Mapping Woody Vegetation and Land Use for Biodiversity Monitoring at the Bec Hellouin farm

MSc Internship Report

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Foreword

I would like to express my sincere gratitude to my supervisor, Rose, who supported me throughout the internship with constant encouragement and positivity. Special thanks also go to Charles, who made this internship possible and generously offered guidance and kindness along the way. I would also like to thank Mathilde, whose company in the office, our chats, and shared coffee breaks made the workdays much more enjoyable. Of course, my thanks go as well to the entire team at the Bec Hellouin farm for their warm welcome, openness, and for creating such an inspiring environment through their daily work. Lastly, I would like to thank my WUR supervisor, Carl Timler, for thinking along with me during this journey and for his valuable guidance and support.

Abstract

The industrial food system is built on unsustainable practices, making it a key driver of current environmental problems. While agricultural intensification can produce high yields, evidence clearly shows that it leads to biodiversity loss, which in turn undermines ecosystem functioning, compromises the delivery of ecosystem services, and reduces the resilience of farming systems to disturbance. Agroecology is advocated as a promising alternative to industrial agriculture, capable of addressing multiple issues in the food system. One agricultural producer actively engaged in agroecological practices is the Bec Hellouin Farm, situated in Normandy, France. In 2026, they will launch a new research program to quantify the farm's biodiversity and its impact on crop health at current levels and its evolution over time. As preparation for this upcoming research program, this study conducted a comprehensive field survey of the farm's woody vegetation and land use. This involved on-site identification and documentation of species, vertical strata, and vegetation health. The collected data, supplemented by a literature review, were used to create a detailed plant database. Based on this information and aerial imagery, multiple spatial maps were created in Vectorworks 2025, covering five categories: Basemap, Land Use, Vegetation Classes, Vegetation ID, and Vegetation Health and Abnormalities. These maps provide a clear reference of existing land uses and vegetation types, enabling changes to be tracked over time and observations to be contextualised. They also facilitate targeted biodiversity monitoring by clearly defining zones and habitats for repeated observation. The Vegetation ID map allows for precise cross-referencing with the plant database, while the vegetation health maps enable tracking of species and cultivars that thrive or struggle under specific conditions. Finally, the maps also function as a communication tool to convey the farm’s ecological complexity to stakeholders, researchers, and the public.

1 Introduction

The industrial food system is built on unsustainable practices, making it a key driver of current environmental problems. Furthermore, it plays a significant role in the exceedance of the ecological planetary boundaries, including global warming, nitrogen cycle disruption, land use change, and species extinction (Björklund et al., 2019). Dependency on fossil fuels, mineral fertilisers, and chemical pesticides add to these issues (Rembiałkowska et al., 2016).

While agricultural intensification can produce high yields, evidence clearly shows that it leads to biodiversity loss, which in turn undermines ecosystem functioning, compromises the delivery of ecosystem services, and reduces the resilience of farming systems to disturbance (Landis, 2017). This reinforces the need to shift the focus from production alone to an approach that equally values the provision of critical ecosystem services, aiming to build farming systems that are both profitable over time and sustainable for future generations (Smukler et al., 2013).

Agroecology is advocated as a promising alternative to industrial agriculture, capable of addressing multiple issues in the food system and contributing to the Sustainable Development Goals. However, the transition to agroecological production is a complex matter and requires cooperation not only from scientific institutions and governments but also with agricultural producers and agroecological movements (Anderson et al, 2019).

One such agricultural producer actively engaged in agroecological practices is the Bec Hellouin Farm, situated in Normandy, France. This experimental micro farm is committed to exploring the links between ecological and economic performance in agriculture. Resilience is the central theme of their work. Founded in 2006, the farm's five hectares of land—originally consisting of four pastures—have since been transformed into a mosaic of silvoarable, silvopastoral, and complex agroforestry systems across 40 distinct plots. A wide variety of crops, including vegetables, cereals, fruits and berries, and aromatic and medicinal plants, are cultivated in a mosaic of habitats that balance rewilding, biodiversity, and productivity, almost entirely without fossil fuels (Institut de La Ferme du Bec Hellouin, 2025a). This complex agricultural landscape provides diverse habitats and supports significant biodiversity (Chapelle, 2018).

Figure 1: Aerial image of the Bec Hellouin farm, Normandy, France (Institut de la Ferme du Bec Hellouin, 2025a)

In 2012, the Bec Hellouin Farm founded a non-profit organisation that supports action-research programs in partnership with various scientific institutions (Institut de La Ferme du Bec Hellouin, 2025b). Since then, the farm has been the subject of numerous scientific and techno-economic studies, such as organic permaculture market gardening and its economic performance, soil fertility, food forests and cereal production without fossil fuels (Institut de La Ferme du Bec Hellouin, 2025b; Institut de La Ferme du Bec Hellouin, 2024). In 2026, a new research program will be launched to quantify the farm's biodiversity and its impact on crop health at current levels and its evolution over time (Institut de La Ferme du Bec Hellouin, 2025b).

To carry out this research effectively, a detailed map of the farm is needed to provide a clear reference of existing land uses and vegetation types, enabling changes to be tracked over time, observations to be contextualised, and zones with similar ecological conditions to be identified, supporting consistent and targeted biodiversity monitoring. Therefore, during this internship, the following deliverables were created:

1. Basemap of the farm including all parcels, water bodies and buildings.
2. Land use map categorising the farm and surrounding areas into agricultural production, natural and semi-natural areas, infrastructure, and human-use zones.
3. Parcel surface area map indicating the size of each parcel.
4. Woody vegetation map showing all trees and shrubs categorised into six vegetation types, with corresponding land cover per parcel.
5. Woody vegetation ID map assigning a unique vegetation ID to each plant, linked to a plant database.
6. Vegetation health map classifying the severity of vegetation abnormality of all woody vegetation into the categories good, moderate, and poor health.
7. Vegetation abnormality type map identifying vegetation health issues grouped into foliage and canopy health, climber and plant overgrowth, and structural issues.
8. Plant database containing all woody vegetation, identified by parcel and vegetation ID, with English and Latin names, vegetation layer, abnormalities, vegetation type, invasive species and for productive species, available information on cultivar, rootstock, growth form, harvest and flowering periods and age.

2 Methodology

A comprehensive field survey of the farm's woody vegetation and land use was conducted, including on-site identification and documentation of species, vertical strata, and vegetation health. This data, complemented by an additional literature review, was used to create a detailed plant database. Based on this, multiple vegetation and land-use maps were developed using Vectorworks 2025 Educational Version.

2.1 Field data collection

To make a comprehensive inventory of the farm's woody vegetation and their location, a data collection sheet and sketches of each parcel's perimeter were made. The data collection sheet contains a table with the following attributes: Parcel ID, Vegetation ID, Species, Strata, Type (tree, shrub, climber), Vegetation health and Land use (see Annex 1). Additionally, a space to note the observation date was included. The sketches of the parcel's perimeter were prepared based on an existing farm basemap (see Annex 2). An example of a finished sketch can be found in Annex 3.

Each parcel was then systematically surveyed by walking in a structured manner from one end to the other (N-S or W-E, depending on the parcel's orientation), recording the species, strata, and abnormalities, and assigning a unique ID on the data collection sheet. Simultaneously, parcel sketches were used to place each plant in its correct location and approximate size, and to mark it with the vegetation ID assigned on the data collection sheet. Lastly, the parcel's land use category was recorded on the data collection sheet. To ensure accurate classification, the land use data was later verified with the farmer. Woody vegetation was identified using the Pl@ntnet Android app (Goëau et al., 2013) and the book “Identifier arbres et arbustes en toutes saisons” (Lüder, 2020). The vegetation strata were categorised into four classes, which can be observed in Table 1.

Table 1: Class definition of vegetation layer used to classify vegetation surveyed at Le Bec Hellouin farm, classes described by Crawford, (2010)

Vertical layer	Number	Class definition
Canopy layer	1	Trees with a height >10m
Medium trees/large shrubs	2	Small trees with a height of 4-9m
Small shrubs/small trees	3	Shrubs between < 3m
Climbers	4	Woody and herbaceous climbers

Vegetation health was assessed based on the observation of abnormalities, as listed in .

Table 2.

Table 2: Vegetation abnormality categories used to classify vegetation surveyed at Le Bec Hellouin farm, adapted from Tierney et al., (2021)

1. Structural Issues	- Trunk/Bark Damage - Leaning Trunk / Needs Stabilisation - Broken Branches - Partially Uprooted / Fallen
2. Foliage and Canopy Health	- Reduced Foliage Density (in season) - Defoliated (in season) - Wilted Foliage (in season) - Yellowing leaves (out of season) - Leaf necrosis - Insects or disease on leaves - Dead Branches Present - Branches growing into each other
3. Climber and Plant Overgrowth	- Ivy Overgrowth - Brambles Overgrowth - Bindweed Overgrowth - Mistletoe Infestation

2.2 Plant Database

After field observations were manually recorded and mapped by hand, the data was digitised and organised into an Excel database, consisting of three worksheets and various attributes, as can be observed in Table 3. To ensure consistency, data entry guidelines (see Annex 4) were established to maintain the database coherently over time.

Table 3: Overview of the Excel plant database, including its worksheets and their attributes, created from the vegetation survey at Le Bec Hellouin farm

Worksheet	Attribute
Woody vegetation	Vegetation ID, Parcel ID, Sub Parcel ID, English name, Latin name, Vegetation layer (as described in Table 1), Vegetation abnormalities (as described in . Table 2), Vegetation health category, Type 1 (tree, shrub, climber), Type 2 (productive vs system), Invasive species
Hedges	Hedge ID, Latin name, Count, Strata
Woody vegetation productive	Vegetation ID, Parcel ID, Sub Parcel ID, English name, Latin name, Cultivar, Rootstock, Vegetation layer, Type 1, Harvest period, Flowering period, Age

Based on the Vegetation health assessment done in the field, all woody vegetation was classified into predefined health categories, as can be observed in Table 4.

