Field margins in the Hoeksche Waard for Biodiversity and Natural Attenuation

Quantification of ecosystem services in a social cost-benefit analysis
Part of the SCBA FAB-Farmers in the Hoeksche Waard
02-05-2022

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Abstract

Nowadays, the need for a transition to sustainable agriculture is increasing, following the decline in farmland biodiversity and other environmental issues due to the intensification of agriculture. A decline in biodiversity can affect the delivery of ecosystem services, including those that are important for agricultural practices. The RIVM is developing a social cost-benefit analysis of the implementation of field margins based on ecosystem services. Within this project, this study focused on the effect of field margins on the ecosystem services ‘biodiversity’ and ‘natural attenuation’ in the Hoeksche Waard in two scenarios: arable land and arable land with field margins. Models for biodiversity and natural attenuation were developed and implemented: (1) attributes were identified that could be used to quantify the delivery of an ecosystem service or the subfunctions underpinning the ecosystem service, (2) a conceptual multi-attribute model for quantification of biodiversity and natural attenuation was developed, (3) input data and information on the potential attributes was collected and organized in tables, (4) the collected data was used for calculating ecosystem services for the two scenarios (arable fields with and without margins). The implementation of field margins in the Hoeksche Waard, with reference value 1 for arable land without field margins, had a positive effect on the biodiversity (biodiversity capacity: 1.31-1.81) and natural attenuation (natural attenuation capacity: 1.78-2.06). The results of this study can be used as information for the social cost-benefit analysis, together with the other non-monetarized ecosystem services. Furthermore, this information is valuable for creating awareness on sustainable agriculture and shows the importance of future research relating to functional agrobiodiversity and sustainable agriculture.

Layman's Summary

Nowadays, the need for a transition to sustainable agriculture is increasing, following the decline in farmland biodiversity and other environmental issues due to the intensification of agriculture. A decline in biodiversity can affect the delivery of ecosystem services, including those that are important for agricultural practices. Ecosystem services can be defined as conditions and processes through which ecosystems sustain and satisfy human livelihood. The RIVM is developing a social cost-benefit analysis of the implementation of field margins in the Hoeksche Waard based on ecosystem services. Field margins are land strips adjacent to arable fields, and they are implemented with the objective to enhance biodiversity and other ecosystem services, such as pest control. Within this project, this study focused on the effect of field margins on two ecosystem services: biodiversity and natural attenuation. Two scenarios will be analyzed, one with and one without field margins. Natural attenuation is an ecosystem service that decreases concentrations of contaminants in soil and water without human intervention. One widely used description for biodiversity is adopted by the Parties to the Convention on Biological Diversity: "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". Multi-attribute models for the ecosystem services 'biodiversity' and 'natural attenuation' were developed and implemented: (1) attributes were identified that could be used to quantify the delivery of an ecosystem service or the subfunctions underpinning the ecosystem service, (2) a practical conceptual model for quantification of biodiversity and natural attenuation was made, (3) data and information on the potential attributes was collected and organized in tables, (4) the collected data was used for modelling of ecosystem services for the two scenarios (arable fields with and without margins). The effect of the implementation of field margins in the Hoeksche Waard, with reference value 1 for arable land without field margins, had a positive effect on the biodiversity (biodiversity capacity: 1.31-1.81) and natural attenuation (natural attenuation capacity: 1.78-2.06). The results of this study can be used in the social cost-benefit analysis together with the information of other non-monetarized ecosystem services are valuable for creating awareness on sustainable agriculture and shows the importance of future research relating to functional agrobiodiversity and sustainable agriculture.

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1. Introduction

1.1 Background

Nowadays, the need for a transition to sustainable agriculture is increasing, following the decline in farmland biodiversity and other environmental issues due to the intensification of agriculture (Bianchi et al., 2013; Delbaere et al., 2014). Agricultural land covers 48% of the world's land surface area and provides and impacts many ecosystem services (Paulin et al., 2021; Zhang et al., 2007).

Ecosystems support human livelihoods through provision of ecosystem services (Sandhu et al., 2010). Ecosystem services can be defined as conditions and processes through which ecosystems sustain and satisfy human livelihood (Zhang et al., 2007). According to CICES (Common International Classification of Ecosystem Services; Haines-Young & Potschin, 2021) , they can be classified in three main categories: provisioning, regulation and maintenance and cultural services (Haines-Young & Potschin, 2021; Maes et al., 2016). Provisioning includes (non-)nutritional material, energetic outputs from living systems and water used for nutrition, materials or energy. The category 'Regulation and maintenance' includes ways in which ecosystems can facilitate or moderate the environment that affects human comfort, health, or safety. Cultural covers all the non-material, non-consumptive and often non-rival, outputs of ecosystems that affect mental and physical state of people (Haines-Young & Potschin, 2021).

Agricultural ecosystems are generally managed to optimally deliver some selected provisioning services i.e., biomass production for food, feed, fiber, or fuel. Farmers improve and adapt management to maximize these provisioning ecosystem services, mostly by applying technical and synthetic measures such as the application of nutrients (manure, fertilizers), tillage, plant protection substances, drainage and irrigation (Maes et al., 2016).

In many places around the world, the encouragement of a modernized and intensified production system has led to a linear production approach. While this approach has increased agricultural production, it has also caused, amongst others, pollution of the environment and a decline in biodiversity (Tsiafouli et al., 2015). A decline in biodiversity can affect the delivery of ecosystem services, including those that are important for agricultural practices, such as pest control and pollination. For example, predators that reduce plant pests and pollinators tend to be lower in landscapes where non-crop habitats are lacking. Intensive conventional agriculture can deteriorate ecosystem services mediated by soil biota, such as nutrient retention, water purification and organic matter cycling (Bianchi et al., 2013), but also, for instance, populations of birds and butterflies. Conservation agriculture is aiming at reducing technical and synthetic measures to rely more on the intrinsic capacities of the soil i.e., to the provisioning services which are intrinsically present (Hobbs et al., 2008; Tsiafouli et al., 2015).

To mitigate the negative effects of intensive agriculture, a more sustainable use of ecosystem assets is needed. Functional agrobiodiversity (FAB) is a science-based concept that focuses on elements of biodiversity on the scale of agricultural fields or landscapes that are important for the delivery of ecosystem services relevant for agricultural production and deliver benefits to the environment and public (van Uden et al., 2013). The FAB approach requires an understanding of natural capital elements that support ecosystem services and approaches for converting this knowledge into custom-made farm and landscape management information (Bianchi et al., 2013). With this information, farmers and society can make a transition to sustainable farm management practices.

1.2 FABulousfarmers and Research Objectives

The project FABulousfarmers (full project name: FABulous Farmers employ Functional AgroBiodiversity as a nature-based solution to reduce use of natural and material resources, delivering benefits for farmers, society, and the environment in Northwestern Europe), an Interreg-funded European project, explores the FAB concept and has set up ten FAB-solutions to implement in Northwestern Europe (Fabulous Farmers | Functionele AgroBiodiversiteit, n.d.; Paulin et al., 2021). FAB-solutions are measures that, when actively implemented, lead to an optimal provision of ecosystem services in and around arable fields and the farm. As part of the project, FAB-solutions are tailored to contribute to the specific environmental and agricultural characteristics of each area, resulting in a specific FAB action plan per pilot region (*Fabulous Farmers | Functionele AgroBiodiversiteit*, n.d.; Paulin et al., 2021).

One of the pilot locations is the Hoeksche Waard in the Netherlands. One goal for farmers in this area is to reduce pesticide application by implementing field margins, i.e. land strips adjacent to arable fields that provide ecosystem services (Marshall & Moonen, 2002). A three year pilot in the Hoeksche Waard showed that implementation of field margins resulted in a reduced need for pesticide application against aphids (van Rijn et al., 2008). Field margins can fulfil a number of functions, such as acting as a habitat for antagonists of pest organisms, stimulating biodiversity (e.g. field bird populations, winter residing insects), improving water quality in ditches, providing aesthetical landscape objects for recreation and other forms of wellbeing, contributing to climate change mitigation and supporting objects for education and research (Paulin et al., 2021; Marshall & Moonen, 2002).

Studies have demonstrated that field margins can have a positive effect on ecosystem services, especially pest control (Marshall & Moonen, 2002). However, the implementation of field margins can also affect farmers negatively since they are required to sacrifice part of their production of agricultural goods to create and then maintain these margins. More research needs to be done to inform decision-makers whether the extra costs of creating and maintaining field margins are justified in terms of societal benefits resulting from the bundle of ecosystem services in these areas.

For the project FABfarmers, the Dutch National Institute for Public Health and the Environment (RIVM) will perform a social cost-benefit analysis (SCBA) of the implementation of field margins in the Hoeksche Waard (Paulin et al., 2021). A SCBA is a method for estimating the societal costs and benefits of measures targeted at tackling societal challenges (Romijn & Renes, 2013). The aim of the SCBA is to provide decision-makers with the necessary information to determine whether the extra costs of creating and maintaining field margins in the Hoeksche Waard are justified in terms of the societal benefits that result from increased ecosystem service provision (Paulin et al., 2021). In a collaboration, stakeholders, and beneficiaries in the Hoeksche Waard, together with the RIVM, created a list of ecosystem services that could be relevant for this SCBA (Table 1). Within this project, the present study focuses on two ecosystem services: ‘NA’ and ‘Biodiversity’.

Table 1*: Ecosystem services and their relevance for the SCBA. Yellow = My focus, P = Provisioning service, R&M = Regulation and maintenance service, C = Cultural service. (Paulin et al., 2021)*

Type	**Ecosystem Service**	**Description**
P	Agricultural production	Volume or biomass of harvested crops and crop residues (shoot and roots)
R&M	Air quality regulation	Filtration / sequestration of atmospheric PM10 concentrations by vegetation, soil, and water
R&M	Water storage	Capacity of vegetation and soils to retain water and release it slowly under dry conditions
R&M	Pest control	Regulation of pests (insects or other organisms) by natural enemies (insects or other organisms)
R&M	Natural attenuation	Regulation of the chemical condition of soils and freshwaters by biological processes
R&M	Carbon sequestration	Regulation of chemical composition of atmosphere due CO2 fixation in soil

Type	Ecosystem Service	Description
C	Biodiversity	Biodiversity and habitat provision as endpoint (not as a regulation and maintenance vehicle).
C	Recreation and tourism	Characteristics of living systems that stimulate activities that promote health, recuperation, or enjoyment through active or immersive interactions
C	Scientific investigation and knowledge	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge
C	Education and training	Characteristics of living systems that enable education and training
C	Culture and heritage	Characteristics of living systems that are resonant in terms of culture or heritage

1.3 Ecosystem Services: Biodiversity and Natural Attenuation

1.3.1 Biodiversity

Biodiversity has various definitions and can be substantiated in different ways (Mace et al., 2012). One widely used description is adopted by the Parties to the Convention on Biological Diversity: “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (Mace et al., 2012; United Nations, 1992).

Ecosystem services often depend on biodiversity as an asset: a regulator of fundamental ecosystem processes and/or goods that can be valued (economically or otherwise) (Mace et al., 2012). Biodiversity does not only underpin ecosystem services but is an ecosystem service in itself if it is valued by humans (beneficiaries) for any reason, such as its intrinsic value, species protection or its inherent value for safeguarding human existence. In this study, biodiversity will be classified as a distinct and overarching ecosystem service because it is considered as a significant value for general human livelihood and beneficiaries specific to the Hoeksche Waard. Besides, biodiversity attributes (measurable characteristics) will also be evaluated in terms of their supporting function for the delivery of the ecosystem service ‘natural attenuation’ (NA) (see Section 1.3.2). Consequently, biodiversity components may be fueled in more than one conceptual model for ecosystem service delivery (Rutgers et al., 2018).

Since 1980, a substantial number of indicators were proposed to measure biodiversity (Bockstaller et al., 2011). These indicators are based on species abundance and diversity among one or several taxa at different scales. These indicators focus on keystone species, umbrella species, all species of a given taxon or threatened species (Bockstaller et al., 2011). Nonetheless, in most biodiversity studies a small subset of organisms is researched providing a snapshot on biodiversity not representing integrated overarching information on the condition of the biodiversity.

Biodiversity and habitat provision captures many aspects of the biotic environment in one overarching concept and aims at including all potentially relevant and reliable case-specific information. Data and indicators which are, according to assessors (scientists) and local stakeholders at various spatial scales, specific for biodiversity in the Hoeksche Waard will be further assessed within this research.

1.3.2 Natural Attenuation

NA is a process lacking human intervention that includes a variety of physical, chemical or biological processes (van Wijnen et al., 2012). This ecosystem service refers to the capacity of the soil to reduce the mass, toxicity, mobility, volume or concentration of pollutants in the system (Xie et al., 2018), so that the area itself or adjacent areas become cleaner, such as the ditches and collecting waterways in the Hoeksche Waard.

A healthy soil ecosystem is essential for sustainable food production and to protect the quality of groundwater, which is important for drinking water and irrigation water production. By reducing the number of pollutants in soils, this service contributes to a healthy habitat for soil organisms and less contaminated feed for species in the whole food web. A healthy habitat in return supports other ecosystem services (van Wijnen et al., 2012).

A variety of soil attributes can be incorporated in a model to evaluate the NAC of soil. van Wijnen et al. (2012) proposed a model that incorporates three microbial indicators and three abiotic indicators to evaluate the performance of NAC in the Netherlands. The microbial indicators include the functional microbial activity, potential carbon mineralization rate and potential mineralization rate of organic nitrogen. The abiotic indicators are soil organic matter (SOM), the pH of the soil and extractable phosphorus content (Rutgers et al., 2012; van Wijnen et al., 2012).

However, this model is not specifically adjusted to soils in fields margins, arable land with and without field margins, or specifically adjusted to the soil type in the Hoeksche Waard (marine clay). Therefore, additional indicators could be added, and weights could be adjusted to make the model relevant for the SCBA. For example, certain chemicals are often present in higher quantities in arable soil (e.g., pesticides) than in average dairy grassland. Attributes for quantifying NA in the

Hoeksche Waard will be further assessed within this research to develop an adapted NA model that is suitable for the SCBA being performed.

