important as it is the objective to maintain a balanced ecosystem. In the end, designing an IPM strategy for rodents starts by reflecting on the actions of the land managers. Identifying the actions that are (inadvertently) supporting the rodent population and that are increasing the amount of damage is crucial. It is a critical step towards creating management options to manipulate the rodent population, its habitat, and the activities and land use practices that decrease or avoid damage. Finally, the evaluation of an IPM strategy should be based on its potential ability to obtain the result of rodent damage reduction. Meanwhile, the practical constraints, method duration, legalities, and the environmental impacts should also be taken into account, especially when dealing with an environment such as food forests. In such a setting, the objectives are often long-term and are restricted by the ecosystem as it exists at any given time.

Relatively little is known about dealing with rodent pests in complex landscapes such as agroecosystems, meaning that any rodent IPM trials are in essence large-scale open field experiments.

There have been some developments in support decisions for rodent IPM strategies, but these are mainly in the form of binary decision-making trees or very simple computer programmes.

It is evident that effective IPM strategies for food forests, excluding chemical interventions, require substantial information that only long-term research of the pest species and environment can provide. Substantiated information does not only aid the creation of more effective strategies, but also greater support and acceptance by the stakeholders and credibility of the implementers (e.g. food forest practitioners). It is unfortunate that, when it comes to rodent research, there is relatively little support for long-term studies. Food forests in particular would benefit from more research on amongst others barrier development, biological control, and habitat manipulation in the form of shelter alteration.

g. The role of birds in agroecosystems

During the past few decades, the study of the benefits of birds in agroecosystems has made a come-back with a focus on ecosystem services (Peisley et al., 2015; Wenny et al., 2011; Whelan et al., 2015). In this context, humans benefit from the predation of birds on insect pests and the consequent reduction of crop damage (Wenny et al., 2011). Biodiversity changes, regardless of being caused intentionally or not, affect the facilitation of ecosystem services (Leemans & De Groot, 2003). Recent efforts have been focusing on finding correlations between changes in biodiversity and ecosystem service facilitation (Isbell et al., 2017). For food forests practitioners, receiving pest control from birds is very beneficial, as no insecticides or other control strategies must be considered. Particularly, chemical interventions are not favoured in food forests, according to the Green Deal Voedselbossen.

Two key insights have incentivised the interest in impacts of biodiversity. The first is the apparent fact that the majority of avian species are insectivorous (Wenny et al., 2011). A recent study estimated that, globally, birds eat around 28 million tonnes of arthropods per year around agricultural areas (Nyffeler et al., 2018). In addition to that, birds of prey like hawks and owls significantly reduced pest bird and rodent abundance in agroecosystems if present (Kross et al., 2016; Shave et al., 2018). A second insight concerns quantitative experiments on the great effects that birds have on arthropod communities, particularly on insect pests (Maas et al., 2019). Notably, pest suppression by birds has been most significant in tropical perennial crops (Maas et al., 2016). An example of this is a collection of studies which excluded birds from Central American coffee crops (Karp et al., 2013; Martínez-Salinas et al., 2016). Researchers found that infestation of coffee berry borer (*Hypothenemus hampei)* grew when birds were absent. Karp et al. (2013) estimated the economic value of bird pest suppression between \$75 and \$310 per ha/year in Costa Rica. However, such studies have not yet been performed in agroforestry settings in temperate systems. Therefore, exact numbers for the economic value of bird pest suppression in agroforestry systems, such as Dutch food forests, are still missing. Having these values could greatly advance decision-making regarding birds in food forests.

Promoting beneficial birds in agroecosystems

Similar to growing interest in positive effects of birds in agriculture, the attention for the development of specific agricultural management practices to support bird-assisted pest suppression has increased (Lindell et al., 2018). A well-known example includes the introduction of nest boxes, either for insectivorous birds or for birds of prey (Jedlicka et al., 2011; Shave et al., 2018). The investment on construction and maintenance of nest boxes is worthwhile, as the monetary value of the crop protection usually far outweighs the costs of facilitating pest-suppressive birds. Bird pest suppression can also be enhanced by the inclusion of non-crop vegetation. For example, complex edge habitat in an otherwise intensive agricultural environment can increase bird abundance and decrease insect pest prevalence (Kross et al., 2016). This therefore suggests that agroforestry practices, such as planting perennial vegetation at field edges, could enhance bird-facilitated pest control. Similar findings were also reported for small organic farms and agroforestry systems (Garfinkel & Johnson, 2015; Perfecto et al., 2004). However, such studies have not yet been done to date in food forest settings.

At larger scales, the complexity of the landscape has also been shown to influence ecosystem services provided by birds. Heath & Long (2019) found that bird predation of codling moth (*Cydia pomonella*) in walnut fields had a positive correlation with semi-natural landscape cover within a 500-meter radius. It would be interesting to continue this research on walnut trees in agroforestry systems. Encouragingly, a recent review on the influence of land use on bird-mediated pest control found that landscape heterogeneity, amount of natural habitat, and vicinity of natural habitat patches increased avian pest control (Boesing et al., 2017).

h. Topics for further research

Research Agenda:

- The effectiveness of measures to exclude hares from food forests. This could include barrier development, biological control, and habitat manipulation. This could be supplemented by long term studies on how Integrated Pest Management strategy can be incorporated in food forest systems with the aim to balance rodent populations.
- To what degree can natural bird pest suppression be beneficial to food forests? What is the economic value of this natural suppression?
- Potential intervention strategies to promote bird (and insect) pest suppression by facilitating measures such as nest boxes?
- The role of heterogeneity of surrounding landscape on bird- and mammal-mediated pest control?
- To what extent are facilitation of predators, or manipulation of natural dynamics, desired in a food forest that aims to be an independent, self-regulated system? How are effects of interventions quantifiable?
- Species specific plant animal relation as to identify beneficial tree species compositions in relation to wildlife occurrence.

