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Biodiversity and ecosystem services:

does species diversity enhance effectiveness and reliability?

WOt-technical report 25

C.C. Vos, C.J. Grashof-Bokdam & P.F.M. Opdam

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For quality of life

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Biodiversity and ecosystem services: does species diversity enhance effectiveness and reliability?

A systematic literature review

C.C. Vos, C.J. Grashof-Bokdam en P.F.M. Opdam

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Abstract
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In this report recent scientific literature was analysed, focussing on systematic review papers to clarify the relationship between species diversity and the effectiveness and reliability of seven ecosystem services. For those services where a relation with species diversity was found, the importance of the Dutch National Nature Network (NNN) and the network of small natural elements (green infrastructure, GI) in the landscape was assessed. Results indicate that species diversity is important for ecosystem service effectiveness. However, reliability is not well studied. NNN and GI are important for ecosystem service effectiveness, but it is not yet possible to derive concrete guidelines on the required amount and spatial configuration of NNN and GI for optimal ecosystem service provisioning. Several suggestions have been made to acquire knowledge on ecosystem services that is needed to improve the implementation of ecosystem services in local landscape planning.

Key words: wild food, carbon sequestration, water purification, soil fertility, natural pest regulation, pollination, well-being, aesthetic appreciation.

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Preface

In policy there is growing attention for the relation between nature and economy. How can we make a wiser and better use of our natural resources, e.g. via resource efficiency or ecosystem services? The European Union put it already on the agenda for the biodiversity targets 2020. The Dutch government launched their 'Nature vison' in 2014, promoting not only a strong fundament for nature, by creating a robust network of nature reserves, but also a better use of ecosystem services; this should promote a better connection of citizens and business with nature.

In the public debate it is the mission of the Netherlands Environmental Assessment Agency (PBL) to present not only facts and figures but also new ideas and policy options. So PBL has presented four typical (extreme) perspectives on nature: vital, experiential, functional and tailored nature[1]. The ideas on functional nature, making optimal use of ecosystem services, are under further consideration in the present TEEB-NL study[2].

There is still a lot of criticism e.g. on the scientific concepts of this functional perspective. For example, there is the important premise that a higher biodiversity would result in a better fulfilment of ecosystem services. That is at least contra-intuitive for the ecosystem service 'production of food' in the case of conventional farming, but may be appreciated differently in sustainable farming. Therefore PBL asked Wageningen UR to review this specific premise using the recent scientific literature. The authors have succeeded in this task by defining clear hypotheses and discussing them in a well-structured and readable manner. I don't doubt this report will be of much use in further discussions induced by the presently ongoing TEEB-NL and Nature Outlook 2015-2050[3].

Jaap Wiertz
PBL Netherlands Environmental Assessment Agency

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1 http://themasites.pbl.nl/natureoutlook/2012/
2 http://themasites.pbl.nl/natuurlijk-kapitaal-nederland/
3 http://themasites.pbl.nl/natureoutlook/2016/

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Summary

The role of nature in society is changing. From areas that need to be protected from human activities to a position of nature in the centre of society, where ecosystems provide services for society representing the utility factor of nature: our natural capital. In parallel with this trend to bring nature closer to people there is also the Natura 2000 network, where the Habitat - and Bird Directive are focussed on the protection of biodiversity, regardless of the potential benefits for humans.

Much debate has been going on whether species richness is an important factor for the provisioning of ecosystem services or that a basic level of functioning of ecosystems is sufficient. If the effectiveness of ecosystem services to some extent depends on biodiversity, which in its turn is supported by the National Nature Network (and the Natura 2000 areas within), this would bring the nature oriented and the human oriented approaches closer together.

In this report recent scientific literature was analysed, focussing on systematic review papers to:

- Clarify the relationship between species diversity and the effectiveness and reliability of ecosystem services provisioning;

And for those services where a relation with species diversity is found:

- To what extent is this service dependent on the National Nature Network and the network of small natural elements (green infrastructure) in the landscape?

Review papers show that there is a considerable amount of information available on the role of species diversity and ecosystem service provisioning, illustrating a growing research effort in the last decade. The majority of studies on biodiversity and ecosystem services focus on regulating services, while little information is available on Well-being and Aesthetic Appreciation. Also Wild Food as a production ecosystem service is hardly studied in temperate climate zones and results can therefore not be extrapolated to the European situation.

Especially from the recent systematic reviews and meta-analyses there is evidence that in the large majority of studies high biodiversity does increase the effectiveness of the ecosystem service studied. A predominately positive relationship was found for the following ecosystem services: Carbon Sequestration, Water Purification, Soil Fertility, Natural Pest Regulation and Pollination. For the service Wild Food insufficient information was available to draw any conclusions for the European situation. For the service Well-being and Aesthetic Appreciation there are indications that species diversity has a positive impact.