1.4 Research question and Objectives

The aim of this study is to build conceptual models for the ecosystem services ‘natural attenuation’ and ‘biodiversity’ specifically for arable system with and without field margins, and thereby contribute to developing a SCBA of the implementation of field margins in the Hoeksche Waard.

The following research questions will be addressed:

1. How can attributes (measurable data and information) and expert knowledge be incorporated in models to quantify biodiversity and NA in arable fields without field margins and arable fields with field margins in the Hoeksche Waard?
2. What is the effect of field margins on biodiversity and NA in the Hoeksche Waard?

Derived from the main research question the following sub-questions will be addressed:

- What are useful attributes for quantifying biodiversity and NA in the arable landscape in the Hoeksche Waard?
- How should attributes be scaled and weighed to build a model for biodiversity and a model for NA to be applied in the SCBA of arable systems with and without field margins in the Hoeksche Waard?

For this study, the existing data were collected from previous studies. Also, experts were consulted to assign weights to attributes to build multi-attribute models for NA and biodiversity. The effects were scaled and quantified in biophysical units.

2. Literature Review

Natural Attenuation (modelling of natural attenuation of arable land with/without field margins)

Soil plays an important role in the regulation and conservation of water resources (Cheng et al., 2021). Natural attenuation (NA) is an ecosystem service that supports the maintenance of clean soils or groundwater without human intervention, and reduces risks posed by contaminants by reducing the mass, toxicity, mobility, volume or concentration of contaminants (Embaby et al., 2017; Environmental Protection Agency, 1999). In doing so, this ecosystem service plays an important role in the production of contaminant-free food and clean drinking water. By reducing the number of pollutants in soils, this service also contributes to a healthy habitat for soil microorganisms. A healthy soil life in return supports other ecosystem services (van Wijnen et al., 2012).

NA is a process that includes a variety of physical, chemical, or biological processes and that is dependent on precipitation and irrigation (Cheng et al., 2021; Environmental Protection Agency, 1999). Precipitation and irrigation increase soil moisture, which can migrate vertically towards groundwater bodies. The flow of soil moisture can reduce the number of chemical pollutants in the soil through physical and chemical processes. However, precipitation and irrigation can also bring soluble substances into surface water through runoff, affecting the water quality (Cheng et al., 2021). NA can be divided into three types: (a) transport processes including advection, dispersion, diffusion and sedimentation, (b) phase transfer processes that are responsible for movement between compartments including sorption and volatilization and (c) chemical and biological transformation processes that effectively reduce the mass of contaminants (Embaby et al., 2017).

Many articles written about NA are related to transport prediction models and interaction of a specific pollutant (e.g. petroleum) with a polluted environment (Balseiro-romero et al., 2018; Embaby et al., 2017; Lv et al., 2018). However, less is written about the soil attributes that can be used to evaluate the generic NA potential in soil. A variety of soil attributes can be selected to evaluate the NA potential in soil (Sandén et al., 2019; D. Wall et al., 2018; D. P. Wall et al., 2020), such as SOM, pH and microbial activity. In this review, an overview is given of some of the attributes that can contribute to the quantification of NA, as well as a selection of the attributes for which data exist for modeling of NA in arable land in the Hoeksche Waard with and without field margins.

van Wijnen et al. (2012) proposed a model with three microbial attributes and three abiotic attributes to evaluate the performance of NAC nation-wide in the Netherlands. To model these attributes the microbial indicators were functional microbial activity, potential carbon mineralization rate (PotC) and potential mineralization rate of organic nitrogen (PotN). The abiotic indicators were SOM, pH of the soil and phosphorus content (PAL). Vieler (2015) extended this model by adding attributes and providing different weights to them, depending on the perceived importance of an attribute for predicting NA by a panel of experts (Rutgers et al., 2014).

Wang et al. (2015) proposed a model with five soil attributes to evaluate the performance of NAC in urban soil in Beijing, China: the soil organic carbon content (SOC), clay content (clay), bulk density (BD), pH, and total soil N contents (TN). Xie et al. (2018) built on this model by including pH, SOM, clay, cation exchange capacity (CEC), microbial biomass carbon (MBC), mineralized carbon (MC), urease (URE), arylsulphatase (ARY), alkaline phosphatase (ALP) and microbial functional diversity (average well color development, AWCD). The attributes were weighed differently depending on the effect they had on heavy metals in urban soils: BD (0.172), AWCD (0.125), SOM (0.118), MC (0.106), Clay (0.099), pH (0.094), ALP (0.091), CEC (0.058), URE (0.0486), ARY (0.045) and MBC (0.039).

As seen in many studies, multiple soil attributes can be selected to evaluate and predict the NA (Table 2). These attributes can be considered to also predict NA in the Hoeksche Waard when the perceived sensitivity to the two scenarios is included i.e., arable land with and without field margins. For instance, the total surface area of fields margins over the total area with arable land relates to the total performance of NA.

Table 2 : *Soil attributes that have been proposed to evaluate NA.*

Attribute	**Description**	**Reference**
Community-level functional microbial diversity	The functional microbial diversity provides information on the catabolic versatility and on decomposition rates of complex mixtures of organic pollutants.	(Röling & van Verseveld, n.d.; van Wijnen et al., 2012)
Potential carbon mineralization rate	The potential carbon mineralization rate is the rate that organic C is converted by microorganisms into inorganic C.	(Spohn & Kuzyakov, 2013; van Wijnen et al., 2012)
Potential organic nitrogen mineralization rate	The potential nitrogen mineralization rate is the rate that organic N is converted by microorganisms into inorganic N.	(van Wijnen et al., 2012)
Soil organic matter	SOM influences the Kd and can adsorb pesticides and metals. SOM serves as a source of carbon and energy for the soil food web.	(van Wijnen et al., 2012; Xie et al., 2018)
Fraction N in surface water	Nitrogen is a nutrient leaching from agriculture soil into waterbodies. There is evidence that unfertilized field margins reduce leaching.	(van Dijk et al., 2003; Zak et al., 2018)

Attribute	Description	Reference
Fraction P in surface water	Phosphorus is a pollutant leaching from agriculture soil into waterbodies. There is evidence that unfertilized field margins demonstrate reduced leaching.	(van Dijk et al., 2003; van Wijnen et al., 2012; Zak et al., 2018)
Fraction pesticide in surface water	Pesticides are pollutants leaching from agriculture soil into waterbodies. There is evidence that untreated field margins demonstrate reduced leaching.	(Pätzold et al., 2007)
Root biomass	Plant roots can reduce the runoff rate and can take up (excess) nutrients.	(Anderson et al., 2009; Yu et al., 2016).
Bulk density	Bulk density is an attribute that describes soil density and compaction, which influences leaching of pollutants and nutrients.	(Xie et al., 2018)
Soil-water distribution coefficient	The soil-water distribution coefficient expresses the ratio between sorbed and dissolved phases. The concentration soluble heavy metal and PAHs in the soil might be correlated to the Kd.	(Sauvé et al., 2000; Soilquality, n.d.; Xie et al., 2018)
Clay content	Sorption and the Kd are influenced by clay content. Clay content is dependent on geography thus not an interesting attribute for this research.	(McAllister & Chiang, 1994; Röling & van Verseveld, n.d.; Xie et al., 2018)
Cation exchange capacity	The CEC is dependent on the clay content, type of clay, soil pH and amount of organic matter and influences the Kd. For this research not an interesting attribute to include.	(Soilquality, n.d.; Xie et al., 2018)
Microbial biomass carbon	Microbial biomass carbon is indicative for total metabolic activity and can be related to mineralization of organic pollutants	(Xie et al., 2018)
Mineralized carbon	Mineralized carbon indicates degradation of organic pollutants.	(Xie et al., 2018)
Urease	Enzyme activity indicates soil microbial functional activities.	(Xie et al., 2018)
Arylsulphatase	Enzyme activity indicates soil microbial functional activities.	(Xie et al., 2018)
Alkaline phosphatase	Enzyme activity indicates soil microbial functional activities.	(Xie et al., 2018)
Soil microbial functional diversity	Soil microbial functional diversity indicates soil microbial functional activities.	(Xie et al., 2018)
Precipitation and irrigation	Precipitation and irrigation increase soil moisture which can migrate to groundwater and to surface water. The flow of soil moisture can reduce chemical pollutants in the soil, the groundwater, and the surface water through physical and chemical processes, effecting water quality.	(Cheng et al., 2021)
Soil temperature	Soil temperature is an important factor in determining the microbial activity and community structure.	(Cao et al., 2016; McAllister & Chiang, 1994)
Soil pH	Kd is influenced by the soil pH. Soil pH is an important factor in determining the microbial activity and community structure.	(van Wijnen et al., 2012; Xie(Aciego Pietri & Brookes, 2009)
Plant diversity	A diverse plant community reduces evaporation from the topsoil and induces high levels of root exudation, which promotes higher soil microbial growth and activity and changes microbial composition.	(Lange et al., 2015)

2.1 Abiotic Attributes

Pollution of surface water and groundwater with nitrogen (N) and phosphorus (P) is a serious problem in Europe and other parts of the world (Zak et al., 2018). Three to four million tons of P_2O_5 are transported from soil to water annually worldwide and between 29.1-67.5% of total N and 25-45.9% of total P flowing into rivers are emitted by farmlands (Cheng et al., 2021). Inorganic N is soluble in water, while P and organic N is bound on soil particles (Bos & Musters, 2014). A shortage of these nutrients can limit primary production and a surplus of nutrients are involved in the development of algal blooms with a negative impact on biodiversity and human health. Despite efforts to reduce fertilizer application, the nutrient pollution of water bodies, and terrestrial nature areas remains a problem (Zak et al., 2018). The application of field margins can reduce the influx of N and P to the surface water (van Dijk et al., 2003). Consequently, attributes related to N and P in the system can be modeled for predicting NA.

Another group of pollutants related to agriculture is pesticides, which are widely applied to protect crops from some insects. Some studies have shown that field margins can reduce pesticide transport from runoff (Pätzold et al., 2007). However, there is some debate regarding the efficiency of different field margins widths on this reduction, although the direction is clear: wider field margins should have a better NAC. Pesticides can enter surface waters in the form of agricultural runoff or by leaching into groundwater (Sjerps et al., 2019). Sorption and degradation are the most important processes to predict the fate of pesticides in soils (Melanie 2007). Sorption is regulated by the organic carbon content, pH, temperature, and the mineralogy of the soil (McAllister & Chiang, 1994; Röling & van Verseveld, n.d.). SOM is the part of soil consisting of organisms in different stages of decomposition. It influences soil properties such as water-holding capacity, cation exchange capacity an availability of nutrients (Brady, 1999). SOM can adsorb pesticides and serves as a source of carbon and energy for the soil food web (van Wijnen et al., 2012; Xie et al., 2018). SOM could be an interesting attribute providing information of sorption since it is less dependent on the geography compared to pH, temperature, and mineralogy.

2.2 Biotic Attributes

Microorganisms are the mediators of biodegradation and transformation of many substances such as organic molecules and inorganic nitrogen compounds (Röling & van Verseveld, n.d.). By transforming and mineralizing contaminants, microorganisms decrease their mass and toxicity. If sorption is higher, the proportion contaminants available for biodegradation decreases. Some of the active microorganisms in the subsurface will be involved in biodegradation (Röling & van Verseveld, n.d.). Consequently, the microbial community or activity in the subsurface of the soil can be considered as attributes for modelling of NA.

Plants can also influence the spreading of nutrients in the soil. Plant roots are key regulators of soil structure and play a role in reducing the runoff flow rate (Anderson et al., 2009; Yu et al., 2016). They enhance aggregate formation and stability resulting in macropores that are important for runoff mitigation due to their width and connectivity (Yu et al., 2016). Plants in field margins can also use the excess of nutrients from crops, resulting in less pollution in surface water (Anderson et al., 2009). The roots of plants also enhance microbial and fungal activity in the rhizosphere, thus stimulating the breakdown of organic pollutants (Gajić et al., 2018). Plant diversity influences ecosystem functioning and microbial activity (Lange et al., 2015). A diverse plant community reduces evaporation from the topsoil, which promotes higher soil microbial growth and activity. High plant diversity results in higher levels of root exudates. Root exudates can change the activity and composition of the microbial community (Lange et al., 2015). Root biomass and plant diversity might be an attribute suitable for modelling NA.

To summarize, there are multiple soil attributes that can be selected to evaluate and predict NA. However, any attribute will be unequally important to quantify NA in arable land with and without field margins for reasons of model constraints and data availability and quality. Consequently, attributes will receive a higher weight depending on relevancy for the model and depending on the reliability of data. The conceptual model as a result of this literature review will be included in Chapter 4.1.2 .

3. Methods

The SCBA for field margins aims to determine costs and benefits of the implementation of field margins in the Hoeksche Waard. The SCBA for field margins in the Hoeksche Waard compared two alternatives: a ‘no field margins present’ and a ‘field margins present’ alternative. In SCBAs, alternatives contain the measures that are being researched (Romijn & Renes, 2013).

The ‘no field margins present’ alternative consists of a situation with agricultural fields without field margins. The field margins alternative comprises a situation where field margins are present, according to the present dimensions, agricultural management practices and vegetation type and cover in the margin. Field margins in the Hoeksche Waard fall into two categories: flower-rich” and “grassy” margins (Interreg NWE, 2019). The effects of the creation and maintenance of field margins are determined in terms of delivery of ecosystem services. A change in the size and distribution of ecosystem assets (e.g., creation of field margins) will lead to changes in ecosystem functions (e.g., biodiversity, NA), which will lead to changes in the composition of benefits humans obtain from ecosystems.

Models for the ecosystem services ‘biodiversity’ and ‘NA’ were developed and implemented based on the following steps. First, attributes were identified that could be used to quantify the delivery of an ecosystem service or the subfunctions underpinning the ecosystem service. The objective was to set up a practical conceptual model for quantification of biodiversity and NA. Second, data and information on the potential attributes was collected and organized in tables. Third, the collected data was used for modelling of ecosystem services for the two scenarios: arable fields with and without margins. At last, a deterministic sensitivity analysis was done. These steps, as well as the study area and the alternatives, are further elaborated in the following subchapters.