Table 4: Vegetation health: severity categories used to classify vegetation surveyed at Le Bec Hellouin farm

Vegetation health category	Criteria
Good vegetation health	- No abnormalities - Minor issues that don't affect vitality
Moderate vegetation health	- Reduced foliage density (in season) - Wilted / yellow / brown / eaten leaves - Partially overgrown by ivy/brambles/mistletoe/bindweed - Branches starting to die, few dead branches - Bark issues: small wounds, spots - Needs stabilization - Skewed/cracked stem without full collapse
Poor vegetation health	- No/very few leaves in growing season - Heavy ivy/brambles/mistletoe/ bindweed overgrowth - Multiple dead branches - Major bark loss or large wounds - Tree fallen/partially uprooted - Stem cracked or fallen

In hedges too dense to map each individual plant properly, the number of species was counted or estimated (Hedge 1), but no sketch was drawn. The estimation for the number of woody vegetation of Hedge 1 was calculated with the following formula:

$$Nr.of\ woody\ vegetation = \frac{Length\ of\ hedge\ [m]}{plant\ density\ [\frac{plant}{m}]}$$

The length of the hedge was measured using Google Earth Pro. The plant density was assumed to be two plants per m of hedge.

Cultivar, rootstock, and growth form data were collected from available reports provided by La Ferme du Bec Hellouin. Harvest and flowering periods were subsequently researched using data from online plant nursery sources.

2.3 Development of a detailed vegetation and land use map

Based on the plant database and field parcel sketches, multiple detailed vegetation and land use maps were created in Vectorworks 2025 Educational Version. The creation of these maps is described in detail in the following sections.

2.3.1 Document setup

First, the document setup was configured in the desired unit, scale and drawing area, as can be observed in Figure 2.

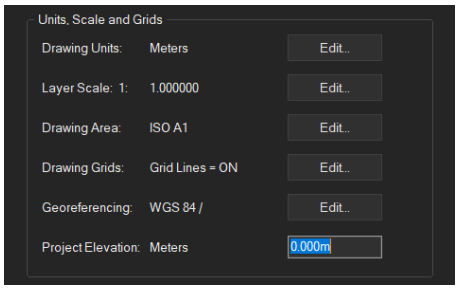

Figure 2: Vectorworks 2025 Educational Version Document Setup for map creation

2.3.2 Basemap

The existing farms' basemap was created from a drone image, resulting in distortion and an unknown orientation and scale. Therefore, a new basemap was created. Google Earth Pro was used to create an aerial image of the farm oriented towards the north and including a scale. With this method, aerial images from 2016, 2018, 2020, 2021, and 2024 were downloaded to extract information from (e.g., the location of newly planted trees is more visible in certain years).

These images were imported into Vectorworks 2025 and added to the Design Layer Aerial images. Further, all aerial images were accurately scaled to ensure that on-screen measurements and drawings correspond to real-world dimensions. Next, a second design layer, “Basemap”, was created. In this design layer, the borders of the whole farm, its 40 parcels, water bodies, and buildings were traced from aerial images and assigned unique colours. This was done with the polyline tool, which connects a series of arcs, curves, and lines into a single entity. There are six modes for drawing polylines, of which the corner and bezier vertex modes were used.

2.3.3 Groundcover

The basemap design layer was duplicated and renamed to ground cover. Using the polyline tool, more detailed features were added, including vegetable beds, paths, embankments, and areas within parcels that represent different ground covers. Nine ground cover categories were identified and assigned, differentiated by fill colour and pattern.

2.3.4 Land use

The groundcover design layer was duplicated and renamed to land use. Based on field-collected land-use data, areas were adapted to assign them to specific land-use classes, differentiated by colour. Additionally, the area surrounding the farm was traced from the aerial image and also assigned to a land use class. 19 Land use classes were identified and grouped into the following three overarching categories: Agricultural production, Natural and semi-natural areas, and Infrastructure and human use.

2.3.5 Vegetation

Next, the design layer “vegetation” was created. Within the Vectorworks plant library, plant 56 of the Concept Plants 2D was chosen to represent all vegetation. Vegetation data gathered in the field were categorised into six classes:

- Fruit tree
- Nut tree
- Fruit shrub
- Nut shrub
- System tree
- System shrub

Each category was assigned a unique colour. A plant database was created by generating 15 plant objects for each plant category, with diameters ranging from 0.5 to 15m. Using field parcel sketches, aerial imagery, and the groundcover map, the location and size of each plant were determined and placed on the map using the Plant Tool. The 'Single Plant' placement mode was used for individual plants, while the 'Polygon' mode ensured straight and aligned placement for vegetation planted in rows. To spread raspberries over a larger area, the 'Triangular Array' mode was used. This was done for all 3155 identified woody plants.

2.3.6 Vegetation health

The vegetation was grouped into vegetation health categories based on the severity and type of abnormality, as can be seen in .

Table 2 and Table 4. This information was used to create two maps regarding vegetation health.

1. Severity of vegetation abnormality

The design layer “vegetation” was duplicated and renamed “severity of vegetation abnormality”. A plant database was created by generating 15 plant objects representing the vegetation health categories “poor” and “moderate”. All vegetation falling into these two categories was updated by replacing the original plant objects with the corresponding category using the 'Replace Plant Style' command. Plants categorised as being in good health were retained in their original green colour.

2. Vegetation abnormality type

The design layer “vegetation” was duplicated and renamed “Vegetation abnormality type”. A plant database was created by generating 15 plant objects for each of the following categories:

1) Foliage and canopy health
2) Climber and plant overgrowth
3) Structural issues
4) Issue 1) and 3) present
5) Issue 1) and 2) present
6) Issue 2) and 3) present

Vegetation without any vegetation abnormalities was removed from the map. All other vegetation was updated by replacing the original plant objects with the corresponding category using the 'Replace Plant Style' command.

2.3.7 Labels and Legends

To ensure clear communication and ease of interpretation, labels and legends were created. A dedicated design layer, “Labels,” was set up for this purpose. Using the text tool, Parcel and Hedge IDs were assigned to their respective areas. Additionally, Vegetation IDs were assigned to all plants to enable accurate cross-referencing with the plant database. Finally, a north arrow was added to indicate the map’s orientation.

Legends in French and English were created for each map and placed in their respective design layers. These legends explain all elements visible on the map and were constructed using the Text, Rectangle, Circle, and Plant tools, with a dedicated design layer assigned to each legend.

2.3.8 Surface area

Using data from the object info palette, the surface area of all parcels was determined and recorded and later added to the land surface area map.

2.3.9 Classes

Classes allow grouping objects by category and assigning coherent graphical attributes, textures, and text styles across that category. Additionally, they can be used to control visibility, allowing certain object classes to be made invisible to generate different map aspects (Vectorworks 2023 Help, 2023a). Therefore, all generated objects were assigned to a specific class.

2.3.10 Design Layers

As mentioned above, various design layers (a total of 37) were created throughout the creation of the map. This was done to keep objects and their information organised and to allow them to be stacked in a useful order (Vectorworks, 2016).

2.3.11 Sheet layers and viewports

Sheet layers are used to create a presentation version of the finalised drawing. They allow setting a unique scale and drawing area according to the specific needs of the map (Vectorworks, 2016). Viewports can display entire and cropped views of a drawing, with specific layer and class visibility settings and orientation parameters (Vectorworks 2023 Help, 2023b).

As the final step in map production, sheet layers were created for each map at the desired sizes (A3, A1). Viewports displaying the appropriate map views and corresponding legends were then added and scaled to fit the sheet layout, ensuring a clear and organised presentation. A scale bar was inserted by editing the viewport annotations using the Scale Bar tool.

To improve readability, Parcels 4, 8, 11, 15, 19, 22, 24, 30, 31, 38, and 40, along with their associated vegetation and Vegetation IDs, were copied into a separate Design Layer. These parcels contain a high density of plants, which required small font sizes for Vegetation ID labels, making them difficult to read at the main map scale. As a solution, these parcels were added as additional viewports at a smaller scale.

2.3.12 Exporting

To share the maps and enable use in various ways, PDFs of each created sheet layer were exported. Additionally, to allow further adaptation of the map, a Vectorworks file containing all layers and classes was downloaded. Lastly, the map's title and the Bec Hellouin farm's logo were added.

3 Results

This section presents the results obtained during the internship and serves as a guide to the created deliverables. First, an overview of the plant database is given, followed by a detailed description of each map, including its content, purpose, and potential applications.

3.1 Plant Database

This database contains detailed information on all woody vegetation on the farm, derived from the vegetation survey. The database consists of four worksheets and includes several attributes, which are described in detail in Table 3. The completed Excel plant database can be found in the deliverables folder provided with this report.