There is insufficient knowledge to draw conclusions on the exact relationship between effectiveness of ecosystem services and biodiversity but a saturating relation is most likely, where effectiveness increases with increasing biodiversity levels until a saturation point is reached, where additional species no longer leads to an increase in service level.

The main focus in the reviewed literature lies on the role of species diversity for the effectiveness of ecosystem services. The role of biodiversity for reliability of ecosystem services is much less studied and therefore no general conclusion can be made. There are however some exceptions. For Carbon Sequestration and Soil Fertility, some studies concluded that biodiversity is important for delivering services over longer time scales, while for Water Purification and Pollination there is evidence that high biodiversity ensures delivery of services during environmental disturbances.

Based on the literature review it can be concluded that the national nature network and the green infrastructure network are both important backbones for the providing of ecosystem services. However, it is not yet possible to derive concrete guidelines for the amount and spatial configuration

of nature areas needed for the optimal provisioning of different services. Our literature review shows, that the quantification of the importance of nature areas for the provisioning of services has rarely been a direct object of study. Studies on the services Natural Pest Regulation and Pollination come closest. Effects of green infrastructure on these services have been found on short distances, often within one kilometre of the crops studied, declining with distance. There is also some evidence that the level of functioning of green infrastructure for Pollination and Natural Pest Regulation is supported by the national nature network like woods and species-rich grasslands.

Several knowledge gaps were identified that need to be filled in order to improve the implementation of ecosystem services:

- There is a need to quantify the importance of species diversity on the reliability of service provisioning in time. Especially because a trade-off could exist between effectiveness and reliability, in those cases where some key-species might be highly efficient in a service under controlled conditions, but do not perform well when disturbances occur.

- There is a need for the further quantification of the optimal size and configuration of nature areas and green infrastructure density in relation to the locations where ecosystem services are required. As insufficient information is available in literature on the direct relationships between the configuration of nature areas and the effectiveness and reliability of ecosystem services, we propose to derive the spatial requirements in an indirect way, based on the requirements of the species that provide the services.

The contribution of ecosystem services to collaborative landscape planning is hardly studied. Although the potential of this approach seems considerable, as the concept of ecosystem services stimulates coalition building and collective action. Therefore there is a need to translate existing knowledge on the relation between desired ecosystem services, species diversity and spatial structure of nature areas and green infrastructure so that it better fulfils the information needs and requirements of groups of local actors and decision-makers.

PART 1 Main findings and conclusions

1 Introduction

The attitude towards nature in society is changing. From areas that need to be protected from human activities to a position of nature in the centre of society, where ecosystems provide services for society representing the utility factor of nature: our natural capital. Examples of this changing position of nature in society are for instance the recent Governmental report on nature and society: 'A natural way forward' (Ministry of Economic Affairs, 2014) and 'The role of nature for sustainability' (Opdam *et al.* 2014). In parallel with this trend to bring nature closer to people there is also the Natura 2000 network, where the Habitat - and Bird Directive are focussed on the protection of biodiversity, regardless of the potential benefits for humans. The question in this report is whether these two approaches, which seem to exist in isolation, could become more integrated, by showing the mutual interdependence between the intrinsic value of nature represented in the Natura 2000 network and the 'utility nature' of the ecosystem services (Daily 1997, Costanza *et al.* 1997, Schröter *et al.* 2014).

Since the successful framing of nature as the provider of diverse services for society (MEA 2005), much debate has been going on about the role of biodiversity in this service provisioning. Is species richness an important factor for the provisioning of ecosystem services or is a basic functioning of ecosystems sufficient? In other words is the level of the provided service, the effectiveness, influenced by a higher biodiversity level. Or is perhaps the reliability of the service enhanced by a higher biodiversity level, resulting in a service that is less vulnerable for disturbances in time and place? As was pointed out in Opdam *et al.* (2014) recent literature reviews show that for some services there is growing evidence for a positive relationship between species diversity and ecosystem service provisioning. A next question is than if there is also a relationship between the Dutch National Nature Network (and the Natura 2000 network within), as the backbone for high biodiversity levels, and the provisioning of ecosystem services? If this would be the case the effectiveness or reliability of a service would improve with the size and distance from the National Nature Network in the surrounding landscape. If the effectiveness of ecosystem services to some extent depends on biodiversity, which in its turn is supported by the National Nature Network (and the Natura 2000 areas within), this would bring the nature oriented and the human oriented approaches closer together. In this report recent scientific literature was analysed, focussing on systematic review papers to:

- Clarify the relationship between species diversity and the effectiveness and reliability of ecosystem services (ES) provisioning;

And for those services where a relation with species diversity is found:

- To what extent is this service dependent on the National Nature Network (NNN) and the network of small natural elements (green infrastructure, GI) in the landscape?