3.1 Study Area ‘the Hoeksche Waard’

The Hoeksche Waard is a municipality in the southwestern part of The Netherlands consisting of around 60 polders (Frazão et al., 2017; Heijting et al., 2011). This area of approximately 324 km^2 is made up of croplands (49%), water bodies (17%), grasslands (13%), nature areas including forest (13%), and built-up and paved areas (9%) (Figure 1)(Paulin, 2022). The economy is primarily agricultural, focused on the production of sugar beet, potato and wheat, rotating with a variety of other crops (Frazão et al., 2017; Paulin et al., 2020). The soil is classified by the FAO World Reference Base for Soil Resources (2006) as calcaric fluvisols (Heijting et al., 2011).

According to the Dutch soil classification system the soil can be identified as marine 'polder vague' comprising hydromorphic calcareous sandy loam to clay formed in marine sediments. The average temperature is 10.8 °C and annual precipitation is 883 mm (Frazão et al., 2017; Heijting et al., 2011). In 2004, the project Functional Agrobiodiversity Hoeksche Waard was established, aiming to reduce chemical pesticides by increasing biodiversity (i.e., the populations of antagonists of pest insects) to enhance biological pest control. This plan has led to the creation of currently 460 km of flower rich and grassy field margins (Paulin et al., 2020).

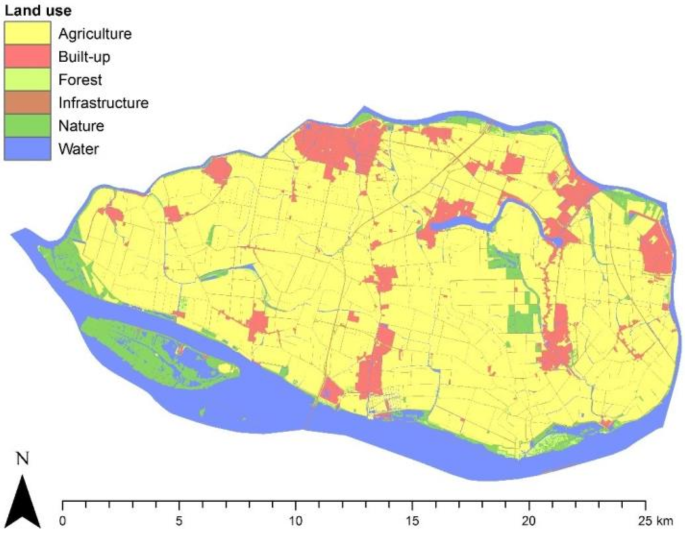

Figure 1: *Land cover in the Hoeksche Waard (Paulin et al., 2022)*

3.2 Conceptual Model

First, sets of attributes that can be used to quantify the delivery of an ecosystem service or the subfunctions underpinning it were identified. An attribute (e.g., pH-soil) is a characteristic or set of characteristics of an ecosystem which can be measured. Attributes can include biotic and abiotic soil indicators, such as pH-H_2O and pH-KCl. The methods used to quantify attributes are called indicators. For biodiversity, the study focused on four groups of organisms for which biodiversity data were available: birds, insects, soil life, and aquatic invertebrates. The existing model for biodiversity of Vieler, (2015) focusses only on soil biodiversity and was judged unsatisfactory for quantification of biodiversity in arable land with and without field margins. The existing proxy-indicator system for NA of van Wijnen et al., (2012), used to produce national maps demonstrating this ecosystem service, was judged unsatisfactory. Since field margins were not incorporated in the nation-wide monitoring, it was believed that it was not dedicated enough for quantification of NA in arable land with and without field margins. Therefore, a literature review was carried out to identify indicators useful for quantification of NA in arable fields with and without field margins, as well as within field margins. This literature review can be found hereafter in Chapter 2.

The collected attributes were combined in practical conceptual models for quantification of biodiversity and NA. The structure for incorporating attributes within models for agricultural systems was developed in the EU project LANDMARK (Debeljak et al., 2019; van Leeuwen et al., 2017). Based on this approach, the conceptual models for biodiversity and NA were built by incorporating attributes into different hierarchical levels ((Debeljak et al., 2019; van Leeuwen et al., 2017); Figure 2)). A single indicator can describe multiple attributes and a single attribute can be described by multiple indicators for its assessment. Attributes can be clustered together into aggregated attribute groups: super attributes called in this study. The combination of these categories together provides a framework for collecting basic data and making efficient use of it to quantify ecosystem service delivery (Debeljak et al., 2019; Rutgers et al., 2018; van Leeuwen et al., 2017).

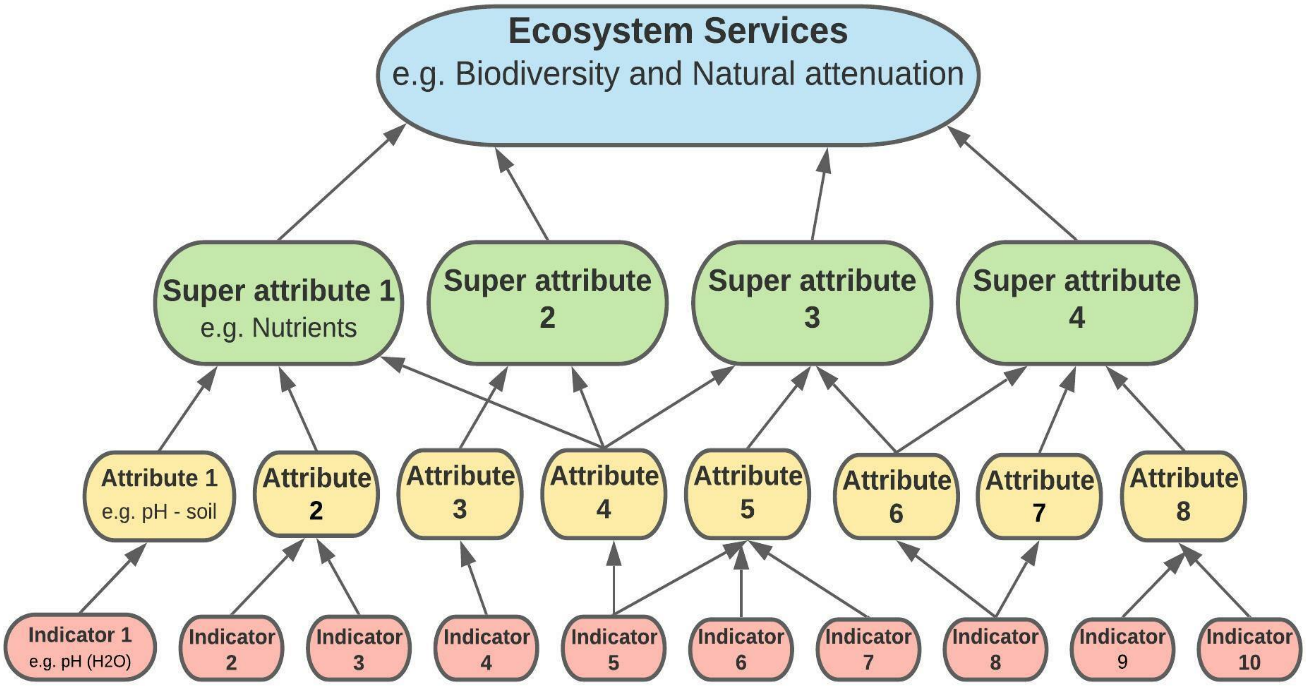

Figure 2*: Diagram of selecting attributes within an ecosystem service (van Leeuwen et al., 2017)*

3.3 Data Selection

Second, data describing attributes for the potential quantification of NA and biodiversity were collected and organized in tables (Appendix 8.2).

3.3.1 Biodiversity

For the ecosystem service ‘biodiversity’, this study focused on four groups of organisms relevant for describing biodiversity condition of the Hoeksche Waard, and for which data were available: birds, insects, soil organisms, and aquatic invertebrates. For birds, insects and aquatic invertebrates data were available for calculating the biodiversity metrics: abundance, richness, Shannon index and evenness.

The dataset of aquatic organisms was collected by Schuurmans (2021) and the data was analyzed by P. van Rijn, (personal communication). This data was collected from 2017 until 2021. For 60 min, samples were collected of a 50-100 m section of a ditch. The ditches were between 1-4 m wide and 30-100 cm deep. For five years, twice a year around nine ditches were sampled, resulting in 92 different sampling moments. Half of the ditches had field margins at both sides and the other half of the ditches had no adjacent field margins (van Rijn, 2018).

The data of birds was collected by Fokker (2020). Eight plots containing flower-rich field margins were compared to different reference plots: five plowed land plots, four winter wheat plots, two lucerne plots and one potato plot. The observation was carried out monthly from December 15 to March 15. The observation started after sunrise and stopped before sunset. It is important to note that this research is not yet completed and this study makes use of the first results of that research (Fokker 2020).

The data on the number and taxa of insects was collected from 2019 until 2021 by P. van Rijn, (personal communication), following the method of van Rijn (2018). Triannual (June, July, August) for 20 min, insects within 2.5 x 50-meter plots were observed and counted for 20 min. All taxa that were possible to distinguish by one person while being in the field were included, such as butterflies, dragonflies, and bumblebees per species, but solitary bees per group. In total, the insect diversity was measured in 131 perennial grass-flower strips and 34 in recently mown grassy-flower strips (van Rijn, 2018). Data of recently mown grassy-flower strips was used instead of arable land without field margins to calculate biodiversity as insects were not measured in arable land.

The model of Rutgers et al. (2018) was used to determine soil biological attributes for soil biodiversity. Soil life was modelled with five attributes: enchytraeids, microarthropods, nematodes, earthworms, and the microbial community. The microbial community attribute was calculated from four metrics: bacterial biomass, fungal biomass, 50% substrate (soil) conversion and slope of dilution to extinction curve. A relative color development technique was done to get the bacterial response to 31 carbon and energy substrates (Rutgers et al., 2016; Sechi et al., 2017). With this technique information on the slope of dilution to extinction curve and amount of soil needed for 50% substrate conversion could be measured. For the other organisms the metrics density, richness, biomass (when available), Shannon index and evenness, were fit into the model. Data of soil life was collected by Sechi et al. (2017) and was further analyzed for this study. In Sechi et al. (2017), various soil parameters were collected from four farms, comparable in terms of crop type, rotation scheme and presence of adjacent field margins. Four spots in arable land (1 x 1 m) and four spots in field margins (1 x 1 m). 50 soil cores (Ø 2.3 cm, depth 10 cm) were collected in each spot and mixed to measure nematode diversity, abiotic soil, and microbial parameters. Three larger cores (Ø 5.8 cm, depth 10 cm) were collected to measure mesofauna diversity. The distance between spots was around 20 m. All analyses were performed using R software 4.0.5 and packages lme4 (Bates et al., 2022), nlme (Pinheiro et al., 2022) and ggplot2 (Wickham et al., 2021). An ANOVA was performed to test the effect of management (arable field vs. field margin), farm and their interaction on soil attributes, using generalized least squares regression (GLS) with a compound – symmetric structure to include correlation between observations within the same farm. Before the analysis, a log-transformation to reach normality of variance was performed on the data. The results and boxplots of this analysis can be found in Appendix 8.1.

3.3.2 Natural Attenuation

Data of SOM, potential C mineralization rate, potential N mineralization rate and pH (KCl) were collected by Sechi et al. (2017). The sub attributes aquatic invertebrates, microbial biomass and functional microbial activity are from the same source as described in the ecosystem service biodiversity (Chapter 3.3.1) (Schuurmans, 2021; Sechi et al., 2017). The super attribute 'plant' is defined as the coverage and richness of plants in that area (Bojacá et al., 2011; van Rijn, 2018). The relative coverage is the fraction of surface that is covered by a plant. This can exceed 1 because different plants can overlap.

3.4 Modelling Ecosystem Services

Third, the collected data was used for modelling of the performance of ecosystem services for the two scenarios.

For this model, an equation by Rutgers et al. (2012), which includes weights assigned by expert judgement, was modified and implemented. The relative performance of an ecosystem service (RESP) between the two scenarios was calculated following Equation 1 and Equation 2.

Equation 1: *Adapted model of relative ecosystem service performance of arable land compared to field margins*

$$RESP^{FM}/_{AL} = 10^{\left(+\left(w^{i}*\left|log\left(\frac{VAR_{FM}^{i}}{VAR_{AL}^{i}}\right)\right|\right)+\ldots-\left(w^{j}*\left|log\left(\frac{VAR_{FM}^{j}}{VAR_{AL}^{j}}\right)\right|\right)\right)}$$

Equation 2: *Adapted model of relative ecosystem service performance of arable land compared to field margins*

$$RESP^{AL}/_{FM} = \frac{1}{RESP^{FM}/_{AL}}$$

Where $VAR^{i\ldots j}$ is any indicator (variable) that contributed to the ecosystem performance. Subscripts ‘FM’ and ‘AL’ indicate Field Margins and Arable land values. $W^{i\ldots j}$ stands for the weight any indicator was given, brought forward by professional panels via evaluation of a survey.

In this equation there are two possible scenarios. Indicators where the VAR_{FM} performs better than VAR_{AL} are from the ‘i’ type (Equation 3). Indicators where the VAR_{AL} performs better than VAR_{FM} are from the ‘j’ type (Equation 4). For most indicators a higher value means it performs better than a lower value. However, a lower value of 50% soil conversion means a better performance and a soil pH closer to 7.6 performance best (Rutgers et al., 2008). In the discussion the advantages and disadvantages of this model are reviewed.