Table 5: Description of all attributes present in excel plant database created from the vegetation survey at Le Bec Hellouin farm

Worksheet	Attribute	Further explanation
Woody vegetation	Parcel ID	The ID of the parcel (1-40), corresponding to the map, in which the vegetation is recorded.
	Vegetation ID	Each plant was assigned a vegetation ID, starting from 1 within each parcel. Combined with the parcel ID, this forms a unique identifier that enables accurate cross-referencing between the plant database and its corresponding location on the map.
	Sub Parcel ID	An edible hedge extends across a large portion of the farm. As it falls under the same land use category and features similar vegetation throughout, it was grouped as a single parcel. Due to the high density of vegetation within this parcel, it was further divided into sub parcels to enhance clarity and organization. Therefore, a unique sub parcel ID was assigned for clear distinction.
	English name	English name of species.
	Latin name	Latin name of species.
	Vertical layer	The woody vegetation is categorised into different vertical layers of growth, depending on their height and growth form (see Table 1).
	Structural Issues	Abnormalities of the vegetation that fall into the category of structural issues (see Table 2) are documented in this section.
	Foliage and Canopy health	Abnormalities of the vegetation that fall into the category of foliage and canopy health (see Table 2) are documented in this section.
	Climber and Plant Overgrowth	Abnormalities of the vegetation that fall into the category of climber and plant overgrowth (see Table 2) are documented in this section.
	Vegetation health category	Based on the Vegetation health assessment done in the field, all woody vegetation was classified into predefined health categories (see Table 4), enabling systematic evaluation and comparison across the site.

	Type 1	Categorises woody vegetation into vegetation types: tree, shrub, or climber.
	Type 2	Categorises woody vegetation into productive and system plants. A productive plant is defined as a plant species that provides food for human consumption. A system plant is defined as a plant species that provides ecosystem services for the ecological health of the system (van Eijk, 2021).
	Invasive species	Indicates whether the selected species can be categorised as invasive or potentially invasive in the study's location. Invasive species are defined as non-native plants that, in their introduced territory, have a proven invasive character and negatively impact biodiversity and/or human health and/or economic activities. Potentially invasive species are defined as non-native plants currently exhibiting a tendency to develop an invasive character within natural or semi-natural communities and whose dynamics within the territory in question and/or in neighboring territories are such that there is a risk of it becoming a proven invasive species (Douville & Waymel, 2019).
Hedges	Hedge ID, Latin name, Strata	As in worksheet Woody vegetation.
	Count	Total count of a species present in a specific hedge.
Woody vegetation productive	Vegetation ID, Parcel ID, Sub Parcel ID, English name, Latin name, Strata, Type 1,	As in the worksheet Woody vegetation.
	Cultivar	A variety of a species that is bred and propagated for desirable functional plant characteristics (Jacke and Toensmeier, 2005).
	Rootstock	The base and root portion of grafted plants (Crawford, 2010).
	Harvest period start (month)	The month in which the harvest of this species starts.
	Harvest period end (month)	The month in which the harvest of this species ends.
	Harvest period start (week)	The week of the year (1-52) in which the harvest of this species starts.
	Harvest period end (week)	The week of the year (1-52) in which the harvest of this species ends.
	Flowering period start (month)	The month in which this species starts flowering.
	Flowering period end (month)	The month in which this species stops flowering.
	Flowering period start (week)	The week of the year (1-52) in which this species starts flowering.
	Flowering period end (week)	The week of the year (1-52) in which this species stops flowering.
	Year of planting	Year in which the species was planted.
	Age year 2026,2031, 2036	Age, in years, of this species in the years 2026, 2031, 2036.

3.2 Woody vegetation and Land use maps

Maps were created across five categories: Basemap, Land Use, Vegetation Classes, Vegetation ID, and Vegetation Health and Abnormalities. This chapter presents each category, providing a detailed description of the maps it contains. All maps created during this study are available in high-resolution PDF format in the deliverables folder provided with this report.

3.2.1 Basemap

The basemap provides a clear overview of the farm's layout, highlighting the 40 parcels that make up the site. The Bec stream and the farm's eleven ponds (two micro ponds in the greenhouse not included) are depicted in light blue, while buildings and the greenhouse are shown in grey. The five sections of the edible hedge (24a–24e) are also colour-coded to enhance visual distinction. Thanks to the basemap's simple and uncluttered design, it serves as a flexible foundation onto which further layers of information can be added as needed.

The Basemap was created in A3 format and is available in three versions with varying details:

- Basemap (North orientated): Land use map oriented north with English legend.
- Basemap (French): Basemap rotated to allow for maximum enlargement with French legend.
- Basemap (English): Basemap rotated to allow for maximum enlargement with English legend, depicted in Figure 3.

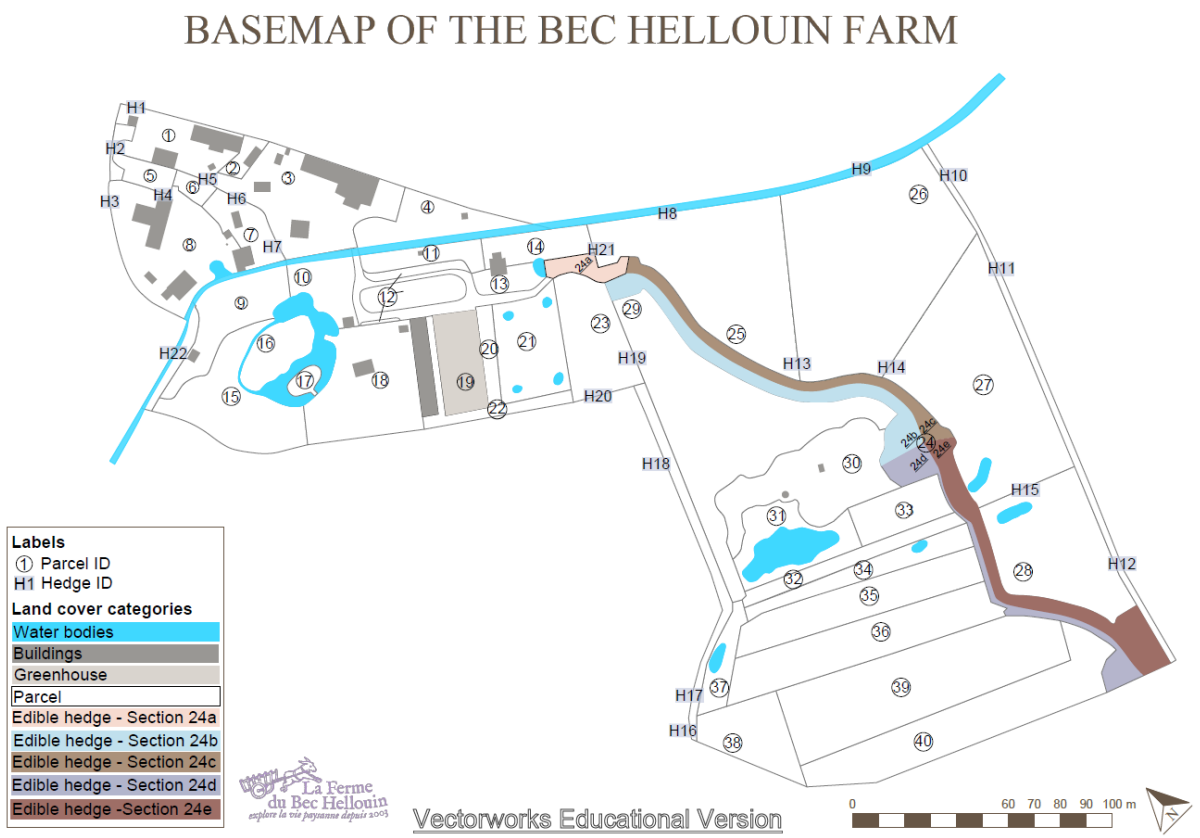

Figure 3: Basemap including all parcels, water bodies, buildings and edible hedges of the Bec Hellouin farm, created with Vectorworks Educational Version.

3.2.2 Land use map

The land use map highlights the changes that have occurred since the farm's establishment. Four parcels of permanent grassland have been transformed into 40 parcels, now classified into 19 land use categories. It thereby provides a visualisation of the farm's complex nature by offering a point of reference against the more uniform land use typically found in the surrounding area.

Agricultural production on the farm is divided into eight categories. The largest one is silvopasture, covering 1.9 hectares. It consists of high-stem fruit and nut trees grazed by sheep, a donkey, and a horse. Two productive food forests cover approximately 2000 m². Parcel 15, the food forest established in the farm's early years, has since been converted into a natural/conservation area and is now maintained in a low-intervention manner. The edible hedge that spans a large portion of the farm adds another 1440 m². Together, all agroforestry systems account for half of the total farm area.

Further productive tree-covered land is found in the orchards and wood gardens, which contribute an additional 6000 m². Woody vegetation is also integrated into the farm's reception, utility, residential, and aquatic vegetation zones, reinforcing the farm's long-term vision of creating a tree-dominated landscape that eventually forms a continuous canopy, with a few clearings dedicated to market gardening or cereals. Overall, the woody vegetation density across the farm is approximately 600 plants per hectare. This density varies significantly across different land use types, ranging from 130 to 3600 plants per hectare. A detailed breakdown of woody vegetation density by land use type is shown in Figure 4.