DISCUSSION

1. Research limitations

a. Scope

For this report, 6 food forest practitioners were interviewed. This represents only a small sample from the >100 food forests present in the Netherlands. The sample was not intended to be fully representative for the highly diverse food forests landscape. The sample was however mainly intended for gaining insights, and a compromise in the external validity therefore was therefore accepted beforehand. Time restrictions mandated a limited selection of interviews to be conducted. Therefore, a qualitative instead of a quantitative approach was followed.

b. Landscape type definition

As described in the methods section, landscape types were divided into three categories: cleared, simple, and complex. Arguably, the margins of these landscape types in percentage of natural area, do not do justice to the actual complexity and specific land uses of the surrounding areas. It was experienced that food forests categorised in the 'simple' landscape type did not categorise themselves there but rather in a clear or complex surrounding. This indicates that a more descriptive division of landscape types, instead of the binary natural-artificial categories used in this project, could display the complexity of the surrounding landscape better. As to prevent or adjust incorrect categorization, observations in the food forests and verifications during the interview were made and commented on in the report.

c. Age as a variab*le in food forest ecosystems*

Although age was not included as a category for analysis, the results obtained from the interviews strongly indicate an effect of food forest age on the wild animals that occur in a food forests. Young food forests have a lot of young trees and saplings, which especially attract herbivores such as hares and roe deer. The interview with the older and more developed food forest revealed that hare herbivory and soil disturbance by moles were actually no issue here anymore. In contrast, birds were identified as the main challenge in terms of wildlife. For future research, the consideration of the age and the development stage of food forests, in relation to beneficial wildlife dynamics and the required level of intervention levels to maintain the productivity of the ecosystems, can be suggested.

d. Differences between landscape types

One could argue that, at least in the Netherlands, differences in landscape complexity are minimal to a degree where it is insignificant for the abundance or diversity of wildlife. No consultations with wildlife experts were conducted for this project. A critical view of the results could conclude that differences in experiences and interactions with wildlife are merely the result of the proximity to natural areas, and not of the degree of landscape complexity. More extensive surveys and research are needed to strengthen the relation between landscape complexity and wild animal interactions in food forests. Furthermore, the perceived impact of faunal interactions on crop yield may alter as food forests move on from early successional stages to a mature and functioning production system.

2. Answering the research questions

a. RQ1: Understanding of ecological processes

Aforementioned interview results, as well as the conducted literature review, addressed the first research question; "What is the current understanding of ecological processes concerning dynamics between vertebrate pests and predators in relation to the ecological sustainability of Dutch food forests?". Concerning vertebrate predator-prey relationships, interviews revealed multiple species of relevance to food forest systems in the Netherlands.

None of the selected practitioners had an agricultural background, although one did have a forestry education background. Due to the small sample size used in this project, a generalisation of the whole food forests movement cannot be easily made. However, for the interviewed food forest practitioners, the intrinsic motivation for nature regeneration dominated over the economic viability of the system. A general lack of in-depth, and practically based knowledge on predator-prey relationships in a food forest setting was apparent from the interviews. Although a basis of knowledge on ecosystem interactions was present, most food forest practitioners showed a largely experimental attitude towards the food forest management and design. A proper understanding of ecological processes in food forests requires practical experience. Although several recent initiatives exist in the Netherlands to monitor food forests, these do not look into ecosystem dynamics (Elvers, 2019; Food Forest Consultancy and Support, 2018; Green Deal Voedselbossen, 2022). An established source of information on practical experience with vertebrate pests and predators in relation to the ecological sustainability of Dutch food forests thus is still missing.

The interview results could partly be supported by literary findings, which in turn revealed in-depth and applicable research, as well as practical experience to be applied to later food forest stages, which need further addressing. On a species level, the effect of animal interactions on food forest systems were made evident in literature research and practice. Throughout interviews, hares were usually mentioned as the most economically damaging species. Contrastingly, larger predator species like martens, foxes, and badgers were never considered a nuisance by the food forest practitioners. Equally, owls, falcons and buzzards were only viewed as having a positive, or at least neutral, effect on the food forest systems. Mice and voles on the other hand, were often considered to be damaging, as they nibble on seedlings and saplings, and consume low-hanging fruit and berries, especially in young food forest systems. Interestingly, blackbirds were mentioned both as a nuisance and as a pest control agent. These omnivorous species eat both fruits and insects, which allows them to take on an overall more neutral factor in the economic outputs of a food forest. This so-called "neutrality" of certain animal species regarding the economic damage of agricultural crops has been subject of discussion before (Pejchar et al., 2018). A special case within the family of the blackbirds, however, is the common starling *Sturnus vulgaris* (Figure 14). Like other blackbirds, the starling is known to eat both insects and fruits, but it also to regularly just slightly damage fruits by taking a few bites from them. Before 1900, starlings were reported to be purely insectivorous, and only turned towards eating fruits after 1900 (Kluyver, & Plantenziektenkundige Dienst, 1934). Moreover, it was found that starlings are not able to survive for long on a diet that consists solely of fruits (Summers, 1985). This might support the hypothesis proposed by one of the food forest practitioners (1), based on personal observations, that starlings damage fruits to create 'insect factories', rather than to directly feed off the fruits (Figure 15).

The most important species in causing damage to food forests include hare and mice, roe deer, and hypothetically badger. Hares and mice are mainly terrestrial animals, although some mice species do climb trees to access food resources (IJsseling, & Scheygrond, 1943). Protective interventions against hares and mice include fences and browsing protection. Predators of hares and mice can be attracted through the facilitation of perches and nesting boxes for birds of prey, as well as the creation of 'messy' corners to provide habitat for foxes, weasels and martens. Roe deer on the other hand can reach higher parts of the trees and travel larger distances. Also, for roe deer, protective interventions are (high) fences and browsing protection. Apart from the wolf, only foxes can be considered potential predators of roe deer, although this only concerns young roe deer. Trap crops that distract roe deer from attacking the most valuable trees can be used to decrease damage. Finally, badgers are mentioned as a possible threat to the harvest in more developed food forest. No interventions were mentioned to keep out badgers, and their only predator in the Netherlands (apart from humans) is the wolf. Although wolves are not expected to play a major role in controlling badger (or roe deer) populations in the near future, wolves do indirectly affect behaviour of prey animals. This could lead to badgers and deer staying more hidden and migrating to areas where the wolves do not come often.