Equation 3: *‘i’ type indicator*

$$+\left(w^{i} * \left|log\left(\frac{VAR_{FM}^{i}}{VAR_{AL}^{i}}\right)\right|\right)$$

***Equation 4**: 'j' type indicator*

$$-\left(w^{i} * \left|log\left(\frac{VAR_{FM}^{i}}{VAR_{AL}^{i}}\right)\right|\right)$$

3.5 Collecting Weights

For the calculation of BC and NAC, weights were assigned by expert judgement. The weights are based on the judgement of three RIVM colleagues and J. Otte. Each individual independently completed a questionnaire in which weights between 1 and 10 had to be given to different attributes.

3.6 Deterministic Sensitivity Analysis

A deterministic sensitivity analysis (DSA) was performed to assess which indicators per alternative (field margins / no field margin) had the highest impact on the uncertainty of the model (*Deterministic Sensitivity Analysis*, 2016; Vreman et al., 2021). For this analysis, the lower and upper bound of 95% confidence interval of every variable (VAR_{FM} and $VAR_{AL)}$ was used to assess the lower and upper bound of RESP. One variable is varied at a time and a 'tornado chart' with results of the various RESP deviating more than 0.1 from the original outcome of the model can be found in Chapter 4.3 . The other results can be found in Appendix 8.3.

4. Results

4.1 Conceptual Models

In this section, the conceptual models of biodiversity and NA in the Hoeksche Waard will be visualized. The procedure to construct these models were derived from the model for soil biodiversity and habitat provision by Rutgers et al. (2018) and Van Leeuwen et al. (2017)

4.1.1 Biodiversity

The ecosystem service biodiversity was split into four super attributes instigated by ample data on four groups of organisms: soil life, aquatic invertebrates, birds, and insects (Figure 3).

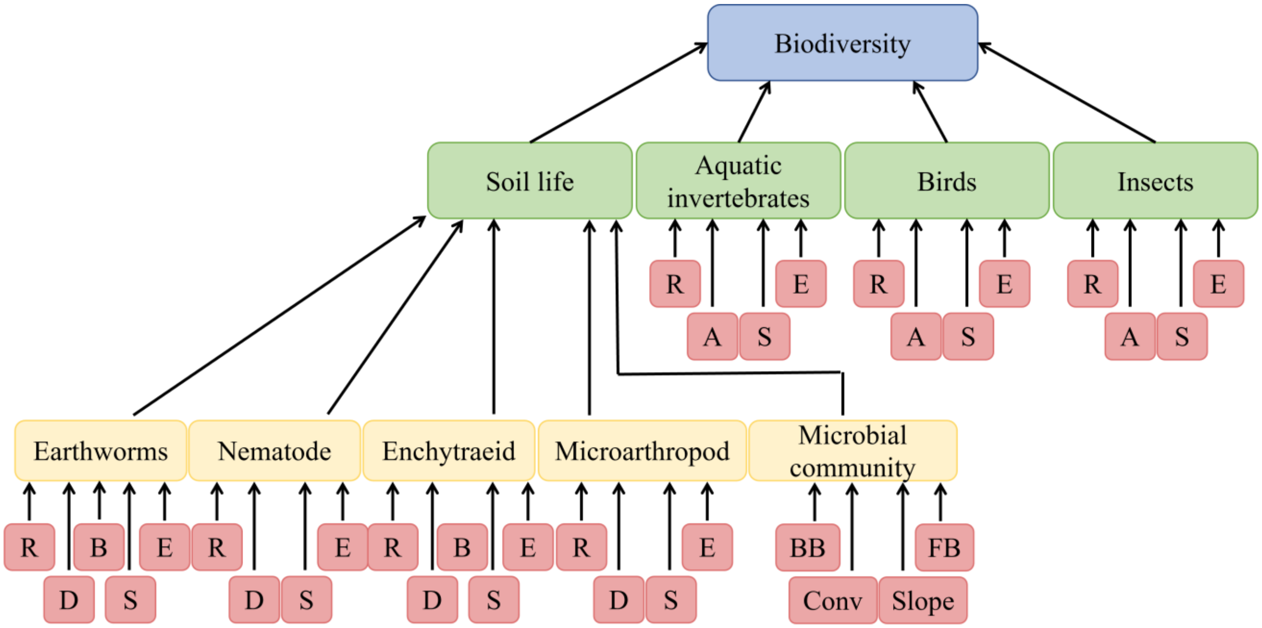

Figure 3: *Conceptual model of biodiversity (blue) and their super attributes (green), attributes (yellow) and indicators (red). R = richness, A = abundance, S = Shannon index, E = evenness, D = density, B = biomass, BB = bacterial biomass, FB = fungal biomass, Conv = 50% soil conversion.*

4.1.2 Natural Attenuation

The conceptual model of NA (Figure 4) is based on the literature review (Chapter 2). Three super attributes (green) mainly influence the NA of field margins and arable land in the Hoeksche Waard: microbial community, aquatic invertebrates, and plants.

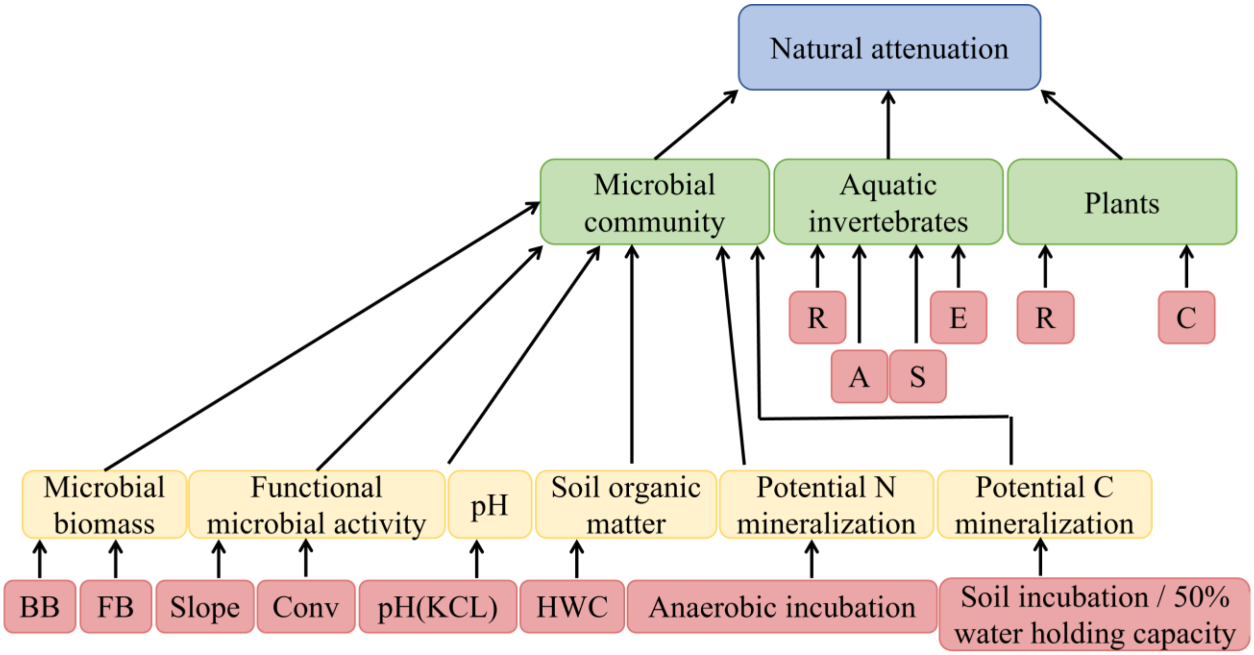

Figure 4: *Conceptual model of NA (blue), their super attributes (green), their attributes (yellow) and indicators (red). R = richness, A = abundance, S = Shannon index, E = evenness, C = coverage, BB = bacterial biomass, FB = fungal biomass, Conv = 50% conversion of soil, HWC = hot-water extractable carbon in soil*

4.2 Model

4.2.1 Biodiversity

The biodiversity model describes the biodiversity capacity (BC) of arable land in the Hoeksche Waard and compares the condition of arable fields with no field margins with the condition of arable fields with field margins. Information on indicators and their weight can be found in Appendix 8.2. The super attributes were given the following weights: soil organisms (0.31), aquatic invertebrates (0.24), birds (0.18), insects (0.27). The calculated BC can be found in Table 3. In one calculation, all differences between indicators were used for calculating the BC. In the other calculation, when the difference between field margin and arable land was not significant for individual indicators, the difference between the arable land and field margin was pinned to 0 for that indicator. For the first calculation, the BC of arable land performed at 0.552 fraction of field margins. In the second calculation, the BC of arable land performed at 0.764 compared to field margins.

Table 3: *BC of field margins compared to arable land and vice versa in two different calculations. FM/AL = ratio between field margins and arable land. AL/FM= ratio between arable land and field margins*

Calculation	Calculated value	FM/AL	AL/FM
1	BC (all differences between indicators were accounted for)	1.81	0.552
2	BC (non-significant indicators were counted as a 0)	1.31	0.764

4.2.2 Natural Attenuation

The natural attenuation model describes the natural attenuation capacity (NAC) of field margins compared to arable land. Information on indicators and their weight can be found in Appendix 8.2. The super attributes were given the following weights: microbial community (0.80), plants (0.09), aquatic invertebrates (0.11). The calculated NAC can be found in Table 4. In one calculation, all differences between indicators were used for calculating the NAC. In the other calculation, when the difference between field margin and arable land was not significant for an indicator, the difference between arable land and field margin was pinned to 0. For the first calculation, the NAC of arable land performed at 0.486 fraction of field margins. In the second calculation, the arable land performed at 0.561 compared to field margins.

Table 4: *NAC of field margins compared to arable land and vice versa in two different calculations. FM/AL = ratio between field margins and arable land. AL/FM= ratio between arable land and field margins*

Calculation	Calculated value	FM/AL	AL/FM
1	NAC(all differences between indicators were accounted for)	2.06	0.486
2	NAC (non-significant indicators were counted as a 0)	1.78	0.561

4.3 Uncertainty Analysis: Deterministic Sensitivity Analysis

For the first calculation of BC and NAC a deterministic sensitivity analysis (DSA) was done. DSA can determine how robust the model is to variables (VAR_{FM} and VAR_{AL}) with a wide 95% confidence interval. Variables that deviate more from the originally calculated RESP (BC = 1.81, NAC = 2.06) have the highest impact on the outcome of the model.

4.3.1. Biodiversity

For each variable the lower and upper bound of the BC has been calculated to assess the influence of variance of indicators on the outcome of the model. The differences were then ranked and the tornado diagram in Figure 5 shows the DSA results of deviations larger than 0.1. The variable with the highest impact on the BC was aquatic invertebrates abundance in arable land. The upper bound resulting in a BC of 1.73 and the lower bound resulting in 2.73. The lower bound of insects abundance (BC:1.34) and aquatic invertebrates abundance (BC:1.17) of field margins, both result in low BCs compared to other indicators.

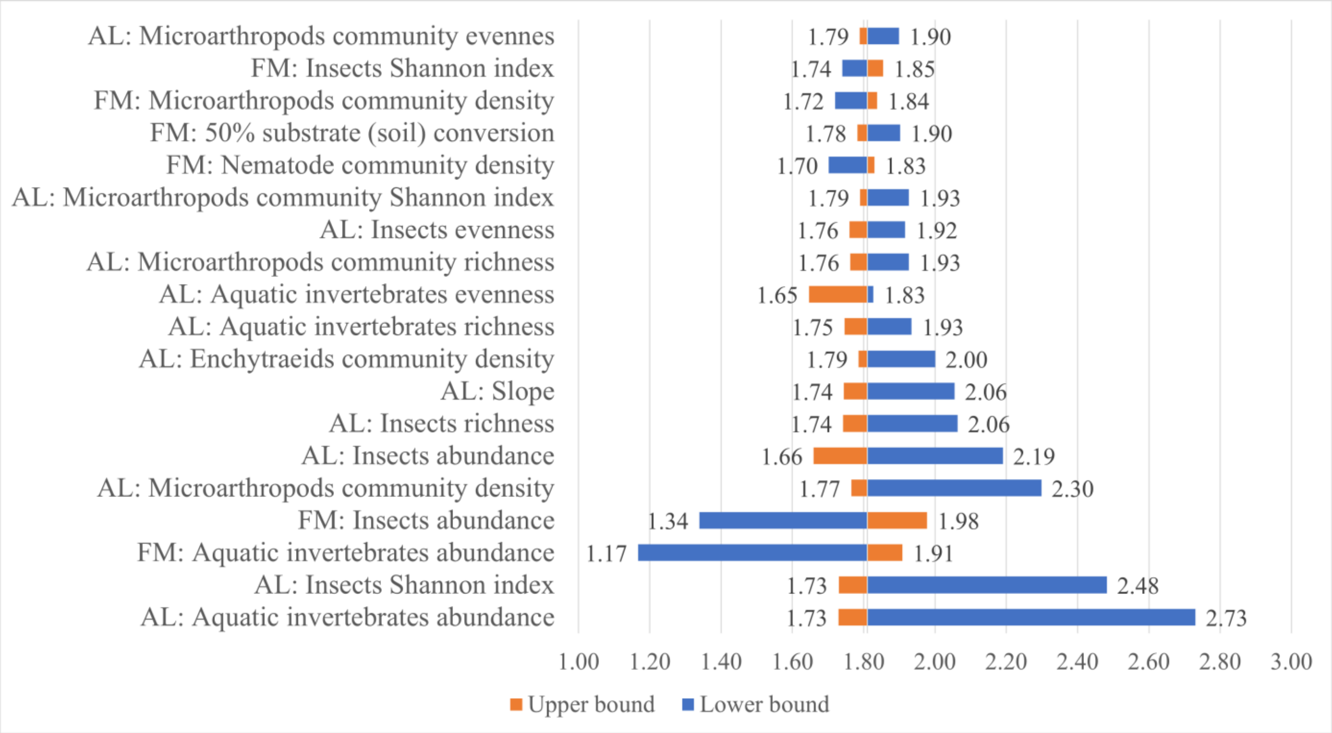

***Figure** 5: Deterministic sensitivity analysis results in a tornado diagram related to biodiversity capacity for deviations larger than 0.1. AL = arable land, FM = field margins*

4.3.2. Natural Attenuation

For each variable the lower and upper bound of the NAC has been calculated to assess the influence of variance of indicators on the outcome of the model. The differences were then ranked and the tornado diagram in Figure 6 shows the DSA results of deviations larger than 0.1. The indicator with the highest impact on the NAC was potential C mineralization of field margins with the lower bound resulting in a NAC of 1.93 and the upper bound resulting in an outcome of 2.54. The aquatic invertebrates abundance of field margins (NAC:1.72) and the 50% substrate (soil) conversion of arable land (NAC: 1.71) both resulting in a lower NAC than other indicators.