Report structure
In Chapter 2 we will present the conceptual framework applied in this study, define some terms and clarify the chosen ES selection.

In Chapter 3 the main findings on the role of biodiversity for ecosystem services (ES) is presented and the role of the NNN for the provisioning of these services.

In Chapter 4 the results are put in a societal context and main knowledge gaps are presented.

In Chapter 5 for each ecosystem service the systematic results of the literature review are presented.

Quantifying the economic benefits/importance of ES compared to for instance technical solutions lies outside the focus of this report. For this aspect we refer to De Knegt (2014), where the contribution of ecosystem services compared to technical services is quantified.

Neither will we assess the monetary value of ES, for this aspect we refer to the international and national TEEB studies (TEEB 2010; Hein 2010). As the costs of ES compared to technical solutions are an important discussion in society, we will discuss this aspect broadening this discussion from the monetary focus into multiple benefits of ecosystems and natural elements and the ES they provide for society.

2 Conceptual framework and selection of ecosystem services

2.1 Conceptual framework

We developed a conceptual framework which formed the basis for our analysis on the potential role of biodiversity for ecosystem service provisioning and the potential relationship between the service provisioning and the NNN. In Figure 1 it is illustrated how a high level of biodiversity has an impact on ecosystem service provisioning by improving both the effectiveness as well as the reliability of services. In turn, a high level of biodiversity depends on the natural ecosystems: the large and protected nature areas that form the NNN and the small scaled natural elements in the GI in the multifunctional landscape.

2.1.1 Effectiveness and reliability of ecosystem services

Although Ecosystem Services (ES) are defined by the benefits they provide to humans, we will not use benefits or values to describe the performance of ES, because these indicators only get meaning if specified for user and place. Instead, we describe the performance by effectiveness and reliability, assuming that in general these indicators are related to benefits and values. The effectiveness of an ES refers to the level of the performance: the higher the effectiveness of a service the higher the amount of the provided service per unit. Examples of effectiveness are for instance the fraction of pollinated flowers in crops (effectiveness of Pollination), or the amount of reduction of nitrogen in ground or surface water (effectiveness of Water Purification). Reliability of an ES refers to a constant and predictable level of the provided service in time, in different places or during environmental disturbances. If humans value the benefits of a service, it is in their interest that no large fluctuations occur in service provisioning, therefore a high sensitivity to disturbances need to be avoided. For instance, pollination of crops should be buffered against variation in spring weather conditions affecting the density of pollinator species.

In literature also the term efficiency is used to describe this high performance level, for instance the efficiency by which ecological communities perform services (Cardinale *et al.* 2012). However, we decided not to use this term as there is some confusion with economic efficiency, where efficiency refers to monetary costs of a service for instance compared to technical measures (Hein 2010).

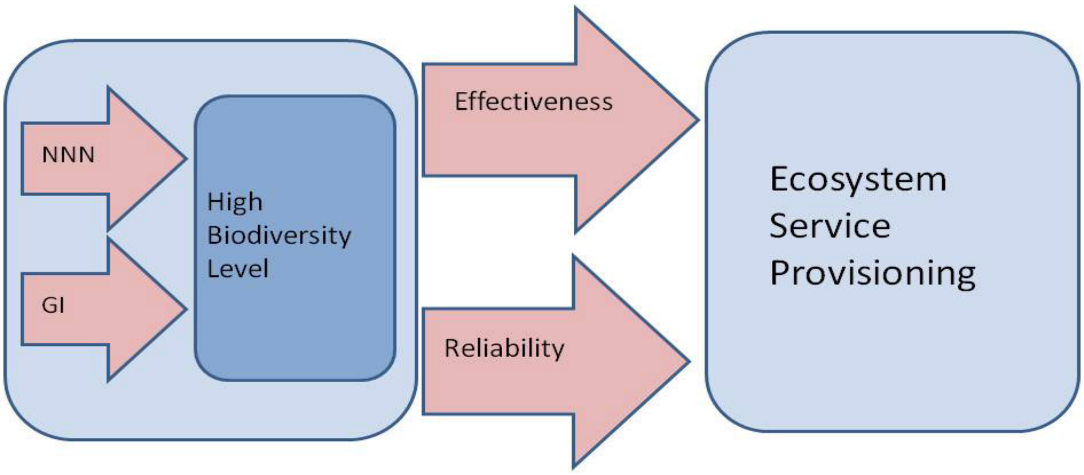


Figure 1*: The effectiveness and reliability of ES provisioning increases with a high level of biodiversity, which in its turn depends on the natural system: the large and protected areas of the National Nature Network (NNN) and the Green Infrastructure (GI), the network of small scaled natural elements in the multifunctional landscape.*