Figure 14. Starling in food forest 1.

Figure 15. Insects (in this case wasps and march flies) are attracted to damaged fruits. This supports the hypothesis that the starlings use fruits as 'insect factories'. Own observations at food forest Droevendaal.

b. RQ2a: Food forests within their landscape

Based on the selection criteria of the food forests, our results address the second question, formulated as: "What are the effects of both the size of a food forest system and the degree of heterogeneity of the surrounding landscape on the ecological dynamics of vertebrate prey (pest) and predator species?".

According to our findings, no conclusions can be drawn about the impact of the size of the food forests. The analysis of Dutch food forest data revealed mainly small (>5 ha) and young (below 10 years) food forests in the Netherlands. Since also small food forests could be identified in cleared landscapes, it is questionable whether these will reach a robust state and independency from their surroundings regarding a functioning ecosystem. Due to the young age, and consequently early stage of ecosystem development, of the selected food forests, no differences could be detected between smaller and bigger ones. Further data would be required about older, already established food forest ecosystems to see if the size significantly influences predator pray dynamics.

Surrounding landscapes show an influence on food forests. These can be attributed to variations in perceived faunal diversity and abundance. For each landscape category, effects on wildlife in the food forest were evident. In other words, a clear contrast was notable between the high biodiversity of food forest and its cleared surroundings. Carnivorous species like foxes and hedgehogs occupied food forests within cleared surroundings. Interestingly, the island biogeography of the food forests situated in cleared landscapes led to the absence of species such as squirrel and wild boar, making protective interventions redundant. Absences of these species could be attributed to dispersal barriers, such as the lack of contiguous forested area, as well as to the presence of a major railway line and highway respectively. The impact of conventional agriculture in the surrounding landscape, in the forms of nitrogen deposition or pesticide contamination, was not viewed as a major issue by food forest holders. As a management decision, an established natural riparian buffer was present at one interview site (3) to enhance and protect natural resources from the adverse impacts of adjacent agricultural practices. Such ecological buffers also provide perennial vegetation that supply a diversity of cover and feed for wildlife (Dosskey, Schultz, & Isenhart, 1997). Thereby they can also take on a facilitative function by functioning as wildlife corridors or improving habitat for large animals (Dosskey, Schultz, & Isenhart, 1997). Clear landscapes might require less protective and more facilitative interventions, as building up (and maintaining) the functioning of the ecosystem is the main issue for these food forests. It should be kept in mind, however, that the overall potential for damage is still very species-dependent. Certain animals, like deer and squirrels, require forest-like areas nearby to fulfil their habitat requirements. In comparison, hares do not naturally occur in forests and are therefore more damaging to food forests in clear landscapes.

In contrast, complex landscapes were indicated to provide ample natural habitat for wildlife, providing a patchy mosaic of corridors for dispersal, foraging areas, and cover. Wildlife appeared less dependent on food forest resources in these settings, reducing the need for buffer zones. The biodiversity in food forests surrounded by a complex landscape was comparable to the biodiversity in its surroundings, and often animals migrate freely between the food forest and its surroundings. This reduces the pressure that wildlife can have on the food forest in terms of herbivory and space. At the same time, ideally, no real barrier exists for wildlife to reach and colonize the food forest, although in fact some food forests are fenced. It is not clear to what extent this 'negative' impact can be outweighed by the higher abundance of natural predators. These foxes, martens, or even wolves, can play a role in controlling populations influence of prey species (3, 4).

Simple landscapes, as a category between clear and complex, naturally show a combination of characteristics that influence food forests. Both in terms of species abundance and required intervention level, simple landscapes display attributes at both ends of the landscape spectrum. Just like with other aspects, the early stage of development and the low sample size made it difficult to assess the actual effects that the landscape has on the food forest yield. As a conclusion, there are no unsuitable surroundings for a food forest from an ecosystem perspective. A different context just requires different management practices to get to a similar result. It might be from an economic perspective that a conclusion would be different, but that was outside of the scope of this study.

c. RQ2b: Intervention level

The extent to which human intervention levels can manipulate predator-prey interactions to create a functioning agroecological production system was explored in this study. Multiple interventions in food forests were observed. The degree to which these interventions were ecosystem-based was variable, but overall, the interventions had a low labour requirement after implementation, and disturbance to the surroundings was low. This is in line with the common food forest practice of keeping disturbance to the environment at a minimal level. Interviewed food forest practitioners mentioned many examples for facilitation of predator animals, in order to reduce prey species. These facilitations mainly took the shape of nesting boxes for birds of prey and sleeping boxes for bats. Facilitation of insects, mainly pollinators, was also an area of great interest. Inviting pollinators through building sandbanks and insect hotels was named as an effective way to make the food forest less dependent on the facilitative properties for pollination from the surrounding landscape. Instead of, or additional to, attracting predator species to manage prey populations, protective interventions against browsing species were often applied as well. These protective interventions were mainly aimed to reduce damage by roe deer and hares, which can be destructive during the establishment phase of food forests. An example of such a protective intervention is the placement of chicken wire, or other such barriers, around tree stems. This was one of the most commonly used interventions in the food forested that were visited. In conclusion, both facilitation of predator species and direct protection against herbivores are combined for wildlife management in practice.

No major differences in the degree and type of interventions were observed between the different landscape categories. As mentioned before, lower predator numbers can result in higher intensity and duration of interventions required for certain species. This study found that food forests strive for becoming a system with minimal management. Therefore, interventions are to be reduced, if not excluded, in later developmental stages of a food forest. The time required for the food forest to reach a self-sustaining system depends on the intentions of a food forest practitioner, and to what extent nature can decide the direction in which the food forest develops.