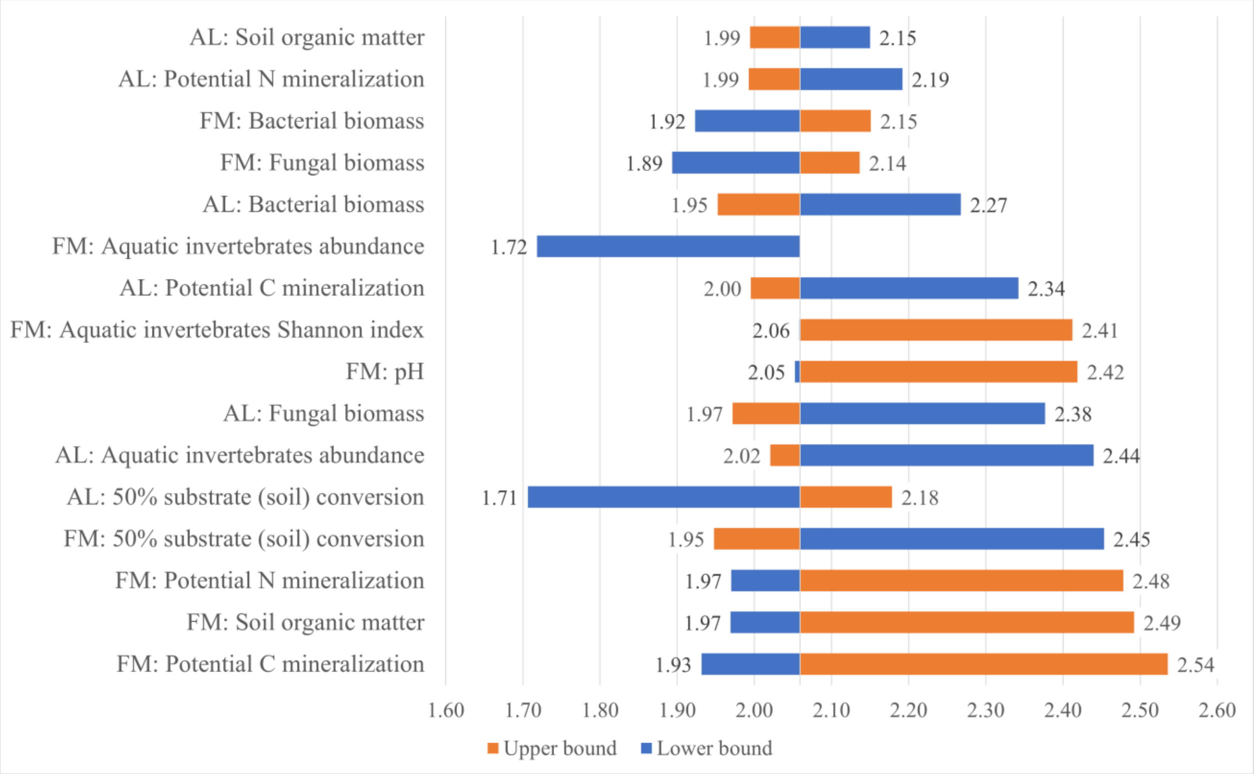

Figure 6: *Deterministic sensitivity analysis results in a tornado diagram related to natural attenuation capacity for deviations larger than 0.1. AL = arable land, FM = field margins*

5. Discussion

5.1 Interpretation of the Results

The conceptual models defined a comprehensive set of indicators for attributes, and proxy indicators for super attributes to link quantifiable system properties with the relevant ecosystem service. For (functional) biodiversity, four super attributes were defined that disclose characteristic organisms in and around arable land: aquatic invertebrates, birds, insects, and soil organisms. The attributes were also chosen based on data availability. Often the indicators were of the type of abundance, richness, Shannon index and evenness. For NA, three super attributes were defined that were found important to include in the model after a literature review: aquatic invertebrates, plants, microbial community.

Different from the original model (Rutgers et al., 2012; van Wijnen et al., 2012), the two calculations were compared to each other instead to a reference condition. A reference condition for a good ecological condition or a maximum ecological potential such as adopted in the EU water framework directive allows assessors or researchers to express results on a ruler running from a very bad condition to, ultimately, a healthy condition. The decision to not use reference values was made due the fact that not for all attributes a reference condition could be formulated. Luckily, adding the reference value on the ruler would give in essence a similar conclusion to the research question.

The results of the multi-attribute models shows that field margins have an overall positive effect on biodiversity and NA in the Hoeksche Waard. The BC of systems with field margins is in the range of 1.31-1.81 compared to arable land. The NAC of systems with field margins is in the range of 1.78-2.06 compared to arable land.

For some indicators, differences suggested a higher BC or higher NAC in the system with field margins, but the differences could not be tested for significance, or differences were not significant. In this study a range of possible outcomes was calculated, with the lowest value for the calculation while pinning al insignificant differences at zero, and the highest value through using all collected data. Although the BC and NAC where somewhat higher when ignoring non-significant indicator results, the BC and NAC still indicated improved conditions in the field margin system. In conclusion the result is robust for replacing some indicator values with a zero when results were not significant. For instance, the data of the field birds demonstrated expected differences between the two systems, with more species and higher numbers in the field margin system, but it was only one observation and statistical significance could not be tested.

For the SCBA, the effects (cost and benefits) are quantified in monetary terms where possible. However, effects in a SCBA do not have to be monetized, since all effects are listed and are considered (Romijn & Renes, 2013). Thus, including ecosystem services that are not-monetized is also important to give decision-makers the necessary information to determine whether the extra costs of creating and maintaining field margins in the Hoeksche Waard can get a justification. For this SCBA it will be beneficial to eventually have one value for biodiversity (BC) and NA (NAC), and to collect all deliveries in the total bundle of ecosystems together. Changes in the BC and NAC can easily be understood by various stakeholders and decision-makers and weighted against the costs of creating and maintaining field margins in the Hoeksche Waard.

As stated in the introduction, not a lot of studies assessing the BC and NAC in field margins have been performed.

Biodiversity policy and management usually focuses on habitat or on specific species in need of protection. The studies that have been performed on biodiversity focus mostly on a subset of organisms.

A study performed by (Smith et al., 2008) researched among other things the effect of grassy field margins on soil macrofauna. Experimental field margin plots were established in 2001 in a winter wheat field in Cambridgeshire UK, using a factorial design of three grassy seed mixes and three management practices (spring cut, herbicide application and soil scarification). In spring and autumn 2005, the soil macrofauna diversity was identified. The diversity was generally higher in field margins than arable land. The Lumbricidae (earthworms), Isopoda (woodlice) and Coleoptero (beetles) having significantly higher richness and abundance in the margins. Similar to this study, the study of (Smith et al., 2008) saw a trend of higher soil macrofauna diversity, yet other taxa being significant higher in field margins than arable land (e.g earthworms). This may be the result of a time-lag in soil macrofauna response or because the changes in plant species diversity which can have an idiosyncratic effect on soil communities (Hedlund et al., 2003). Different management styles involving field margins can also extend a time-lag. For example, removing biomass after mowing can decrease food/nutrients (Hedlund et al., 2003). This does not affect the relevance of these studies but shows how important more data and research can be to secure the results.

In a study done by Jobin et al. (2001), habitat structure and bird use of field margins were researched in three types of field margins in southern Québec. Herbaceous field margins had fewer birds than the field margins containing natural hedgerows with trees and shrubs and planted windbreaks with coniferous trees and shrubs. This study concluded that many birds have birds and shrubs as habitats. This difference could be explained by different bird species. The Netherlands has various meadow birds, while this study counted a lot of birds residing in trees and shrubs. Another differences is that the birds counted by Fokker (2020), was done in winter while this research was done in late summer and early fall. Not many birds hibernate in southern Canada, while some birds hibernate in the Netherlands.

Not much research on natural attenuation in field margins is done. Research on natural attenuation is mostly focused on specific contaminants and riparian buffers. Riparian buffers are wider margins often containing woody plants. These buffers are specially installed to remove contaminants. In a research done by Lee et al., (2003), switchgrass buffers of 7.1 m were installed and removed 80% of total-nitrogen, 62% of nitrate-nitrogen, 78% of total phosphorus and 58% of phosphate-phosphorus. However, these strips were 7.1 m and field margins in the Hoeksche Waard are around 4 m. It is expected that the removed nitrogen and phosphorus will be lower than found by Lee et al., (2013).

5.2 Uncertainty

The model as well as the data included in the models may have some uncertainty, which is an inherent limitation of a model based approach. The data presents uncertainties through variation that should be taken into consideration and the model can have uncertainties through the exclusion of attributes.

First, to assess the impact of the uncertainty regarding the input of input parameter values, a DSA was performed. The results of the DSA are in line with the expectations that the various BC and NAC calculated in the DSA will be above 1. Meaning that despite the uncertainty of variables the expected effect is still present which makes the outcome more robust. One reason for the robustness of this model is the use of multiple attributes. However, a limitation of DSA is that indicators with no 95% confidence interval or standard deviation could not be included in the analysis.

The differences in calculated BC and NAC could be explained by the sensitivity of the models and the 95% confidence interval of the data. A high weight for an indicator in the model or a high SD can give a wide range of BC and NAC in the DSA. For example, potential C mineralization of field margins got a weight of 1.15×10^{-1}, SD of 4.18×10^{1} and a mean of 1.48×10^{2}. The calculated NACs in the DSA are 1.93 and 2.54. Especially the upper bound (2.54) deviates more from the standard calculated NAC (2.06) than other indicators. In the DSA of BC, the effect of a high SD can be seen in the lower bound of insects abundance (BC:1.34) and aquatic invertebrates abundance (BC:1.17) of field margins, both result in low BCs compared to other indicators. More research into the variables with a large influence can make the model less uncertain.

Another limitation of the use of DSA with this model is calculating NAC or BC with a negative number. For example, the lower bound of 95% confidence interval of aquatic invertebrates abundance result in an indicator with a negative number (e.g., lower bound field margins: -3.19×10^{2}). The model cannot handle negative numbers, thus negative numbers were replaced by 1. However, this is a conservative assumption as calculated values are less deviated from the standard NAC and BC than should be. Another limitation of using a DSA is that some indicators are correlated with each other. While this does not necessarily influence checking the sensitivity of the model, the NAC is realistically feasible without other indicators changing. For example, several biodiversity indices and indicators are correlated. When changing richness or abundance, it is expected that the evenness and Shannon index will also change.

Second, the lack of attribute data can be debated. Although most data were measured in the Hoeksche Waard, the data was gathered from different sources. Some sources are more extensive than others. Most soil data (Sechi et al., 2017) was in possession of the RIVM, information about the method and raw data was therefore easier to find. Other data was gathered through other researchers or reported in the grey literature. For example, data related to bird diversity were found in a report about ongoing research (Fokker, 2020). The bird counting was done in winter (2019-2020) and no statistical analysis was included. Because the research is still in progress, raw and/or statistical data was not available.

Third, handling non-significant values can be addressed in different ways. As stated before, some of the results were not significant or could not be analyzed. This study made a percentage range were the potential NAC and BC could be situated. However, it should be noted that a higher percentage is more difficult to achieve.

5.3 Strengths and Limitations of this Research

The current study has multiple strengths of which the study area is a large contributor. The Hoeksche Waard is a demonstration area for adopting functional agrobiodiversity in the management of the arable farms. This area has been researched in many projects, giving access to various farms, many data, and many stakeholders willing to contribute. The fact that most data for the models come from the Hoeksche Waard makes the outcome of the model calculations for the condition of NA and biodiversity useful and ready to include in the SCBA.

A strength of the biodiversity model is the inclusion of multiple organism groups. As stated before, policy and management usually focus on habitat or on specific species in need of protection, but other organism groups have a functional role in arable systems, e.g. insects to counteract plague organisms, and microorganisms to retain nutrients in the soil. For this project it is necessary to be overarching for the interpretation of the concept of biodiversity. This is preferable for the SCBA and to be more accessible for various stakeholders.

Lastly, the current study is one of the first studies to calculate an overarching regional biodiversity unit specific for arable systems with and without field margins and to model natural attenuation to quantify the positive effect of field margins. Agriculture is a large contributor to biodiversity loss among other things by releasing pollutants including leaching of phosphorus and nitrogen into waters (Heinis & Evers, 2007). Both these ecosystem services are important to include in the SCBA and general effect of field margins.

In addition to some strengths, it is important to note that the current study also has several limitations among other things caused by assumptions that were made in the model.

First, sometimes there was no data available of arable land with field margins and arable land without field margins and therefore a close alternative was used. For the super attribute ‘insects’, indicators of mowed grassy field margins were used to calculate BC instead of indicators of arable land without field margins. This alternative was chosen because both lack flowers and are disrupted by humans. For soil indicators obtained by Sechi et al., (2017), soil of the field margins was compared to the soil in the adjacent arable fields. Preferable, soil indicators were measured in the middle of arable land with and without field margins and the outer fields containing field margins (arable land with field margins) or arable land (arable land without field margins). Not only because of the research questions but also because the inside and outside of an arable field could differ in soil functionality. With these measurements, the effect of field margins on the whole system can be researched. Because these surrogate measurements were used, the NAC relates more to the outer fields of arable land than the overall fields. For future research, it would be interesting to measure soil indicators and insects in arable land without field margins.