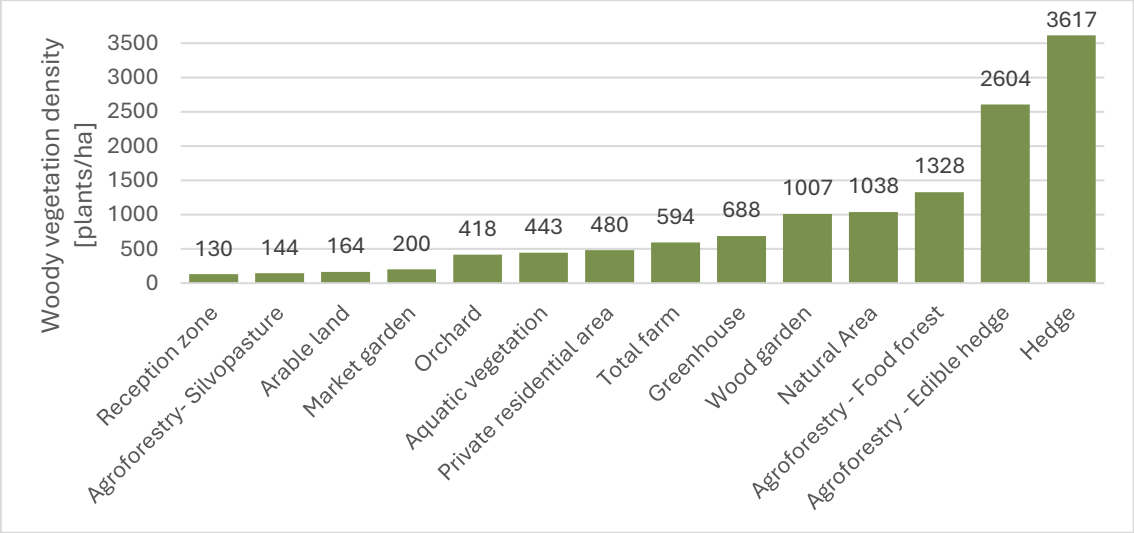

Figure 4: Woody vegetation density per land use type [plants/ha] of the Bec Hellouin farm

As mentioned above, while most of the farm is characterised by tree-covered zones, some clearings dedicated to marked gardening and arable land support vegetable and cereal production. The market garden area, including a greenhouse, spans 1700 m², while an additional 6500 m² of arable land is used for the cultivation of vegetables and cereals.

Natural and conservation zones span about 800 m², and approximately 3000 m² of hedgerows have been planted across the farm. Together with the diverse agroforestry systems and tree-covered land, these features enhance ecological connectivity. The farm's proximity to the forest to the north further strengthens this network, forming a potential biodiversity corridor that expands habitat availability and food sources for local wildlife.

The land use map has a paper size of A3 and was created in six versions with varying details:

- Land use (north orientation, English): Land use map oriented north with English land use category legend.
- Land use (English): Land use map rotated to allow for maximum enlargement with English land use category legend.
- Land use (French): Land use map rotated to allow for maximum enlargement with French land use category legend.
- Land use (parcel surface size, English): Land use map rotated to allow for maximum enlargement with English land use category legend and surface area legend indicating surface area per parcel.
- Land use (parcel surface size, French): Land use map rotated to allow for maximum enlargement with French land use category legend and surface area legend indicating surface area per parcel, facilitating spatial analysis and comparison across zones.
- Surrounding land use (north orientation, English): Land use map of the farm and its surrounding area oriented north with English land use category legend, depicted in Figure 5.
- Surrounding land use (north orientation, French): Land use map of the farm and its surrounding area oriented north with French land use category legend.

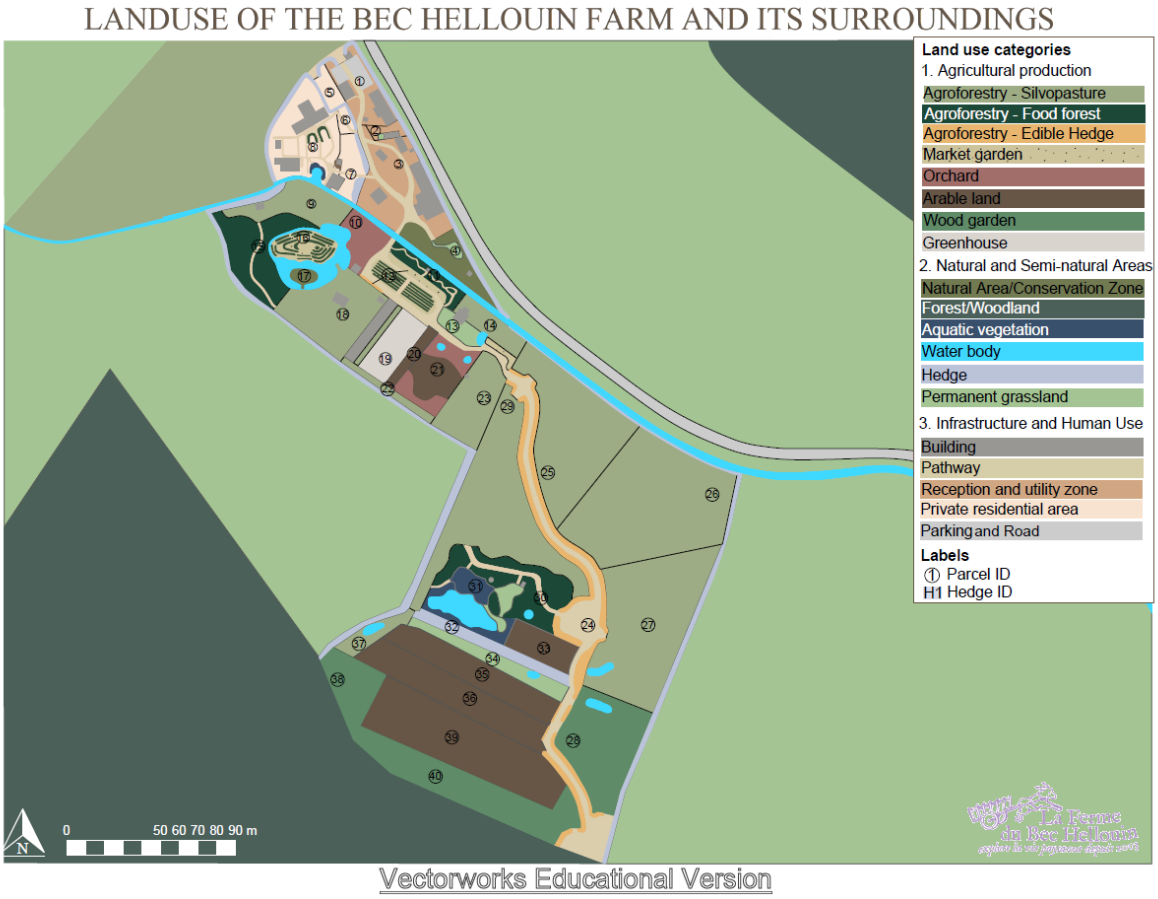

Figure 5: Land use categories of the Bec Hellouin farm and its surrounding area, including parcel and Hedge IDs for accurate identification, oriented towards north, created with Vectorworks Educational Version.

3.2.3 Vegetation classes map

The vegetation classes map clearly depicts the farm's efforts to create a landscape highly dominated by woody vegetation (see Figure 7). Woody vegetation is classified into seven categories, distinguishing between vegetation type (trees, shrubs, and climbers) and their primary function: production (fruit- or nut-bearing) or providing ecosystem services (system vegetation).

The woody vegetation on the farm comprises 3215 individuals: 1975 trees, 1176 shrubs, and 14 climbers. Among these, 1439 are identified as productive species, while 1776 serve system-supporting roles. A total of 70 genera are represented across all vegetation, with 50 individuals currently unidentified. This rich diversity highlights both the productivity and ecological multifunctionality of the farm's agroforestry system.

As can be observed in Figure 6, within the productive species, fruit trees account for 650 individuals, and nut trees for 129. Additionally, there are 536 fruit shrubs and 110 nut shrubs. Climbers present a relatively small group within the woody vegetation, within the productive vegetation with thornless blackberry (5) and grape (9). Non-productive climbers such as brambles, bindweed and ivy were not recorded within this study, but rather classified as potentially negatively impacting tree health, which is described in more detail in section 2.3.6 Vegetation health.

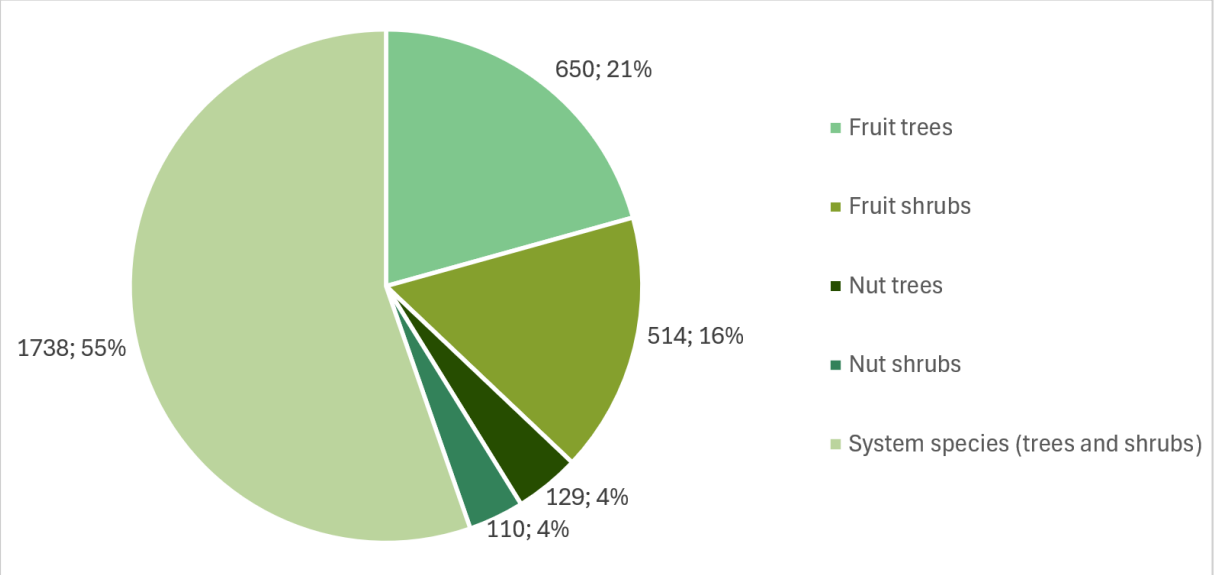

Figure 6: Woody vegetation count and proportion by vegetation class (total amount; percentage). Climbers are not included in this graph, as they represent a relatively small proportion of the total.