3. Personal thoughts

The role of wildlife in Dutch food forests is an interesting one. On the one hand, food forest systems strive for a balanced ecosystem where enough yield remains for human consumption. On the other hand, a balanced ecosystem needs to be achieved through human intervention in the existing landscape. Wildlife is present in all Dutch landscapes, be they clear, complex, or otherwise. Therefore, a way must be found for wildlife to be incorporated into the food forest to, preferably, the greatest benefit of both the ecosystem and the food forest yield. Precisely this consideration in the establishment of a food forest makes it crucial to account for the animal species that surround a food forest from the start. Informed decisions on intervention levels can best be achieved with a thorough understanding of the landscape, wildlife, and their dynamic. As an example, hares are less likely to cause damage when foxes are present, and foxes are more abundant if there is a larger, complex natural habitat nearby. The issue for food forest practitioners lies in deciding what to do with that available information. Does a hare problem warrant the active facilitation of hare predators, or is it simply easier to build passive barriers or plant trap crops? A larger context of both the surrounding landscape as other food-forest-specific features will need to be considered when deciding on a food forest management strategy.

Current food forest management practices largely address an agroecological system through its plant-to-plant interactions, facilitating a diversity of perennial species. Apart from an agricultural production system, food forests serve educational and recreational purposes. Integrating management aspects, and planning considerations to accommodate faunal components, might contribute to the multifaceted output of food forests. Enriching overall biodiversity by accommodating, if not facilitating, fauna species appears to align with the general philosophy of food forestry and may be of special value in an agricultural landscape as barren and patchy as that of the Netherlands. Additionally, rewilding efforts of fallow agricultural land have gained much traction in recent years and food forests may well act as both a physical and symbolic buffer between land-use practices that appear to either work for or against nature.

Inherent to the nature of food forests, wild animals are incorporated in the ecosystem. The food forest is desired as an open system in which smaller animals like birds, rodents, and insects may easily disperse. It is therefore not surprising that for a functioning ecosystem to be established, thought must be given to how to incorporate their natural predator species as well. Of course, this may not always be an option for every food forest. In the Netherlands, fragmentation and size of complex nature area does not always facilitate the presence of (often) larger predator animals. In this case, strategies must be employed to either actively attract predator species (e.g. nest boxes, refuge areas), or strategies to mitigate prey species damage (e.g. trap crops, physical barriers).

4. Offering a critical view

There is an argument to be made for not making food forest the complex, inter-connected ecosystems they can be. Making a food forest, especially a larger one, a self-sufficient and sustainable system without need for external input from the surroundings, sounds especially alluring. Establishing a food forest in an otherwise biodiversity-poor area increases the complexity of the environment as a whole and contributes to ecosystem regeneration. In the scope of this research, large prey and predator species seemed also to play a subordinated role in the challenges and functions of the young food forests. To evaluate the long-term effects and the necessity of larger animals in a food forest long term monitoring and studies should provide clearer evidence.

The findings of this study consistently illustrate a consensus amongst members of the Dutch food forest sector with regards to the acceptance, application, and feasibility of adopting faunal diversity as a means of regulating and facilitating ecosystem processes within their systems. As promised in the project proposal, the specified scope of this study grants opportunity to refine trans-disciplinary ideas and approaches. Additionally, novel outlooks on prospective research can be derived from broader ecological and agricultural concepts. However, insights from practical experiences were limited to early-stage food forests and lacked detailed information about future perspectives. Despite a bulk of literature on European wildlife dynamics, and agricultural practices applying these ideas to a narrowed scope such as it applies to food forests, remains a novel practice, and a scarcity of information may be encountered.

However, broader concepts and understandings of ecological principles integrated in agriculture, ecosystems, and environment appear both apposite and pertinent to the scope and scale of the Dutch food forest network.

FOOD FOREST T. E. A. M.

5. Recommendation for practitioners/ the network

From the approach taken for this report and the gained data, it is difficult to establish concrete guidelines for wildlife management practices in food forests. This is further enhanced by the fact that food forest management and development are highly dependent on the context in which the food forest is situated. Nevertheless, the following recommendations are derived from personal thoughts and observations, combined with existing knowledge of both interviewees and authors:

- The purpose of a food forest defines the intervention level. Starting food forest practitioners should take the surrounding landscape type into account:
    - A cleared landscape could imply a less stable ecosystem in, and around, the food forest. A higher intervention level might then be required to establish the desired food forest ecosystem.
    - A complex landscape imposes larger effects on the food forest, which implies that interventions will have less effect.
- When land is already settled, an assessment of the landscape type can be made to determine what type of interventions are possible in advance.
    - The required buffer-zone size is specific for the landscape and food forest size. Smaller food forests may require a larger buffer-zone to buffer spill-over effects and to provide habitat for a diversity of animal species.
    - Landscape assessment can determine the relative effectiveness of an intervention. For instance, open areas in the food forest have a greater impact when the surrounding landscape is more forested.
- Defining a threshold of pre-harvest losses to the food forest ecosystem and yield is useful for weighing up intervention costs against damage inflicted by wildlife. This can be done, for instance, by setting a maximum yield that wildlife may consume.
- Damage can be reduced by initially planting less expensive or vulnerable species. More expensive or vulnerable tree species can be planted once an understanding of the species dynamics is established that might cause damage in the food forest and how extensive the losses are.
- Continuing monitoring of wildlife in and around the food forest promotes awareness of the ecosystem, meaning which species occur in which niches in the food forest. This allows for a prediction of possible negative and positive effects of wildlife and potential interventions.
- Facilitation of predator species by making nesting boxes or creating microhabitats in the food forests benefit and attract the predator species. This improves overall biodiversity.
- Natural dynamics of the food forest development and succession should be considered: current flora and fauna species might disappear when the food forest develops, other species might find a home only later in the food forest's life.
- More interventions regarding wildlife management may be needed in the beginning of a food forest's life to establish a functioning ecosystem. Once it is established, lower facilitative and protective intervention levels can be expected as the ecosystem is capable to regulate itself. Considering the yield: level of intervention might remain high in case only low yield losses are accepted.
- Sharing experiences and insights among food forest practitioners within the Dutch Voedselbossen network is an efficient means to improve food forestry in the Netherlands and raise awareness for areas which need more research.