Second, in this model no difference was made between field margins due lack of data availability. However, various field margins are present in the Hoeksche Waard: flower-rich, grassy, grassy-herbaceous. Most data were measured in grassy-herbaceous field margins. To be consistent, preferably data of grassy-herbaceous field margins was used. However, in some cases other data was not available, e.g., bird population was measured in an area containing flower-rich field margins.

Third, in line with previous limitations. The assumption was made that plant coverage in arable land was comparable between crops. The coverage of crops in the Hoeksche Waard was not measured. For the model of NA, measured potato coverage of Bojacá et al., (2011) was used for calculating NAC.

Fourth, a reference of good ecological quality would be desirable. This model calculates the NAC and BC of field margins compared to arable land. Preferably, field margins and arable land is compared to a reference of good ecological quality. The good ecological quality would be most desirable and calculated NAC and BC would be under 1. Besides, if you want to include more locations or alternatives (field margins / no field margins), the result would be easier to compare. In the Netherlands such system is already in place for water bodies (Evers et al., 2012; Heinis & Evers, 2007), and suggestions to adopt this for the soil system was made by Rutgers et al., (2008). The ecological status of a water body can be measured against the good ecological status (GET) or good ecological potential (MEP). This classification system considers biodiversity and other parameters that could be ecological relevant such as phosphorus and nitrogen. A comparable system for agriculture could be useful. A study done by Rutgers et al., (2008), described biological soil quality references in ten soil ecosystem found in the Netherlands, and one of them (arable land on calcaric marine silt loam) was used to calculate ten ecosystem services against a reference which was considered as the most sustainable farms in a nation-wide monitoring. Researchers with expertise, including soil ecology, microbiology and rural management, selected sites where they believed data was representative of good soil quality. Data of these sites were collected resulting in ten references for biological soil quality. An extension of this research including aboveground attributes could be useful to get more insight in the good ecological status of various farmland.

Sixth, in future research the external validity of the research could be increased by including more experts in the panel that acquired weights. For NA, a panel could be more reliable than a literature review to assess which attributes are most important to predict NA in the Hoeksche Waard when the perceived sensitivity to the two alternatives (field margins/ no field margins).

6. Conclusion

The implementation of field margins in the Hoeksche Waard has a positive effect on the biodiversity and natural attenuation in arable systems. The BC of systems with field margins is between 1.31-1.81 compared to arable land. The NAC of systems with field margins is between 1.78-2.06 compared to arable land. Even though the current study has several limitations the results of this study are useful in the projected SCBA and valuable for creating awareness with respect to sustainable agriculture. This research also shows the importance of future research relating to FAB, sustainable agriculture, a reference of good ecological status and the importance of data collection to develop a more robust model.

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8. Appendix

8.1 Statistical Analysis of Soil Organisms

In this section the results of the statistical analysis on the basis of the raw data of Sechi et al., (2017) are shown. Significant effects of the management (field margins vs no field margins), farm and their interaction on soil parameters are shown.

8.1.1 Earthworms

Table S1: Mean, SD, management and farm effect of various biodiversity indicators of earthworms. Asterisks indicate significant effect (p < 0.05, ** p < 0.01, *** p < 0.001)*

Attribute	Field Margin		Arable land		Management effect	Farm effect	Interaction effect
	Mean	**SD**	**Mean**	**SD**			
Shannon index	0.86	0.35	0.69	0.41	n.s	n.s	n.s
Richness	2.88	0.96	2.63	1.09	n.s	n.s	n.s
Biomass	46.69	38.20	51.14	29.15	n.s	**	n.s
Density	295.31	209.01	350.00	174.88	n.s	**	n.s
Evenness	0.86	0.11	0.78	0.17	n.s	n.s	n.s

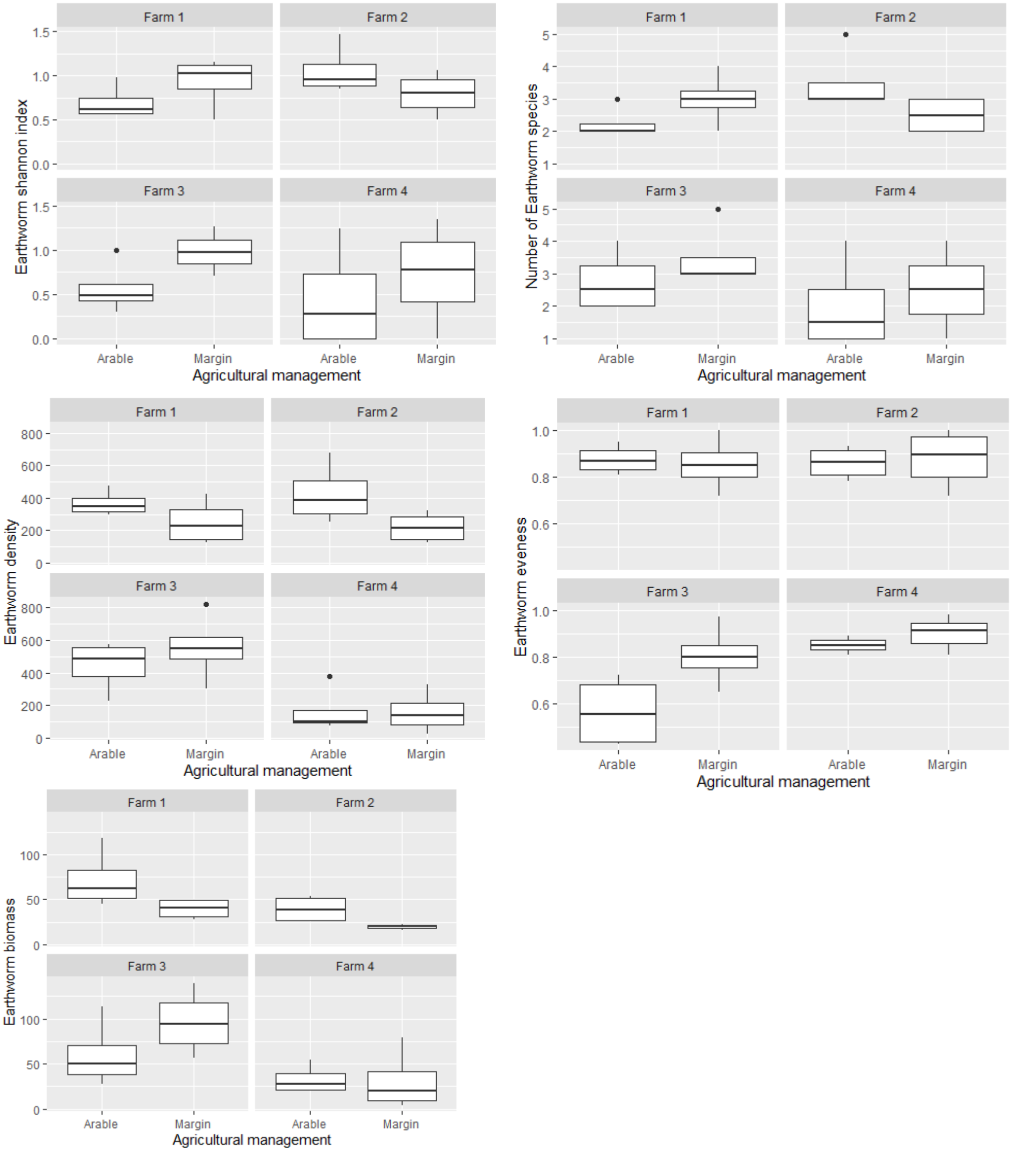

Figure S1: *Boxplots of the Shannon index, richness, biomass, density and evenness of earthworms*

8.1.2 Nematodes

Table S2: Mean, SD, management and farm effect of various biodiversity indicators of nematodes. Asterisks indicate significant effect ($p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)*

	Field Margin		**Arable land**		**Management effect**	**Farm effect**	**Interaction effect**
Attribute	**Mean**	**SD**	**Mean**	**SD**			
Shannon index	2.52	0.27	2.58	0.18	n.s	**	n.s
Richness	26.13	4.29	25.00	3.06	*	**	n.s
Density	2599.88	1300.07	2133.19	486.05	n.s	***	n.s
Evenness	0.78	0.05	0.80	0.04	*	*	n.s

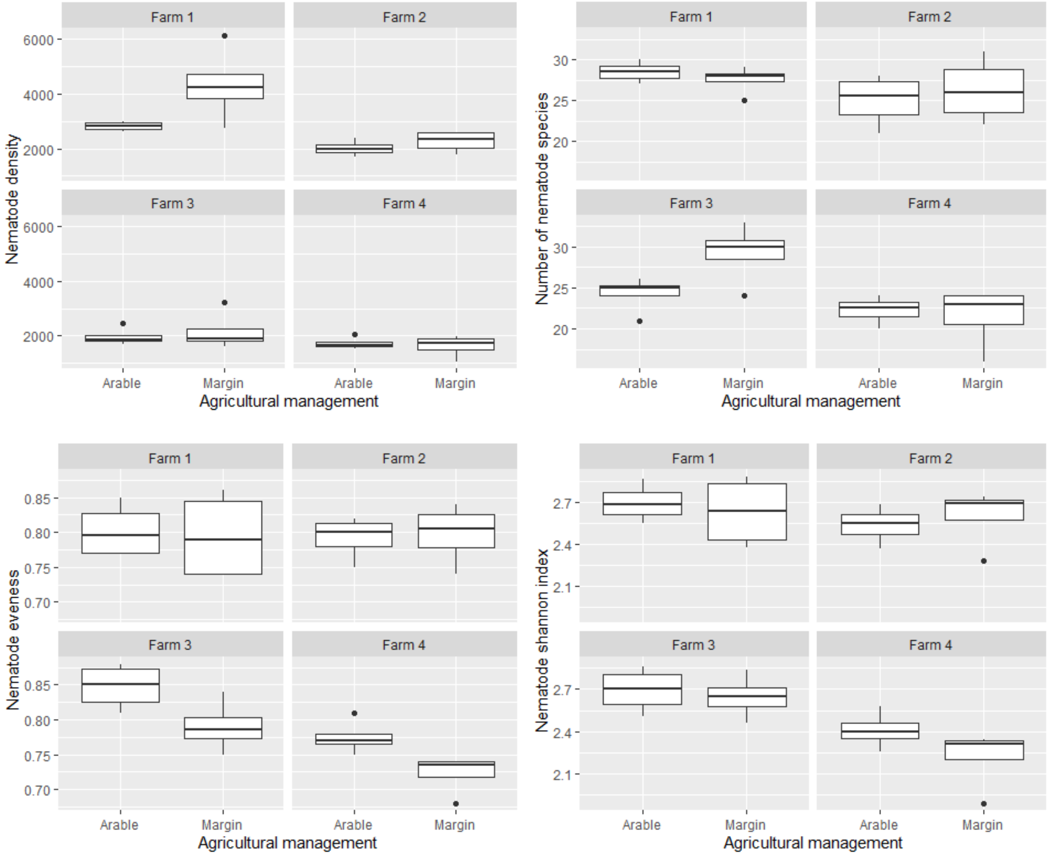

Figure S2: Boxplots of the Shannon index, richness, density and evenness of nematodes

8.1.3 Enchytraeids

Table S3: Mean, SD, management and farm effect of various biodiversity indicators of enchytraeids. Asterisks indicate significant effect (p < 0.05, ** p < 0.01, *** p < 0.001)*

Attribute	**Field Margin**		**Arable land**		**Management effect**	**Farm effect**	**Interaction effect**
	Mean	**SD**	**Mean**	**SD**			
Shannon index	1.81	0.30	1.33	0.37	***	***	*
Richness	8.13	1.63	5.00	1.63	***	**	n.s
Biomass	7.52	5.56	1.88	1.51	***	**	n.s
Density	22016.56	11028.3	8068.25	4729.63	***	n.s	n.s
Evenness	0.87	0.06	0.84	0.10	n.s	***	**

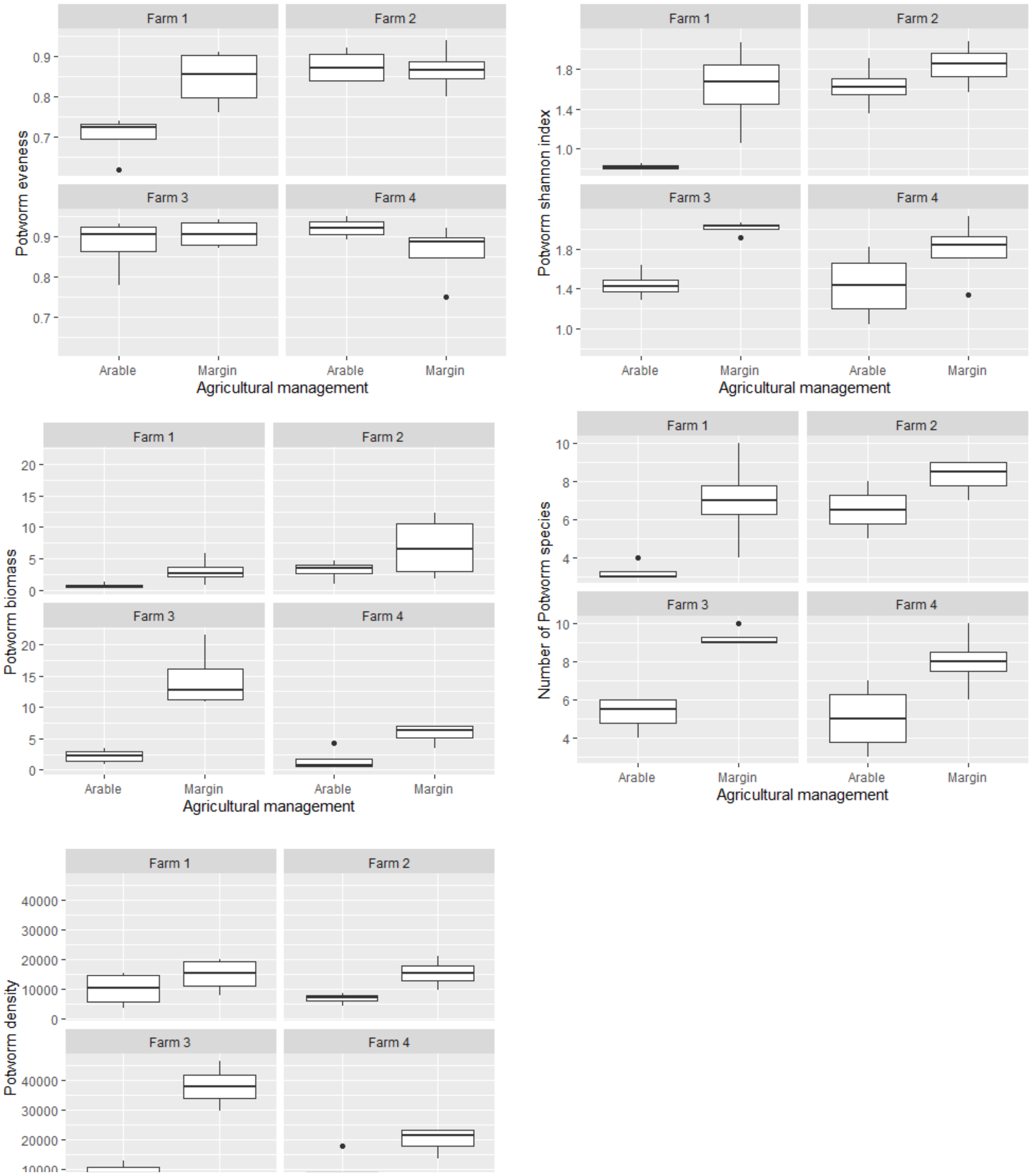

Figure S3: Boxplots of the Shannon index, richness, biomass, density and evenness of enchytraeids