The most common productive species include apple (153), cherry/plum (164), pear (120), and currant (176). Other notable species include hazel (110), elder (96), chestnut (93), gooseberry (31) and sea buckthorn (31). An overview of species counts of all productive species can be found in Table 6.

Table 6: Productive woody vegetation identified during vegetation survey at the Bec Hellouin farm, listed by category, species and total count.

Category	Species	Total count
Fruit trees	Apple	153
	Apricot	13
	Citrus	23
	Cherry/Plum	164
	Feijoa	2
	Fig	15
	Lotus Persimmon	2
	Medlar	22
	Mulberry	9
	Nashi	16
	Olive	4
	Peach	33
	Pear	120
	Plum	64
	Quince	7
	Strawberry tree	2
Fruit shrubs	Aronia	34
	Autumn Olive	23
	Bay laurel	1
	Currant	176
	Dogwood	59
	Elder	96
	Goumi	22
	Goji	15
	Gooseberry	31
	Honeyberry	7
	Juneberry	6
	Raspberry	19
	Saskatoon	8
	Sea buckthorn	31
Nut trees	Chestnut	93
	Walnut	36
Nut shrubs	Hazel	110
Climbers	Thornless blackberry	5
	Grape	9

In addition to the vegetation types, this map also displays the land cover categories of each parcel (see Figure 7), revealing that a large portion of the farm is covered by permanent grassland, with an even greater area (including forest floor, pathways, and organic mulch) maintaining year-round ground cover. Furthermore, a separate map was created based on land use, illustrating tree cover across the various land-use types.

The vegetation class map has an A1 paper size and was created in four versions with slightly varying details:

- Vegetation classes (north orientation, English): Vegetation class map oriented north with English legend.
- Vegetation classes (English): Vegetation class map rotated to allow for maximum enlargement with English legend, depicted in Figure 7.
- Vegetation classes (French): Vegetation class map rotated to allow for maximum enlargement with French legend.
- Vegetation classes and Land use (French): Vegetation class map with Land use types rotated to allow for maximum enlargement with French legend.

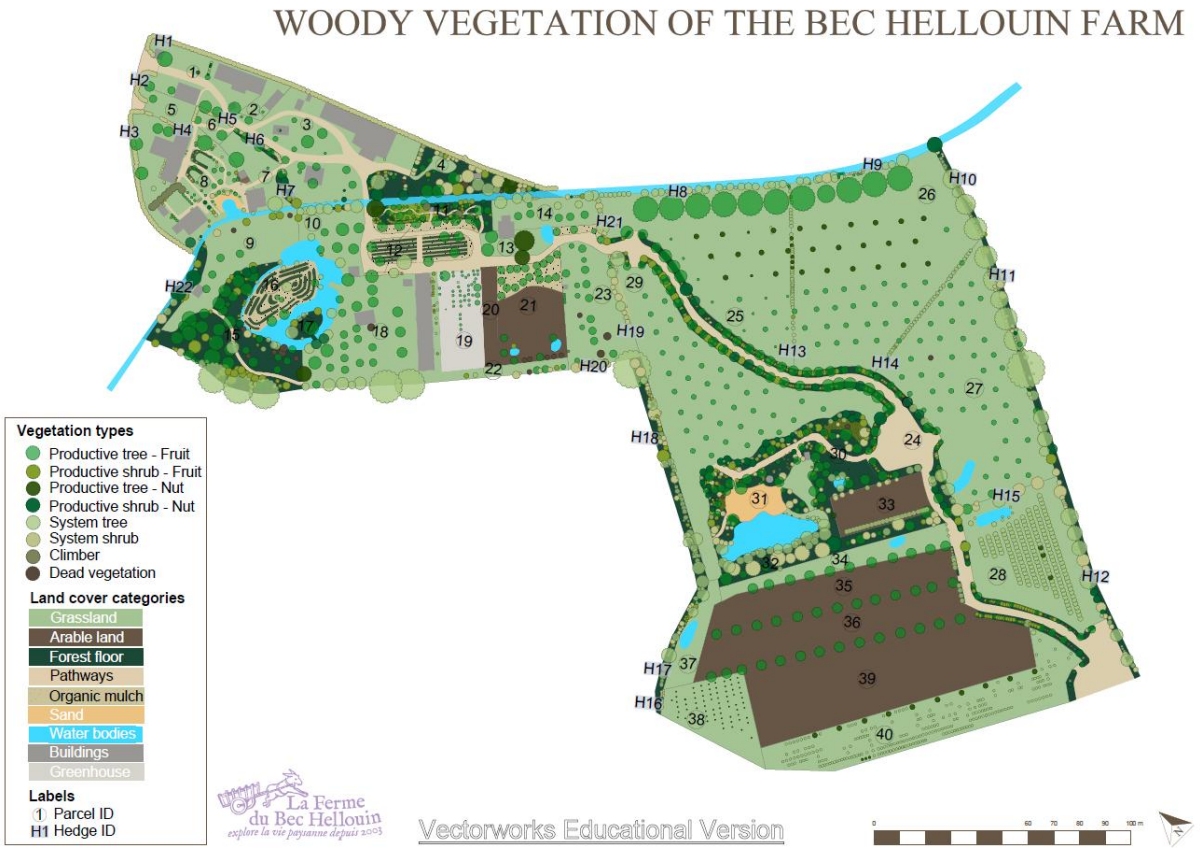

Figure 7: Vegetation classes map of the Bec Hellouin farm indicating woody vegetation types and land cover categories, including parcel and Hedge IDs for accurate identification, created with Vectorworks Educational Version.

3.2.4 Vegetation ID map

The vegetation ID map enables precise cross-referencing between the plant database and plant locations by clearly linking each vegetation ID to its corresponding plant. To maintain readability, parcels containing a particularly high density of plants, making vegetation labels difficult to read at the A1 format of the map, are additionally displayed at a smaller scale.

The vegetation ID map has an A1 paper size and was created in four versions with varying details:

- Vegetation classes incl. Veg ID (north orientation, English): Vegetation class map oriented north with English legend, including all vegetation IDs except vegetation situated within the hedges, depicted in Figure 8.
- Vegetation classes incl. Veg ID (north orientation, French): Vegetation class map oriented north with French legend, including all vegetation IDs except vegetation situated within the hedges.
- Vegetation classes incl. Veg ID + Hedges (north orientation, English): Vegetation class map oriented north with English legend, including all vegetation IDs.
- Vegetation classes incl. Veg ID + Hedges (north orientation, French): Vegetation class map oriented north with French legend, including all vegetation IDs.

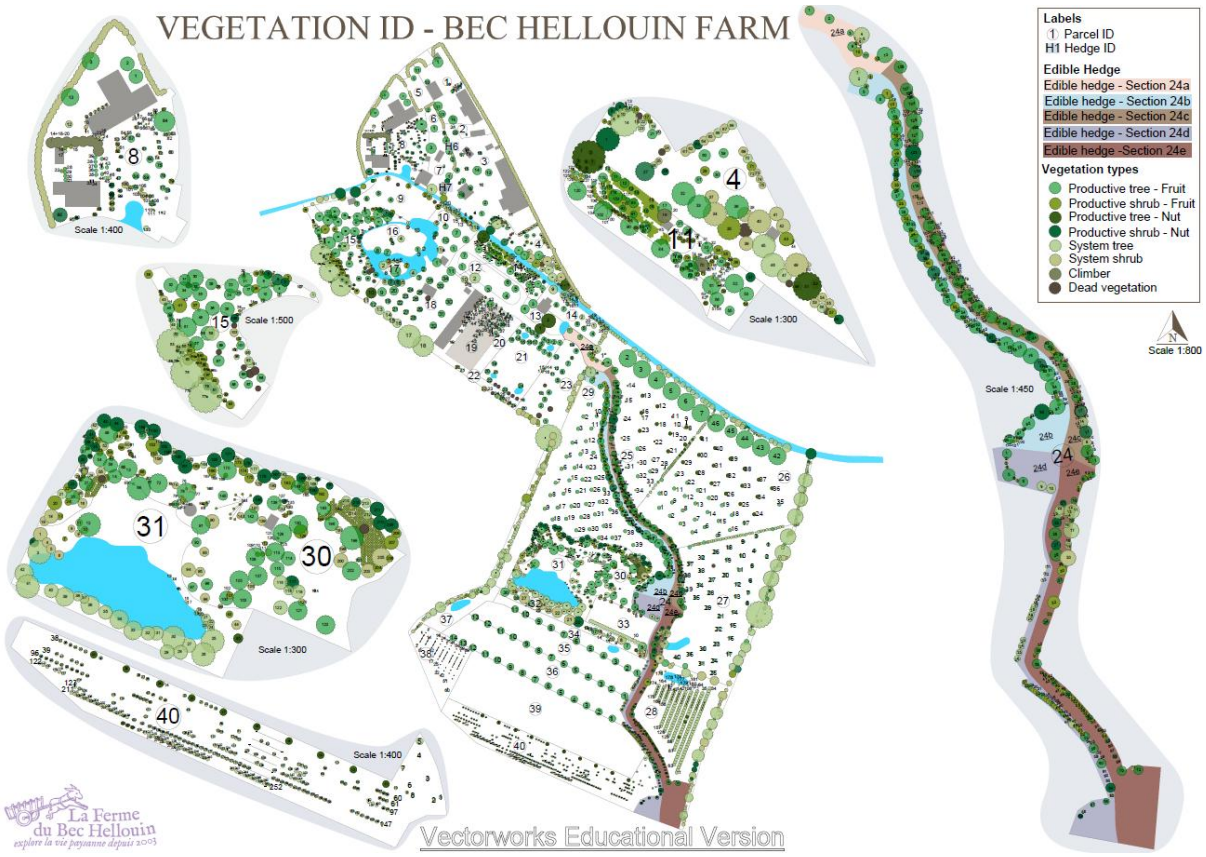

Figure 8: Vegetation ID map of the Bec Hellouin farm indicating woody vegetation IDs and vegetation types, including parcel and Hedge IDs for accurate identification, created with Vectorworks Educational Version.