6. Suggestions for improvements in future work

This project used mainly food forests of at most five years old as a reference. This is mainly because of the low number of older food forests in the Netherlands, and the lack of response from the practitioners of older food forests. However, young food forests are not yet high in production, and the effects of wildlife food forest yield could therefore not properly be assessed. The food forest movement would therefore especially benefit if future research would put its focus mainly on older, more developed food forests.

When conducting similar research in the future, particular note should be taken of increasing the sample size. There is no shortage of food forests in the Netherlands which could be surveyed in terms of wildlife population and abundance. Further, experiences from similar landscapes such as in the United Kingdom could be included in further studies. It would be of great interest to review the findings of this report against a larger sample size. Despite only using a limited number of samples, this report has uncovered a valuable area of study in the Dutch food forest landscape.

CONCLUSION

Food forests in the Netherlands experience many challenging but also beneficial wildlife interactions. These are often most visible in relationships between herbivorous mammals, birds, and their predators. In this report, these interactions were highlighted, and an overview of different approaches of interacting with predator and prey species in a food forestry setting was provided.

The intervention methods in this research imply that young food forests may benefit from protection against herbivory. For the general practice of food forestry, this suggests that a "no-human-intervention strategy" might only be possible in older, well-established food forests. This is perhaps contradictory for some philosophies of food forest managers who prefer to employ a more "hands-off" approach to wildlife management.

The type of landscape which surrounds the food forest also plays an important role in determining the type and abundance of animals which interact with the food forest. The phenomenon of the surrounding landscape influencing agroecosystems is already well-known. Both in organic agriculture and in nature-inclusive agriculture such as agroforestry systems are influenced by their surrounding areas with regards to biodiversity and the overall agroecosystem. The exact relationship between food forests and their surroundings is an area of great interest, with unfortunately very little research dedicated to it.

The place of food forests in modern agriculture remains a modest one. Nevertheless, food forestry and the need for more sustainable forms of food production speak volumes about the potential of an ecosystem approach to agriculture.

The roles of wild animals and landscape contexts in food forests remains under investigation and would benefit greatly from more scientific research in this area. Equally important is increasing the degree of monitoring and surveying of the biodiversity development in food forest landscapes. As such, the benefits of animal diversity and abundance can be assessed for both the food forest and the surrounding areas. This would also benefit food forest managers who are interested in actively facilitating the role of wild animals in the food forest ecosystem.

To extend monitoring and survey efforts, resources and organisation are needed. Increased funding for organisations like *Staatsbosbeheer* could go a long way in better understanding the impacts and relations between food forests and their relative ecosystems. The main massage that resulted from this project is that a holistic approach is key when one aims to work alongside nature in order to create a well-balanced system that provides both food for humans as well as a valuable living environment for a large variety of life forms. Ecosystems are notoriously complex and stimulating a similar kind of complexity in our food production systems is a true challenge, but it is exactly this complexity which holds the power to create robust systems that are ecologically sustainable. Although the answers to many questions may not be clear yet, it is clear that this direction is worth further exploring. Promoting the functionality of food forest holds the potential of integrating food production and nature, and this must be considered promising… food for thought.

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Appendix I. Interview questions

I. Introductory questions
These are questions to get practical information – this helps to categorize the food forests further

☐ How large is the food forest?
☐ How long have you (the practitioner) been working on the food forest?
☐ What kinds of plants/crops are present in the forest?
- Has that changed during the lifetime of the food forest?
☐ What is the source of income for the food forest?

(If no answer was given on production: How much of the income will come from the actual yield?)
- Possible terms: educational; production; aesthetic; hobby; etc

These questions are about personal motivation – Why are they doing it? What is the intention?

☐ Do you have a specific philosophy regarding food forests?

(If not mentioned in answer: ask about ecological sustainability; viability as an agricultural system; what is their definition of sustainable – what level of intervention do they allow?)

☐ Why did you start a food forest?

(This question relates to the focus of the food forest/ source of income/ philosophy)

II. Landscape-related questions
We ask these questions to identify differences of size-effects between the surrounding landscape and food forest functionality.
~ Introduce our classification of complexity (heterogeneity and natura 2000) – indicate categories (clear – simple – complex landscape; small – big food forest) ~

☐ How diverse do you think your surroundings are? (animal and plant species)

(They might categorize themselves differently, this is to check the current situation of the food forests)

☐ What interactions do you experience between the food forest and the surrounding nature/landscape?

(This question could focus on wildlife, but other interactions could also be interesting to note down)

☐ Do you think that the food forest can function as an independent ecosystem?
  - Does the food forests need the surroundings to function?

III. Pest-related questions
Mention that we are specifically looking at vertebrate species interactions in this study to keep the focus on that.

☐ Which animals do you see around the food forest?
☐ Which of these animals forms a **pest species** to your food forest, if any?

(This question does not focus on predators.)

Prey species	Specific species	Counting (seasonal, weekly, daily,...)
Birds		
Rodents		
Deer		

☐ Do you know of neighbours/ nearby farms that experience similar issues?
☐ What methods of pest control do your neighbours use?
(This question could also bring up other conflicts like spill-over effects, that we could note down, but don't want to focus on.)
- Do their methods (biological/ conventional) effect you?

☐ Do you see any **predator species** around the food forest and what kind? (see table)
- Would you welcome the wolf (or other specific predators) in your food forest?
- How far would you go in accepting natural dynamics?

☐ Do you see any predator/prey relationships at the food forest?
(This could already indicate a negative or positive effect on the food forest)
- Is this relationship already suppressing presence of pests?

☐ What are your current and/or past methods for control of pests?
(This question aims for the level of human intervention.)
- Do you do anything specific to facilitate predators in the food forest? (owl boxes)
- Do you have any other methods to reduce damage from vertebrate pests?

☐ How much of the harvest/products is lost due to pests?
(This question addresses the viability of food production in the food forest.)
- Is this damage level acceptable to you?
- What are the limits of pest damage that you are willing to tolerate?