8.1.4 Microarthropods

Table S4: Mean, SD, management and farm effect of various biodiversity indicators of microarthropods. Asterisks indicate significant effect (p < 0.05, ** p < 0.01, *** p < 0.001)*

	Field Margin		**Arable land**		**Management effect**	**Farm effect**	**Interaction effect**
Attribute	**Mean**	**SD**	**Mean**	**SD**			
Shannon index	2.27	0.30	1.83	0.37	**	n.s	n.s
Richness	15.69	4.57	12.06	4.02	**	**	n.s
Density	23396.31	10619.8	26850.06	37455.8	n.s	***	n.s
Evenness	0.84	0.06	0.76	0.20	n.s	*	n.s

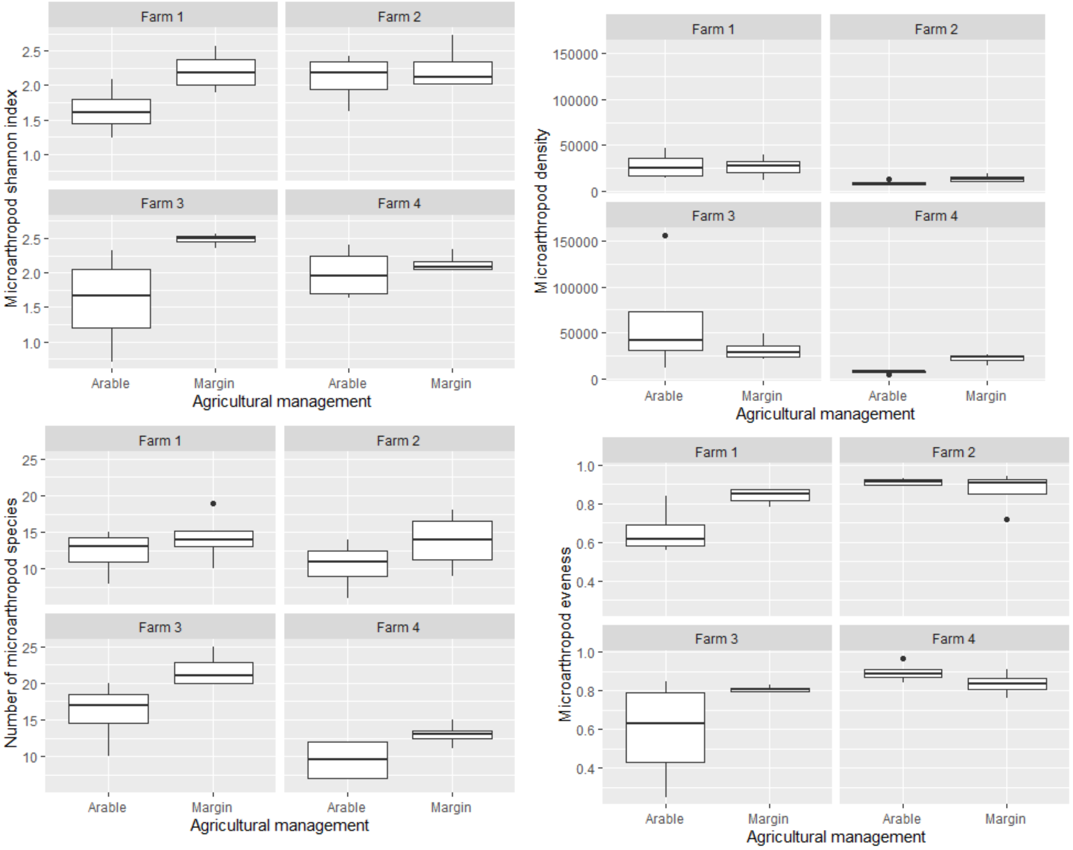

Figure S4: Boxplots of the Shannon index, richness, density and evenness of enchytraeids

8.1.5 Microbial Community

Table S5: Mean, SD, management and farm effect of various biodiversity indicators of microbial community. Asterisks indicate significant effect (p < 0.05, ** p < 0.01, *** p < 0.001)*

	Field Margin		**Arable land**				
Attribute	**Mean**	**SD**	**Mean**	**SD**	**Management effect**	**Farm effect**	**Interaction effect**
Fungal biomass	98.49	35.33	17.03	7.60	***	n.s	*
Bacterial biomass	133.35	29.02	76.07	21.10	***	n.s	n.s
Slope	0.52	0.05	0.48	0.52	n.s	n.s	n.s
50% conversion	2162.02	945.75	7247.95	3219.09	***	*	*

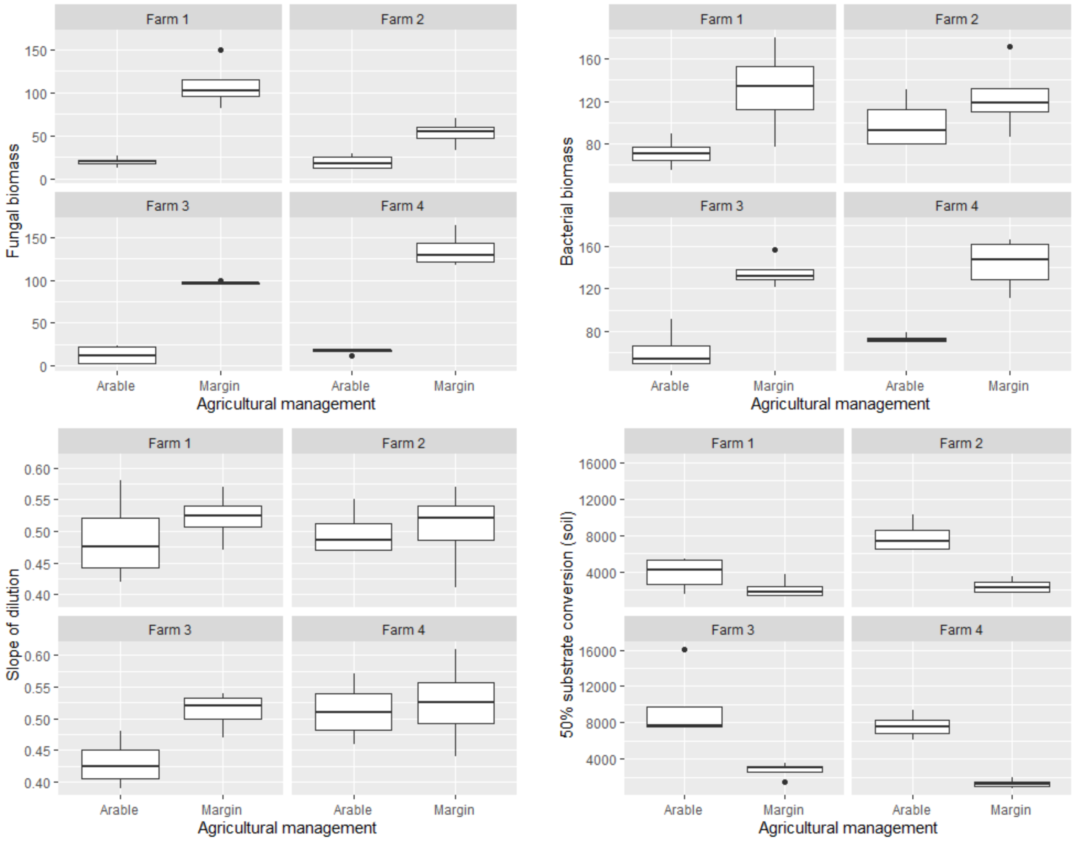

Figure S5: Boxplots of the fungal biomass, bacterial biomass, slope and 50% conversion of soil

8.2 Data Selection

Biodiversity

In Table S6 the data collected on attributes relating to biodiversity is summarized. Not all attributes were significantly different between groups, e.g. insects, earthworms. Attributes relating to birds could not be analyzed.

Table S6: Collected data for quantifying attributes relating to biodiversity. Asterisks indicate significant effect ($p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)*

Indicator	Weights	Field Margin		Arable land		Sign.	Reference
		Mean	**SD**	**Mean**	**SD**		
Aquatic invertebrates							
Shannon index	4.38×10^{-2}	2.93×10^{1}	2.10×10^{-1}	2.45	2.90×10^{-1}	Yes	(Schuurmans. 2021)
Abundance	6.32×10^{-2}	1.04×10^{3}	6.93×10^{2}	6.66×10^{2}	3.63×10^{2}	Yes	(Schuurmans. 2021)
Richness	8.23×10^{-2}	4.81×10^{1}	4.25	3.54×10^{1}	9.99	Yes	(Schuurmans. 2021)
Evenness	5.03×10^{-2}	7.59×10^{-1}	6.00×10^{-2}	7.01×10^{-1}	6.00×10^{-2}	Yes	(Schuurmans. 2021)
Birds							
Shannon index	4.35×10^{-2}	1.69	-	5.70×10^{-1}	-	No	(Fokker, 2020)
Abundance	3.69×10^{-2}	1.69×10^{2}	-	9.90×10^{1}	-	No	(Fokker, 2020)
Richness	6.50×10^{-2}	1.10×10^{1}	-	6.00	-	No	(Fokker, 2020)
Evenness	3.45×10^{-2}	7.05×10^{-1}	-	3.18×10^{-1}	-	No	(Fokker, 2020)
Insects							
Shannon index	6.39×10^{-2}	1.96	4.60×10^{-1}	1.40	7.40×10^{-1}	No	(van Rijn, 2018)
Abundance	7.33×10^{-2}	6.10×10^{1}	7.27×10^{1}	1.34×10^{1}	1.57×10^{1}	No	(van Rijn, 2018)
Richness	7.10×10^{-2}	1.27×10^{1}	4.72	6.31	4.31	No	(van Rijn, 2018)
Evenness	5.87×10^{-2}	7.99×10^{-1}	1.30×10^{-1}	7.58×10^{-1}	2.40×10^{-1}	No	(van Rijn, 2018)
Earthworm community							
Shannon index	7.07×10^{-3}	8.58×10^{-1}	3.50×10^{-1}	6.93×10^{-1}	4.10×10^{-1}	No	(Sechi et al., 2017) Raw data
Richness	8.15×10^{-3}	2.88	9.60×10^{-1}	2.63	1.09	No	(Sechi et al., 2017) Raw data
Biomass	1.09×10^{-2}	4.67×10^{1}	3.82×10^{1}	5.11×10^{1}	2.92×10^{1}	No	(Sechi et al., 2017) Raw data
Density	8.21×10^{-3}	2.95×10^{2}	2.09×10^{2}	3.50×10^{2}	1.75×10^{2}	No	(Sechi et al., 2017) Raw data
Evenness	5.03×10^{-3}	8.57×10^{-1}	1.10×10^{-1}	7.79×10^{-1}	1.70×10^{-1}	No	(Sechi et al., 2017) Raw data
Nematode community							
Shannon index	1.27×10^{-2}	2.52	2.70×10^{-1}	2.58	1.80×10^{-1}	No	(Sechi et al., 2017) Raw data
Richness	2.61×10^{-2}	2.61×10^{1}	4.29	2.50×10^{1}	3.06	Yes	(Sechi et al., 2017) Raw data
Density	1.58×10^{-2}	2.60×10^{3}	1.30×10^{3}	2.13×10^{3}	4.86×10^{2}	No	(Sechi et al., 2017) Raw data
Evenness	1.25×10^{-2}	7.76×10^{-1}	5.00×10^{-2}	8.04×10^{-1}	4.00×10^{-2}	Yes	(Sechi et al., 2017) Raw data
Enchytraeids community							

Indicator	Weights	Field Margin		Arable land		Sign.	Reference
		Mean	SD	Mean	SD		
Shannon index	9.90×10^{-3}	1.81	3.00×10^{-1}	1.33	3.70×10^{-1}	Yes	(Sechi et al., 2017) Raw data
Richness	1.52×10^{-2}	8.13	1.63	5.00	1.63	Yes	(Sechi et al., 2017) Raw data
Biomass	9.24×10^{-3}	7.52	5.56	1.51	1.88	Yes	(Sechi et al., 2017) Raw data
Density	1.11×10^{-2}	2.20×10^{4}	1.10×10^{4}	8.07×10^{3}	4.73×10^{3}	Yes	(Sechi et al., 2017) Raw data
Evenness	5.28×10^{-3}	8.69×10^{-1}	6.00×10^{-2}	8.44×10^{-1}	1.00×10^{-1}	Yes	(Sechi et al., 2017) Raw data
Microarthropods community							
Shannon index	1.19×10^{-2}	2.27	3.00×10^{-1}	0.48	1.83	Yes	(Sechi et al., 2017) Raw data
Richness	2.49×10^{-2}	1.57×10^{1}	4.57	1.21×10^{1}	4.02	Yes	(Sechi et al., 2017) Raw data
Density	2.34×10^{-2}	2.34×10^{4}	1.06×10^{4}	2.69×10^{4}	3.75×10^{4}	No	(Sechi et al., 2017) Raw data
Evenness	1.10×10^{-2}	8.37×10^{-1}	6.00×10^{-2}	7.63×10^{-1}	2.00×10^{-1}	No	(Sechi et al., 2017) Raw data
Microbial community							
Bacterial biomass (µg C/g dry soil)	1.59×10^{-2}	1.33×10^{2}	2.90×10^{1}	7.61×10^{1}	2.11×10^{1}	Yes	(Sechi et al., 2017) Raw data
Fungal biomass (µg C/g dry soil)	1.13×10^{-2}	9.85×10^{1}	3.53×10^{1}	1.70×10^{1}	7.60	Yes	(Sechi et al., 2017) Raw data
50% soil conversion (µggrond/50%omz.cap.)	2.53×10^{-2}	2.16×10^{3}	9.46×10^{2}	7.25×10^{3}	3.22×10^{3}	Yes	(Sechi et al., 2017) Raw data
Slope	3.27×10^{-2}	5.16×10^{-1}	5.00×10^{-2}	4.82×10^{-1}	5.20×10^{-1}	No	(Sechi et al., 2017) Raw data

Natural Attenuation

In **Fout! Verwijzingsbron niet gevonden.**S7 the data of collected indicators relating to NA is summarized. Most data, except the slope, is significantly different between the two groups. However, the coverage and richness of the plant community could not be analyzed.