3.2.5 Vegetation health map: severity and type

The vegetation health maps present two approaches to categorising vegetation health. First, overall health is assessed depending on the severity of the vegetation abnormality, using four categories: good health, moderate health, poor health, and dead vegetation. Second, vegetation issues are classified by type, including foliage and canopy health, climber and plant overgrowth, structural issues, or a combination of two issue types. A colour scheme is used to visually represent either the severity or the type of vegetation abnormality across the site.

The farm-wide health assessment showed that the majority of woody vegetation is in good condition, with a smaller portion showing moderate health and only a few plants in poor condition. Exact proportions are depicted in Figure 9.

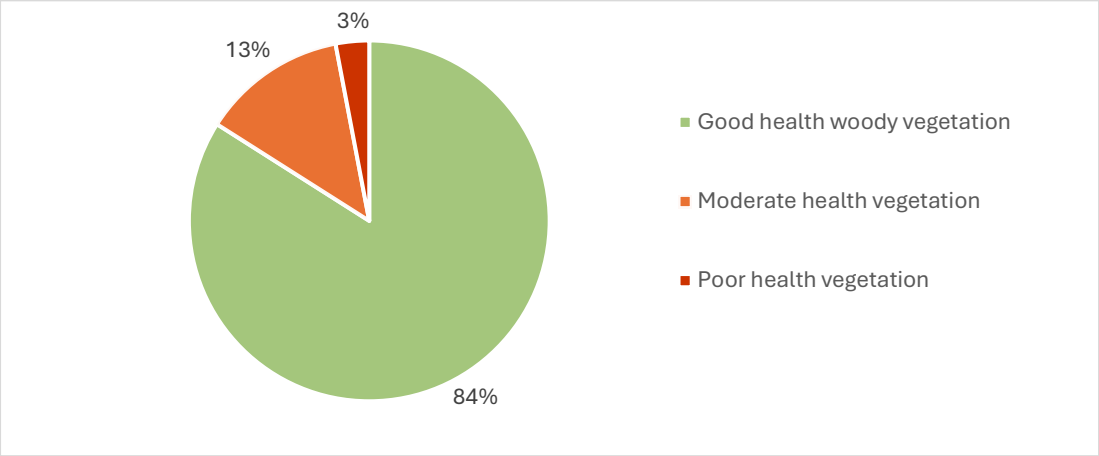

Figure 9: Woody vegetation health classified into three categories (good, moderate, poor), showing the percentage of vegetation in each category, based on the vegetation survey conducted at the Bec Hellouin Farm. Dead vegetation is not included in this graph.

Climber and plant overgrowth (e.g., ivy, brambles, bindweed) emerged as the most frequently observed issue across the farm. This was followed by foliage and canopy health problems, while structural issues were the least frequently recorded (see Figure 10).

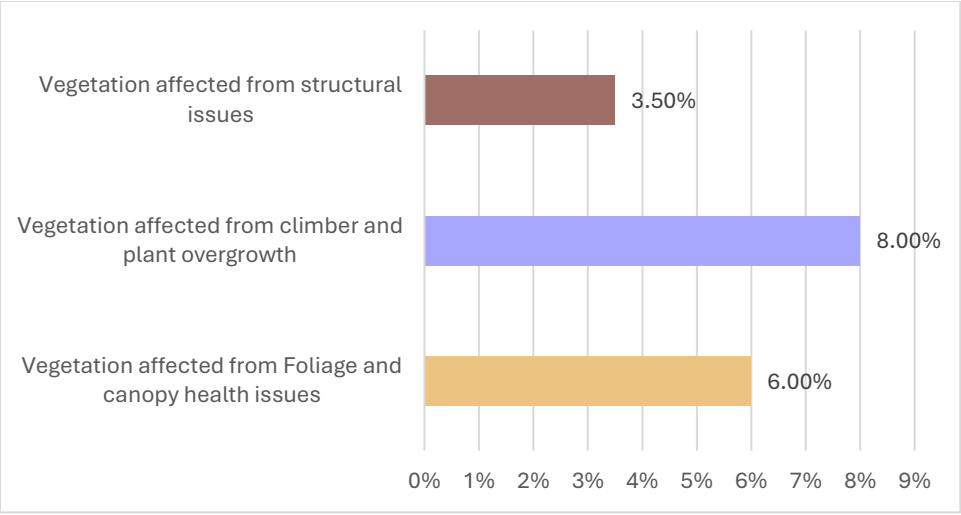

Figure 10: Vegetation abnormality classified into three categories, showing the percentage of vegetation in each category, based on the vegetation survey conducted at the Bec Hellouin Farm. These percentages exceed the 16% of vegetation in moderate or poor health because a single plant may exhibit multiple types of issues simultaneously.

The two vegetation health maps (Figures 11 and 12) reveal several areas with a higher occurrence of vegetation in moderate to poor health. Parcel 27 displays a notable proportion of trees affected by foliage and canopy issues as well as structural damage. Similar issues are observed in Parcels 18 and 23. Additionally, food forests and the edible hedge (Parcels 11, 15, 24, 30–32) exhibit increased overgrowth of climbers and plants.

The vegetation health map “severity of abnormality” (Figure 11) has an A1 paper size and was created in four versions with varying details:

- Vegetation health category (English): Vegetation health category map rotated to allow for maximum enlargement with English legend, depicted in Figure 11.
- Vegetation health category (French): Vegetation health category map rotated to allow for maximum enlargement with French legend.
- Vegetation health category (English, north orientation): Vegetation health category map oriented north with English legend.
- Vegetation health category (French, without dead vegetation): Vegetation health category map rotated to allow for maximum enlargement with French legend, without dead vegetation.

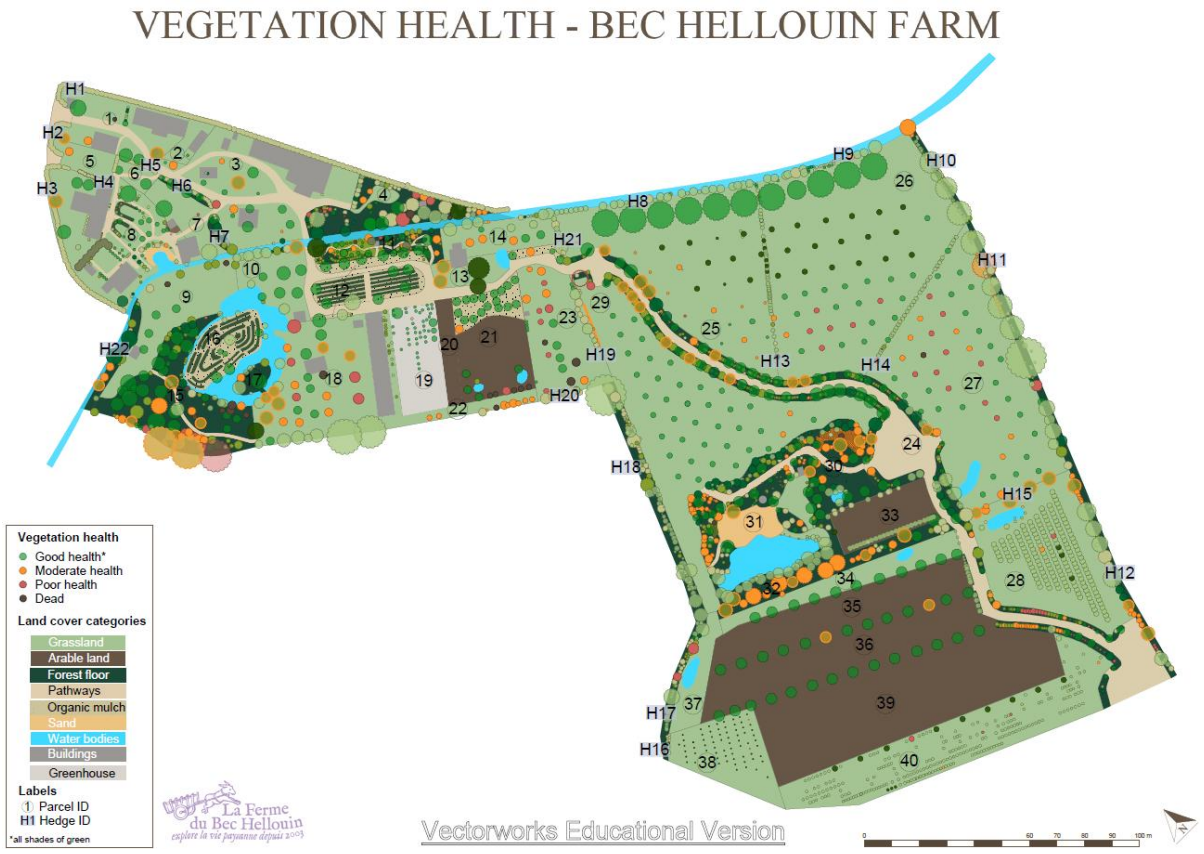

Figure 11: Vegetation health map “severity of abnormality” showing woody vegetation classified as being in good, moderate or poor health, as well as, land cover categories, including also parcel and Hedge IDs for accurate identification, created with Vectorworks Educational Version.

The vegetation health map “type of abnormality” (Figure 12) has an A1 paper size and was created in three versions with varying details

- Vegetation health type (English): Vegetation health type map rotated to allow for maximum enlargement with English legend, depicted in Figure 12.
- Vegetation health type (French): Vegetation health type map rotated to allow for maximum enlargement with French legend.
- Vegetation health type (English, north orientation): Vegetation health type map oriented north with English legend.