☐ How do you view the future of predator-prey relationships for food forests?
(Note if they feel positively or negatively about the integration of predator-prey relationships in food forests)
- Do you think that predator-prey relationships have a place in the future of food forests?
  - Or in your own food forest?
- How could predator-prey relationships be improved in food forests?

IV. Additional questions

☐ What would be helpful for you to include as a topic for further research around food forests?
(This question aims to steer the research agenda; this is not necessarily focused but preferable on pest/ wildlife interactions& control)

Appendix II. List of relevant species

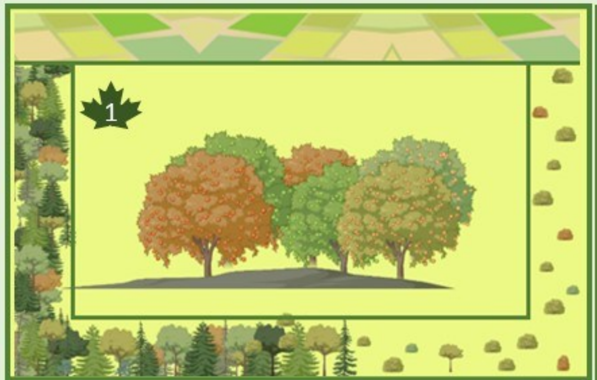
Species groups	Species name (English)	Species name (scientific)	Abundance	Predator / herbivore / insectivore	Specificity in food	Type of food	Habitat & requirements for space	Additional notes	Source
Birds of prey	Northern Goshawk	*Accipiter gentilis*	abundant	predator	variable	birds and mammals, including hare and rabbit	mosaic landscapes, nesting preferably in forests of >100 ha		Génsbøl, Bertel, & Meesters, 2007
	Eurasian Sparrowhawk	*Accipiter nisus*	very abundant	predator	specialized	birds	mosaic landscapes, nesting preferably in forests of >10 ha (nesting mainly in firs)		Génsbøl, Bertel, & Meesters, 2007
	Common buzzard	*Buteo buteo*	very abundant (most abundant bird of prey in the Netherlands)	predator	somewhat specialized	mammals, also sometimes birds and other prey	mosaic landscape with variety of landscape characters	nests in forest edges	Génsbøl, Bertel, & Meesters, 2007
	Eurasian Hobby	*Falco subbuteo*	common/rare and declining	predator	somewhat specialized	birds and insects	open habitat, including forests with open spaces.	nests in old crow nests	Génsbøl, Bertel, & Meesters, 2007
	Common Kestrel	*Falco tinnunculus*	very abundant	predator	somewhat specialized	mammals, also sometimes birds and insects	open habitat with small groups of trees and nesting space (trees, buildings, nesting boxes)		Génsbøl, Bertel, & Meesters, 2007
	Owls	*Strigidae sp.*	common/rare	predator	somewhat specialized	mammals and sometimes birds	forest edges, open forests and open areas		IJsseling, & Scheygrond, 1943 Vogelbescherming Nederland, n.d.
Carnivorous mammals	Wolf	*Canis lupus*	very rare	predator	somewhat specialized	large mammals including sheep, goats, beavers, deer, wild boar and sometimes humans	large natural areas, including forests, mountains, croplands and steppes; space requirement in Europe is between 120 and 350 km2 for a pack of wolves to survive; tends to avoid coastal regions	normally hunt by night; domesticated dogs form a good protection against wolf attacks	Ambarlı, 2019; IJsseling, & Scheygrond, 1943; Sidorovich, Schnitzler, Schnitzler, Rotenko & Holikava, 2017; Wolven In Nederland, 2021
	Cat	*Felis catus, Felis silvestris*	common/rare	predator	generalist	all macrofauna	urban areas (*F. catus*) and forests (the extremely rare *F. silvestris*)		IJsseling, & Scheygrond, 1943
	European Pine Marten	*Martes martes*	common/rare	predator, herbivore	generalist	squirrels, birds, eggs, hares, rabbits, honey, fruits and insects	forested areas	nest in squirrel or bird nests or hollow trees	IJsseling, & Scheygrond, 1943
	European Badger	*Meles meles*	common/rare	predator, herbivore	generalist	belowground arthropods, rodents, moles, frogs, snakes, eggs, young birds, deer calves, wasp and bee nests, roots, fruits and nuts	hilly areas	social animals of which a single family can live for centuries in the same sett (badger den)	IJsseling, & Scheygrond, 1943
	Weasels	*Mustela* spp.	common/rare	predator	generalist	rodents, eggs and birds	forest edges and neighbouring fields, also sparsely populated areas	nests in holes, trees (pollarded willows) and barns	IJsseling, & Scheygrond, 1943
	Red Fox	*Vulpes vulpes*	common	predator (herbivore)	generalist	rodents, birds, eggs, reptiles, insects and fruits (sometimes also deer calves)	mosaic landscapes of forest, heather, arable land and meadows; can occur everywhere except the dunes	foraging distances are high, distances of 5 km are not unusual	IJsseling, & Scheygrond, 1943