Table S7: Data and information of collected indicators relating to NA.

Indicators	Weights	Field Margin		Arable land		Sign	Reference
		Mean	SD	Mean	SD		
Potential C mineralization (mg C/kg.wk)	1.15×10^{-1}	1.49×10^{2}	4.18×10^{1}	9.04×10^{1}	3.11×10^{1}	Yes	(Sechi et al.. 2017) supplementary
Potential N mineralization (mg N/kg.wk)	7.21×10^{-2}	8.71×10^{1}	2.04×10^{1}	4.13×10^{1}	1.22×10^{1}	Yes	(Sechi et al.. 2017) supplementary
SOM (%)	1.27×10^{-1}	5.41	8.20×10^{-1}	2.93	4.30×10^{-1}	Yes	(Sechi et al.. 2017)
pH	1.08×10^{-1}	7.31	1.10×10^{-1}	7.53	1.70×10^{-1}	Yes	(Sechi et al.. 2017)
Plants							
Coverage	4.61×10^{-2}	1.15×10^{2}	-	8.30×10^{1}	-	No	(Bojacá et al.. 2011; van Rijn. 2018)

Indicators	Weights	Field Margin		Arable land		Sign	Reference
		Mean	SD	Mean	SD		
Richness	4.21×10^{-2}	1.81×10^{1}	-	1.00	-	No	(van Rijn. 2018)
Aquatic invertebrates							
Shannon index	2.84×10^{-2}	2.93×10^{1}	2.10×10^{-1}	2.45	2.90×10^{-1}	Yes	(Schuurmans. 2021)
Abundance	2.61×10^{2}	1.04×10^{3}	6.93×10^{2}	6.66×10^{2}	3.63×10^{2}	Yes	(Schuurmans. 2021)
Richness	3.26×10^{-2}	4.81×10^{1}	4.25	3.54×10^{1}	9.99	Yes	(Schuurmans. 2021)
Evenness	2.01×10^{-2}	7.59×10^{-1}	6.00×10^{-2}	7.01×10^{-1}	6.00×10^{-2}	Yes	(Schuurmans. 2021)
Microbial biomass							
Bacterial biomass (µg C/g dry soil)	1.23×10^{-1}	1.33×10^{2}	2.90×10^{1}	7.61×10^{1}	2.11×10^{1}	Yes	(Sechi et al.. 2017) Raw data
Fungal biomass (µg C/g dry soil)	6.91×10^{-2}	9.85×10^{1}	3.53×10^{1}	1.70×10^{1}	7.60	Yes	(Sechi et al.. 2017) Raw data
Functional microbial activity							
50% soil conversion (µggrond/50%omz.cap.)	8.99×10^{-2}	2.16×10^{3}	9.46×10^{2}	7.25×10^{3}	3.22×10^{3}	Yes	(Sechi et al.. 2017) Raw data
Slope	1.02×10^{-1}	5.16×10^{-1}	5.50×10^{-2}	4.82×10^{-1}	5.00×10^{-2}	No	(Sechi et al.. 2017) Raw data

8.3 Deterministic Sensitivity Analysis

Table S8 and S9 show the DSA outcomes of BC and NAC. In these tables the deviation from the base case and the upper and lower bound of the BC and NAC is calculated.

Table S8: Determnistic sensitivity analysis outcomes of biodiversity capacity

BC			**Base case:**	**1.81**	
parameter	**outcome min**	**outcome max**	**difference -**	**difference +**	**difference**
AL: Aquatic invertebrates abundance	2.730580071	1.72912947	-2.73058	1.729129	1.001
AL: Insects Shannon index	2.482134139	1.730026841	-2.48213	1.730027	0.752
FM: Aquatic invertebrates abundance	1.167129745	1.908717351	-1.16713	1.908717	0.742
FM: Insects abundance	1.339372246	1.97755123	-1.33937	1.977551	0.638
AL: Microarthropods community density	2.298523627	1.765065907	-2.29852	1.765066	0.533
AL: Insects abundance	2.190284316	1.65923322	-2.19028	1.659233	0.531
AL: Insects richness	2.063607494	1.741963141	-2.06361	1.741963	0.322
AL: Slope	2.055060147	1.744433997	-2.05506	1.744434	0.311
AL: Enchytraeids community density	2.000662831	1.785657299	-2.00066	1.785657	0.215
AL: Aquatic invertebrates richness	1.934538518	1.74605081	-1.93454	1.746051	0.188
AL: Aquatic invertebrates evenness	1.827276654	1.646932593	-1.82728	1.646933	0.180

BC			**Base case:**	**1.81**	
parameter	**outcome min**	**outcome max**	**difference -**	**difference +**	**difference**
AL: Microarthropods community richness	1.926421909	1.762152788	-1.92642	1.762153	0.164
AL: Insects evenness	1.916474119	1.75985893	-1.91647	1.759859	0.157
AL: Microarthropods community Shannon index	1.926526057	1.789807599	-1.92653	1.789808	0.137
FM: Nematode community density	1.702136633	1.830	-1.70214	1.830058	0.128
FM: 50% substrate (soil) conversion	1.901755427	1.7823768	-1.90176	1.782377	0.119
FM: Microarthropods community density	1.719436831	1.837638163	-1.71944	1.837638	0.118
FM: Insects Shannon index	1.740534025	1.854789349	-1.74053	1.854789	0.114
AL: Microarthropods community evennes	1.898616519	1.789104527	-1.89862	1.789105	0.110
FM: Earthworm community density	1.727873072	1.823448742	-1.72787	1.823449	0.096
AL: Earthworm community biomass	1.889553364	1.795774223	-1.88955	1.795774	0.094
FM: Earthworm community biomass	1.736413079	1.829391831	-1.73641	1.829392	0.093
FM: Enchytraeids community density	1.73170217	1.824273599	-1.7317	1.824274	0.093
FM: Nematode community richness	1.733403446	1.823696495	-1.7334	1.823696	0.090
FM: Insects richness	1.800048315	1.882382934	-1.80005	1.882383	0.082
FM: Insects evenness	1.770113017	1.840132086	-1.77011	1.840132	0.070
AL: Earthworm community density	1.869050262	1.800350608	-1.86905	1.800351	0.069
AL: Earthworm community Shannon index	1.865545562	1.800634671	-1.86555	1.800635	0.065
FM: Microarthropods community richness	1.77267495	1.830972427	-1.77267	1.830972	0.058
AL: fungal biomass	1.853645164	1.797602931	-1.85365	1.797603	0.056
AL: Enchytraeids community evennes	1.840950371	1.78673869	-1.84095	1.786739	0.054
FM: Aquatic invertebrates richness	1.782343243	1.834433482	-1.78234	1.834433	0.052
FM: Enchytraeids community biomass	1.777014996	1.825513977	-1.77701	1.825514	0.048
AL: 50% substrate (soil) conversion	1.793393881	1.839333117	-1.79339	1.839333	0.046
AL: bacterial biomass	1.833166536	1.790784618	-1.83317	1.790785	0.042
AL: Enchytraeids community richness	1.838740697	1.796916645	-1.83874	1.796917	0.042
AL: Aquatic invertebrates Shannon index	1.831517501	1.794005176	-1.83152	1.794005	0.038
FM: fungal biomass	1.785687554	1.82144419	-1.78569	1.821444	0.036

BC			**Base case:**	**1.81**	
parameter	**outcome min**	**outcome max**	**difference -**	**difference +**	**difference**
AL: Earthworm community richness	1.835454032	1.801703141	-1.83545	1.801703	0.034
FM: Enchytraeids community evennes	1.793913701	1.825047303	-1.79391	1.825047	0.031
AL: Nematode community density	1.828514188	1.799971033	-1.82851	1.799971	0.029
FM: Aquatic invertebrates evenness	1.795	1.823647114	-1.79519	1.823647	0.028
FM: Earthworm community Shannon index	1.790	1.818006719	-1.79002	1.818007	0.028
FM: bacterial biomass	1.79455197	1.820713051	-1.79455	1.820713	0.026
AL: Nematode community richness	1.824561408	1.800342545	-1.82456	1.800343	0.024
FM: Earthworm community richness	1.794854226	1.817915798	-1.79485	1.817916	0.023
FM: Enchytraeids community richness	1.797	1.819624001	-1.79677	1.819624	0.023
FM: Slope	1.798049647	1.820789483	-1.79805	1.820789	0.023
AL: Enchytraeids community Shannon index	1.824679929	1.802677738	-1.82468	1.802678	0.022
AL: Enchytraeids community biomass	1.82215307	1.803682499	-1.82215	1.803682	0.018
FM: Enchytraeids community Shannon index	1.803445646	1.815517389	-1.80345	1.815517	0.012
FM: Microarthropods community Shannon index	1.803995139	1.815458232	-1.804	1.815458	0.011
FM: Nematode community Shannon index	1.805061892	1.814856488	-1.80506	1.814856	0.010
AL: Earthworm community evennes	1.815562766	1.807229145	-1.81556	1.807229	0.008
AL: Nematode community Shannon index	1.813852064	1.807526515	-1.81385	1.807527	0.006
FM: Nematode community evennes	1.807	1.813161758	-1.80742	1.813162	0.006
FM: Microarthropods community evennes	1.807465773	1.813082478	-1.80747	1.813082	0.006
AL: Nematode community evennes	1.813874771	1.808366999	-1.81387	1.808367	0.006
FM: Earthworm community evennes	1.807832141	1.812515014	-1.80783	1.812515	0.005
FM: Aquatic invertebrates Shannon index	1.809	1.811575091	-1.809	1.811575	0.002

Table S9: Deterministic sensitivity analysis outcomes of natural attenuation capacity

NAC			**Base case:**	**2.059**	
parameter	**outcome min**	**outcome max**	**difference -**	**difference +**	**difference**
FM: Potential C mineralization	1.931	2.535763376	0.128	0.476763376	0.604
FM: Soil organic matter	1.969198881	2.492201079	0.089801119	0.433201079	0.523
FM: Potential N mineralization	1.970006151	2.477902881	0.088993849	0.418902881	0.508
FM: 50% substrate (soil) conversion	2.453061562	1.947812293	-0.394061562	-0.111187707	0.505
AL: 50% substrate (soil) conversion	1.706490307	2.178438811	0.352509693	0.119438811	0.472
AL: Aquatic invertebrates abundance	2.439423922	2.020588742	-0.380423922	-0.038411258	0.419
AL: Fungal biomass	2.376912202	1.971756752	-0.317912202	-0.087243248	0.405
FM: pH	2.05262823	2.418865094	0.00637177	0.359865094	0.366
FM: Aquatic invertebrates Shannon index	2.058	2.412270347	0.000579084	0.353270347	0.354
AL: Potential C mineralization	2.342233493	1.995354868	-0.283233493	-0.063645132	0.347
FM: Aquatic invertebrates abundance	1.718291406	2.0650952	0.340708594	0.0060952	0.347
AL: Bacterial biomass	2.267424814	1.952373266	-0.208424814	-0.106626734	0.315
FM: Fungal biomass	1.893527713	2.136411881	0.165472287	0.077411881	0.243
FM: Bacterial biomass	1.923366217	2.15104157	0.135633783	0.09204157	0.228
AL: Potential N mineralization	2.191788519	1.992529564	-0.132788519	-0.066470436	0.199
AL: Soil organic matter	2.149777494	1.994	-0.090777494	-0.064740493	0.156
FM: Slope (metabolic functional diversity)	2.002350621	2.099300611	0.056649379	0.040300611	0.097
AL: Slope (metabolic functional diversity)	2.10736132	2.012360938	-0.04836132	-0.046639062	0.095
AL: Aquatic invertebrates richness	2.114	2.047755571	-0.054960788	-0.011244429	0.066
AL: Aquatic invertebrates Shannon index	2.074768169	2.047064067	-0.015768169	-0.011935933	0.028
FM: Aquatic invertebrates richness	2.046532366	2.021379962	0.012467634	-0.037620038	0.025
AL: Aquatic invertebrates evenness	2.066857344	2.044183928	-0.007857344	-0.014816072	0.023
FM: Aquatic invertebrates evenness	2.043635675	2.065217746	0.015364325	0.006217746	0.022
AL: pH	2.062361837	2.049680447	-0.003361837	-0.009319553	0.013