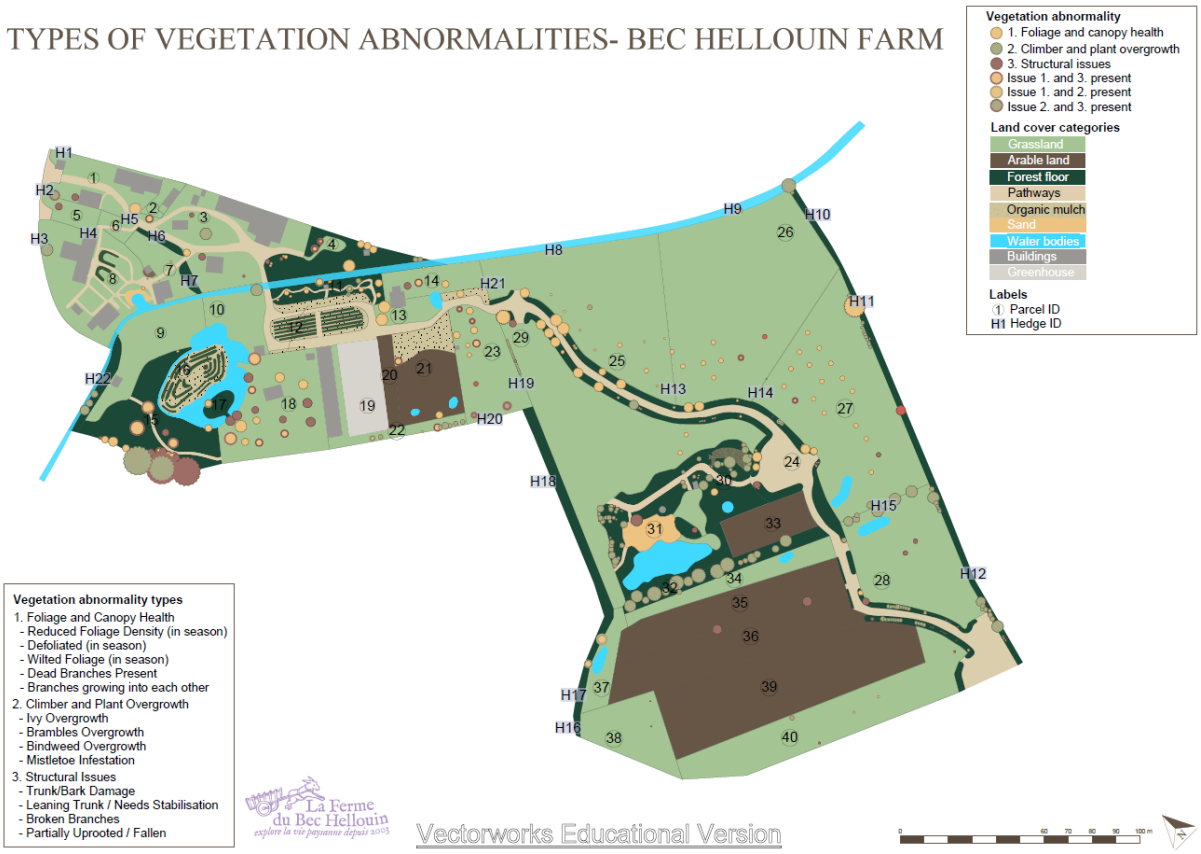

Figure 12: Vegetation health map “type of abnormality” showing woody vegetation classified by type of vegetation abnormality. Includes land cover categories, as well as parcel and Hedge IDs for accurate identification, created with Vectorworks Educational Version.

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4 Discussion

The results of this study provide insights into the complexity of the woody vegetation and land use of the Bec Hellouin farm, outlining the information derived from the mapping process and its potential applications. The following sections explore the interpretations, implications, and limitations of these findings. Finally, recommendations for future research are presented.

Within agroforestry systems, the creation of detailed spatial maps of woody vegetation is a key component of the design process and initial establishment phase (van Eijk, n.d.; Forest4EU, n.d.; Crawford, 2010; Jacke & Toensmeier, 2005; Yann, 2016). At La Ferme du Bec Hellouin, spatial maps were also produced during the design phase of several agroforestry systems. However, such maps are typically not updated over time, and subsequent changes in vegetation are rarely documented, an aspect addressed in this study.

A baseline biodiversity study conducted in a food forest included creating a spatial map detailing existing woody vegetation and other key elements, which facilitated the placement of sampling locations within the study area (Elvers, 2019). This specific study was focused on arthropod activity. Therefore, the spatial map created within this study enabled the identification of locations deemed important for potential shifts in arthropod communities. However, this map did not differentiate between vegetation types, genera or vegetation layer. As a result, the influence of these aspects on arthropod communities could not be assessed. In contrast, the detailed woody vegetation maps produced in this study can support such analyses in future biodiversity research done at the Bec Hellouin farm.

Similarly, another biodiversity study, focusing on wild herbs in Dutch food forests, developed a zoning map to compare species richness across six land use categories (Honer, 2023). Similarly, this study classified the study area into 19 land use categories, enabling similar comparisons in future biodiversity assessments at the Bec Hellouin farm. These examples highlight the value of spatial data in supporting biodiversity monitoring and analysis.

Vegetation health maps revealed several areas with a higher occurrence of moderate to poor vegetation health. In Parcel 27, this may be linked to flooding that occurred in the area the previous year. In parcels 18 and 23, the observed decline could be attributed to the age of the trees, which were among those planted in the early years of the farm's establishment. Increased climber and plant overgrowth in more complex systems, such as the food forests and edible hedges, may indicate higher labour demands for maintaining these areas.

Field data were recorded on a paper data collection sheet and later transferred into the Excel database. Although the transfer was carried out with care, the possibility of transcription errors cannot be excluded. Additionally, vegetation strata and diameters were estimated rather than precisely measured, which may have introduced some degree of inaccuracy.

Field data collection was conducted from late summer to early autumn over the course of several weeks. This timing should be taken into account when interpreting foliage health assessments, as vegetation observed later in the season, or species that naturally shed their leaves earlier, may have been misclassified compared to those assessed earlier or that retain foliage longer.

The harvesting window for productive vegetation, where the cultivar could be identified, was estimated using data from online plant nursery sources. However, these estimates should be considered approximate, as harvesting periods can vary between seasons depending on weather conditions. Additionally, microclimatic variations at each plant's location may influence the actual timing of harvest.

Nevertheless, the results of this study provide a clear reference for existing land uses and woody vegetation, enabling changes to be tracked over time and observations to be contextualised within subsequent biodiversity studies. It also facilitates consistent, targeted biodiversity monitoring by clearly defining zones with similar ecological conditions based on land use, land cover, and woody vegetation types (including genus or species, where available) for repeated observation. They also highlight key ecological features such as hedgerows and ponds that contribute to biodiversity. Further, the farm-wide woody vegetation health assessment allows for the identification of which plants, in which locations, are affected by specific issues and to what extent. Therefore, these maps help highlight problem areas across the farm. When combined with the plant database, they enable tracking of species and cultivars that perform well, or poorly, under certain conditions. This provides a valuable baseline for monitoring plant health and prioritising targeted management interventions. Finally, the maps serve as a powerful communication tool to convey the farm's ecological complexity to stakeholders, researchers, and the public.

4.1 Recommendations

To further enhance the farm's spatial maps, complementary research on hydrology, soil properties, topography and wind patterns is recommended in order to improve the characterisation of spatial heterogeneity across the site and identify microclimates. Wet and dry zones could be identified through groundwater and soil moisture monitoring. Topographic data, including elevation and slope, would support understanding of water runoff paths and identifying low points where water accumulates after heavy rainfall. Stratified random soil sampling, based on the identified land use categories, could provide insights into spatial variation in key soil parameters such as texture, structure, pH, organic matter content and nutrient availability. Lastly, information on prevailing and cold winds, obtained from on-site weather stations or online meteorological tools, could provide valuable insights into wind exposure across the farm.

During this study, system vegetation was identified at the genus level (e.g., willow, ash, hornbeam), without distinguishing between individual species. In some cases, multiple species were grouped into a single category. Future research could aim to identify vegetation at the species level, to allow for assessment of species richness, an aspect that can provide valuable insights for subsequent biodiversity studies. Additionally, identifying productive species on the cultivar level could help to analyse how specific cultivars perform under differing conditions and how this may evolve over time.

It is recommended to conduct further research on herbaceous vegetation, as it can offer valuable insights into habitat quality. The presence and distribution of herbaceous species, including indicator species, can reflect key environmental factors such as light availability, microclimatic conditions, soil moisture and pH. Monitoring these species could serve as a useful tool for assessing habitat conditions and detecting environmental changes over time.

The plant database created during this study contains information on the harvesting and flower period of productive vegetation from which the cultivar could be determined. It is recommended to continue

filling in missing data by systematically recording harvesting and flowering periods throughout the seasons and updating the database accordingly. This information can then be used to generate a harvesting calendar to visualise yield and labour distribution over time, as well as a spatial harvesting map indicating the harvesting periods of all woody vegetation. Such tools would improve clarity and planning, ultimately enhancing harvesting efficiency within this complex landscape. Furthermore, knowledge of flowering periods can indicate seasonal resource availability for pollinators.