Large herbivores	Roe Deer	*Capreolus capreolus*	abundant	herbivore	generalist	twigs, branches, nuts, buds, needles and mosses.	forested areas, interspersed with open areas (younger forests, arable land or meadows), and forest edges.	Usually tend to reside in the same area, in groups of 3-10 animals.	IJsseling, & Scheygrond, 1943
Rodents	Voles	Arvicolinae	abundant	herbivore	somewhat specialized	seeds, nuts, bark and buds, also herbaceous plants and grasses	multi-layered forests and forest edges (tend to central parts of dark forests), but some species also live in open grasslands	mainly problematic in arable land and young plantations, not so much in forests; mainly predated by Red Foxes, Weasels, Moles, Brown Rats, Common Buzzards, Northern Goshawks, Common Kestrels and owls; sensitive to melting snow that enters mouse holes and refreezes at night	IJsseling, & Scheygrond, 1943
	European Beaver	*Castor fiber*	common	herbivore	specialized	tree bark and leaves and roots of (semi-)aquatic plants	aquatic environments (rivers and lakes) bordered with trees at the shore		IJsseling, & Scheygrond, 1943
	European Hare	*Lepus europaeus*	abundant	herbivore	generalist	aromatic and 'juicy' herbaceous plants, during winter also bark, heather or blueberry	open fields on sandy or clayey soils, avoids large forests and busy areas	strips bark upwards or eats it from twigs that are bitten off the tree; foraging area is up to several hundreds of ha (distances of over a km can be covered easily)	IJsseling, & Scheygrond, 1943
	Old World Rats and Mice	Murinae	very abundant	herbivore, predator	generalist	seeds, nuts, grasses, plant storage organs, small animals (including bird eggs), insects and processed foods	generally open fields or urban environments	only the wood mouse (*Apodemus sylvaticus*) is a forest species, living mainly from nuts of oak, beech and hazel; large foraging area, where distances of 400 meter around the nest are not unusual; mainly predated by cats, weasels, owls and other birds of prey	IJsseling, & Scheygrond, 1943
	European Rabbit	*Oryctolagus cuniculus*	common	herbivore	generalist	leaves of grasses and herbaceous plants (incl. crops), also bark	open fields on mainly sandy soils	lives in warrens (groups of rabbits), doesn't drink water, fences are usually the only effective way to protect young trees. Foraging range usually within 100m around	IJsseling, & Scheygrond, 1943

	Red Squirrel	*Sciurus vulgaris*	very abundant	herbivore	somewhat specialized	nuts and seeds (including apple and pear seeds), but also buds, bark, mushrooms, galls and insects	forests with high trees, low humidity and enough shadow.	the nest. Mainly predated by Red Foxes, Weasels and Common Buzzards. Primarily predated by the European Pine Marten, but also by bird of prey like the Northern Goshawk	IJsseling, & Scheygrond, 1943
Other mammals	European Hedgehog	*Eraniceus europaeus*	common	predator	generalist	invertebrates, reptiles, amphibians, moles, young hares, bird eggs, fruits, seeds and mushrooms	areas with a rich undergrowth and plenty of hiding places	solitary lifestyle	IJsseling, & Scheygrond, 1943
	Shrews	Soricidae	abundant	insectivore	somewhat specialized	invertebrates, possibly also young mice	areas with abundant undergrowth, including forests and forest edges		IJsseling, & Scheygrond, 1943
	European Mole	*Talpa europaea*	common	insectivore	somewhat specialized	belowground invertebrates, mainly feeds in rainworms	not too wet grasslands and forests.	hunts by smell, active during winter, moles live solitary and only allow other moles in their territorial during mating season	IJsseling, & Scheygrond, 1943
Reptiles	Snakes	Serpentes	rare	predator	generalist	amphibians, small mammals, bird eggs and young birds	landscapes with enough open spots and presence of (small) water bodies. Tend to avoid closed forests.	coldblooded animals, need sun to become active	Ravon, n.d.
Songbirds e.o. (insectivores & herbivores)	Doves	Columbidae	very abundant	herbivore	generalist	seeds, buds and leaves	landscape with shrubs and trees		Bird Spot, 2022; Vogelbescherming Nederland, n.d.
	Crows	Corvidae	very abundant	predator, insectivore, herbivore	generalist	insects, small mammals, small birds, eggs, nuts and berries	mainly open landscapes or forest edges	Eurasian Jays are famous for their nut collecting behaviour in autumn and winter, but are predatory during most of the rest of the year	Royal Society for the Protection of Birds, n.d. Vogelbescherming Nederland, n.d.
	Finches	Fringillidae	abundant	herbivore	somewhat specialized	seeds and nuts, including those from birch, black elder, pines and herbaceous plants. Also berries like rose hips, hawthorn berries and bramble berries	forests (type of forest depending on the species), but also more open landscapes with trees and shrubs		Gardeners' World, 2019; Garden Bird, n.d. Vogelbescherming Nederland, n.d.
	Tits	Paridae	very abundant	insectivore, herbivore	generalist	insects, seeds and nuts	forests and other landscape with (old) trees	nests mainly in hollow trees. Food consists mainly of insects in nesting season and mainly of seeds (beech nuts, pine seeds) in late autumn and winter	Gardeners' World, 2019; Vogelbescherming Nederland, n.d.
	Leaf Warblers	*Phylloscopus* spp.	common	insectivore	somewhat specialized	mainly insects, also fruits	forests and other landscape with trees	fruits (such as blueberry, elderberry	Vogelbescherming Nederland, n.d.

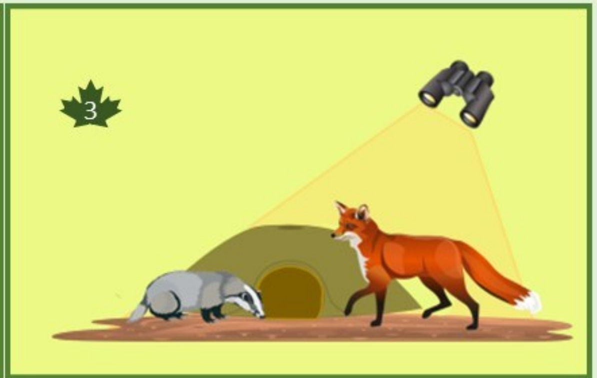
								and birch seeds) are only part of the diet in autumn	
	Woodpeckers	Picidae	common	insectivore, herbivore	somewhat specialized	insects (mainly ants), fruits and seeds	forests and other landscapes with an abundance of trees	fruits and seeds are only part of the diet during winter. In spring, some woodpeckers might also eat eggs and young birds	Gardeners' World, 2019; Vogelbescherming Nederland, n.d.
	Eurasian Nuthatch	*Sitta europaea*	abundant	insectivore, herbivore	somewhat specialized	insects, seeds and nuts	diverse forests with some open spots		Gardeners' World, 2019; Vogelbescherming Nederland, n.d. Woodland Trust, n.d.
	European Starling	*Sturnus vulgaris*	abundant but declining	insectivore, herbivore	generalist	insects and fruits	all landscapes, as long as trees for nesting are present	fruits (including apple) are only part of the diet in autumn.	Vogelbescherming Nederland, n.d.
	Thrushes	Turdidae	very abundant	insectivore, herbivore	generalist	insects, fruits and nuts	open landscape with some trees.	insects (and worms) during spring and summer, fruits and nuts during autumn and winter	Vogelbescherming Nederland, n.d.