Lastly, the green-blue veining approach to assess the degree of potential natural pest suppression from the ecological networks currently present at the farm could be applied as part of the biodiversity study on crop health. Ecological networks consist of multiple habitat types (woody vegetation, herbaceous vegetation, and water elements) and provide natural enemies of pests with nectar or pollen, winter habitat, an attractive microclimate and alternative prey after crop harvest, thereby facilitating pest suppression (Steingrover et al., 2010). Assessing the quality of ecological networks relative to the surrounding landscape could therefore provide scientific support for the farm's steady improvement in crop health.

5 Conclusion

The permaculture farm Bec Hellouin is characterised by high spatial and ecological complexity. This complexity provides resilience and multifunctionality but also poses challenges for effective monitoring and planning. To address this, this research aimed to create a detailed spatial map that identifies woody vegetation and different ecological zones, providing a baseline for future studies on topics such as biodiversity and pest and disease dynamics.

Maps were created across five categories: Basemap, Land Use, Vegetation Classes, Vegetation ID, and Vegetation Health and Abnormalities. The Basemap offers a clear overview of the farm's layout and serves as a flexible foundation for layering additional information. Land use maps in combination with vegetation maps serve as a valuable tool for identifying zones with similar ecological conditions, supporting consistent and targeted biodiversity monitoring over time. Vegetation ID maps enable precise cross-referencing between the plant database and plant locations by clearly linking each vegetation ID to its corresponding plant. The vegetation health maps identify problem areas across the farm. In combination with the plant database, they enable tracking of species and cultivars that thrive or struggle under specific conditions. This provides a valuable baseline for monitoring vegetation health and prioritising targeted management actions. Finally, the maps also function as a communication tool to convey the farm’s ecological complexity to stakeholders, researchers, and the public.

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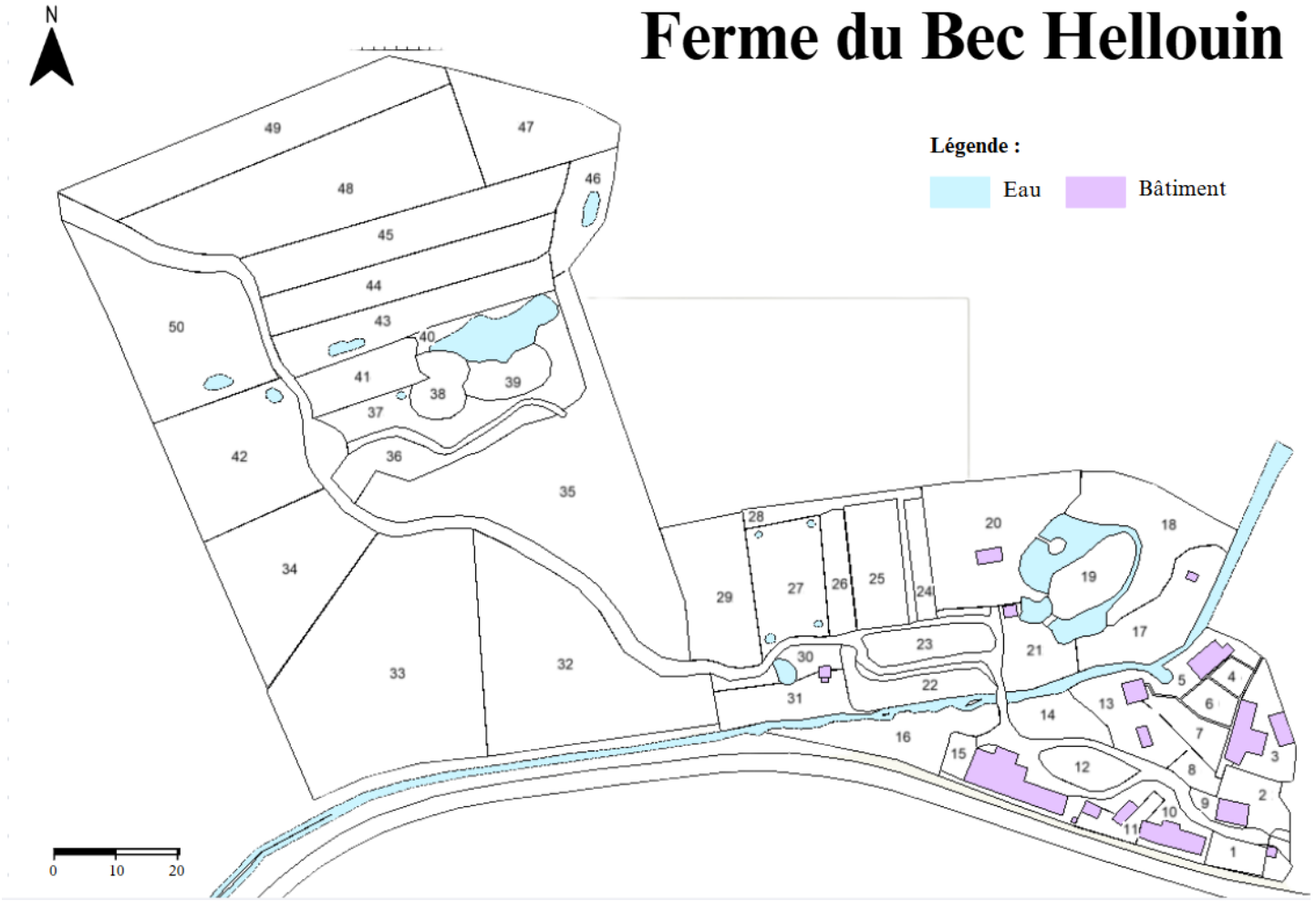
During the preparation of this work, the author used Grammarly for Microsoft Office (version 6.8.263 accessible via: Grammarly.com) in order to improve grammar, spelling and fluency. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

7 Appendix

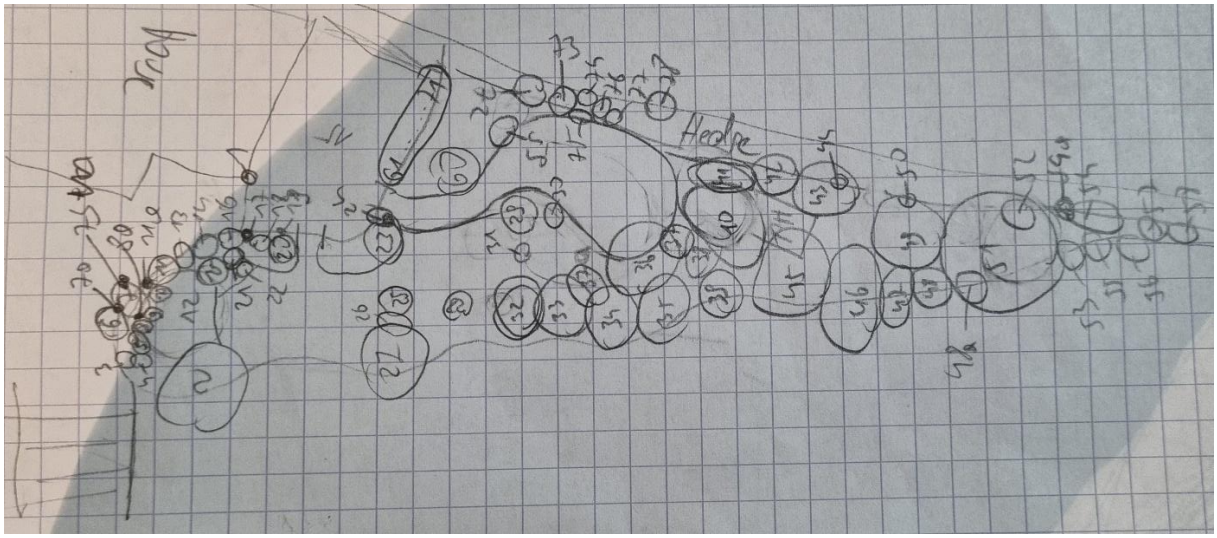
Annex 1: Woody vegetation data collection sheet

ID nr.	Parcel nr.	Species	Strata	Abnormalities	Land use

Annex 2: Basemap of La Ferme du Bec Hellouin prior to this study



Annex 3: Example sketch of Parcel 4



Annex 4: Data entry guidelines

Vegetation ID	Each vegetation has its unique ID to be able to trace back the information on the map.
Parcel ID	The number of the parcel (1-40, corresponding to the map) in which the vegetation is recorded.
Sub parcel ID/Sub vegetation nr.	ID of sub-parcels (a-e) of parcel 24./Addition to vegetation ID if two plants have received the same vegetation and Parcel ID.
English name	English name of species or genus.
Latin name	Latin name of species or genus.
Vertical layer	As described in Table 1.
Vegetation abnormalities	As described in . Table 2.
Vegetation health category	As described in Table 4.
Type 1	Categorises the woody vegetation into the categories tree, shrub and climber.
Type 2: productive	A productive plant is defined as a plant species that provides food for human consumption.
Type 2: system	A system plant is defined as a plant species that provides ecosystem services for the ecological health of the system.
Invasive species	Indicates whether the selected species can be categorised as invasive or unwanted.
Cultivar	A variety of a species that is bred and propagated for desirable functional plant characteristics (Jacke and Toensmeier, 2005).
Rootstock	The base and root portion of grafted plants (Crawford, 2010).
Harvest period start (month)	The month in which the harvest of this species starts.
Harvest period end (month)	The month (included) in which the harvest of this species ends.
Flowering period start (month)	The month in which this species starts flowering.
Flowering period end (month)	The month in which this species stops flowering.
Harvest period start (week)	The week of the year in which the harvest of this species starts.
Harvest period end (week)	The week of the year in which the harvest of this species ends.
Flowering period start (week)	The week of the year in which this species starts flowering.
Flowering period end (week)	The week of the year in which this species stops flowering.
Year of planting	Year in which species was planted.
Age year 2026, 2031, 2036	Age, in years, of this species in the years 2026,2031, 2036.