Appendix III. Food forest factsheet



The surrounding landscape has a direct impact on the dispersal and colonization of wildlife in food forest systems. Significant factors include the complexity and heterogeneity of the greater landscape network. For biodiversity; complexity is better and connected is better than isolated!

Birds of prey contribute to biodiversity and trophic level interactions; regulating rodent and songbird populations within food forest systems. Their presence may be facilitated through the placement of perches, nest boxes (owl boxes), and the presence of standing deadwood.



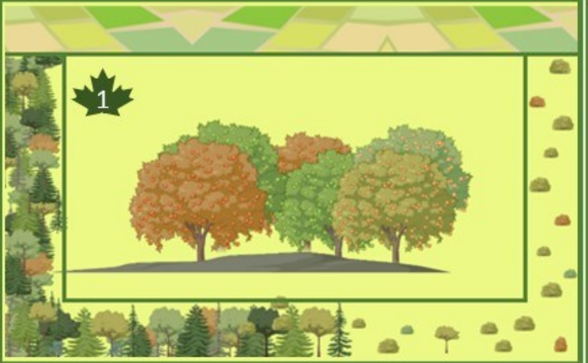
Mammalian predators, as visitors or residents to food forests, indicate a degree of system health. They also may actively regulate populations of prey species, which at high densities might adversely impact productivity. Monitoring is a key step in establishing the presence of predators and the influence they exert on the system!

Fructivore species, such as birds have the potential to be both a negative and a positive influence on the food forest. On the one hand, birds eat part of the fruits and harvest. On the other hand, they improve ecosystem functions by controlling insect presence, including species like the oak processionary caterpillar.

Herbivores, such as roe deer and hare, represent a major threat to sapling recruitment and growth in some food forest settings. Simple fencing around individual saplings suffices as a low-cost, low-intervention solution to mitigate browsing damage. Additionally, larger plot fences might be considered to exclude herbivores entirely.

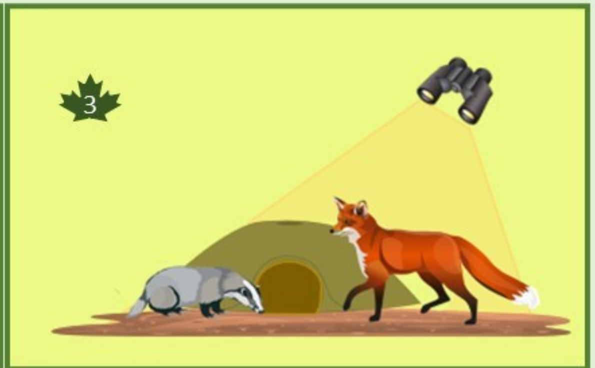
Food forests in less biodiverse landscapes may benefit from buffer zones to reduce impact of farming into and pest migration out of the food forest to the surrounding areas. Those buffers can facilitate specific species abundance by habitat creation and include 'trap crops' for mammals and birds to reduce harvest loss.


"Fauna in voedselbossen: De Factsheet"
Een voedselbos is een productief ecosysteem, ontworpen door mensen om een natuurlijk bosecosysteem na te bootsen.
Met veel verschillende meerjarige en houtige planten, creëren voedselbossen verschillende niches en leveren ze vruchten, zaden, noten, en andere gewassen.
Als een multifunctioneel systeem kan voedselproductie gecombineerd worden met bijvoorbeeld natuurherstel, onderwijs, en het onder de aandacht brengen van voedselbossen.
Onderzoek aan effecten van dierlijke interacties in Nederlandse voedselbossen.
• De soortenrijkdom en interacties binnen de voedselketen.
• De mogelijke interventies om interacties tussen soorten te beïnvloeden.
FOOD FOREST T. E. A. M.



De omgeving heeft een directe invloed op de verspreiding en kolonisatie van wilde dieren in voedselbossen. Belangrijke factoren zijn onder andere de complexiteit en verscheidenheid binnen het grotere geheel van het Nederlandse landschapsnetwerk. Voor biodiversiteit geldt: hoe complexer, en meer verbonden, hoe beter!

Roofvogels dragen bij aan de biodiversiteit en aan de interacties binnen de voedselketen. Ze reguleren knaagdier- en zangvogelpopulaties in voeselbossystemen. Je kunt roofvogels aantrekken door het platen van zitplekken en nestkasten en het laten staan van dode bomen.



De aanwezigheid van zoogroofdieren in voedselbossen zijn een indicatie van een gezond ecosysteem. Ze kunnen ook actief prooidierpopulaties reguleren, welke anders schade kunnen aanrichten. Monitoren is een belangrijk onderdeel in het vaststellen van de aanwezigheid en invloed van deze roofdieren in het voedselbos.

Fruitetende vogelsoorten kunnen zowel een negatieve als positieve invloed hebben op een voedselbos. Aan de ene kant eten vogels een deel van de oogst, aan de andere kant spelen ze een belangrijke rol in het ecosysteem door het eten van insecten zoals de eikenprocessierups.

Herbivoren, zoals reeën en hazen, vormen een groot probleem voor jonge beplanting in sommige voedselbossen. Een eenvoudig hek rondom een jonge boom dient als een makkelijke en goedkope oplossing om vraat tegen te gaan. Bovendien kunnen hoge hekken ook planteneters volledig buiten het voedselbos houden.

Voedselbossen in een minder biodivers landschap kunnen voordeel hebben van een bufferzone. Deze buffers kunnen negatieve interacties met een landbouwomgeving beperken. In bufferzones kunnen habitats voor verschillende dieren gecreëerd worden, maar ook kunnen “trap crops” worden geplant voor planteneters om de schade aan gewassen te beperken.