Effectiveness

Figure 2 gives a few examples of the hypothetical relationship between biodiversity level and ES effectiveness. In Figure 2a the ES effectiveness increases in a linear fashion with higher species richness. In Figure 2b ES effectiveness increases with species richness, until a maximum saturation level is reached, above which additional species do not increase effectiveness (Cardinale *et al.* 2012). Saturating curves can either be logistic (S-curve as shown) or logarithmic. Figures 2c and 2d are examples where high species diversity does not increase ES effectiveness. In Figure 2c there is a positive effect of increasing species diversity until optimal species richness is reached, and additional species diversity decreases the effectiveness. This effect could be possible, when additional species that are not effective for a service interact with effective species (e.g. in competition, predation), which as a consequence reduce in abundance. Finally, in Figure 2d the effectiveness of the ES is highest with low species diversity, assuming some highly efficient species exist in performing the service, while with higher species diversity the effectiveness stables on a lower level.

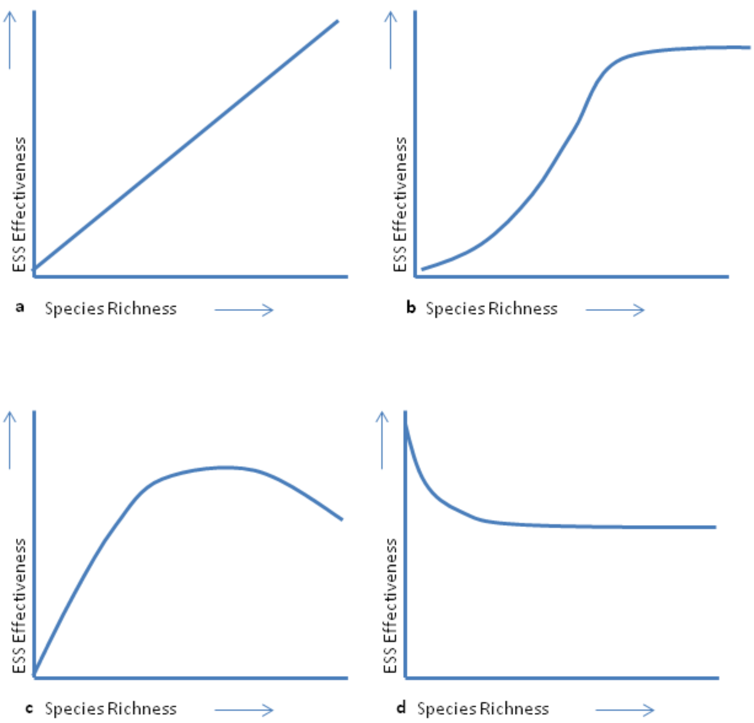


Figure 2: *Several hypothetical relationships between ecosystem service (ES) effectiveness and species richness.*

Reliability

The reliability of ecosystem service provisioning in time and space is another important factor when considering the value of ES for society. If agriculture depends on certain ecosystem services for instance Pollination or Natural Pest Regulation, then it is important that these services function on a constant level. It becomes problematic when services are very sensitive to disturbances, with large fluctuations in performance (Figure 3).

Following the principles of resilience science, a high species richness or functional diversity is important for ecosystem functioning (Gunderson 2000, Elmqvist *et al.* 2003). Ecosystem resilience is the ability of an ecosystem, subject to disturbance and change, to reorganize and renew itself and keep functioning (Carpenter *et al.* 2001). A high species diversity contributes to the ecological resilience of an ecosystem as it contributes to functional diversity, multiple species performing similar functions in the system (functional traits), and to the response diversity, species that differ in their sensitivity to disturbances. In these species rich systems disturbances have a smaller impact on ecosystem functioning, because of the redundancy factor, or insurance factor (Yachi and Loreau 1999, Isbell *et al.* 2011). An example how species diversity contributes to the reliability of an ecosystem subject to environmental disturbances is a study on soil fertility in a river flood plain (De Lange *et al.* 2013). Individual species in the earthworm community, a species group that is important for soil fertility, differ in their tolerance for inundation. Along an inundation gradient, species with a high tolerance for inundation were more often found in the lower elevations of the floodplain, compared to higher elevations. The diverse sensitivity within the earth worm species community is expected to ensure ecosystem functioning under diverse environmental conditions.

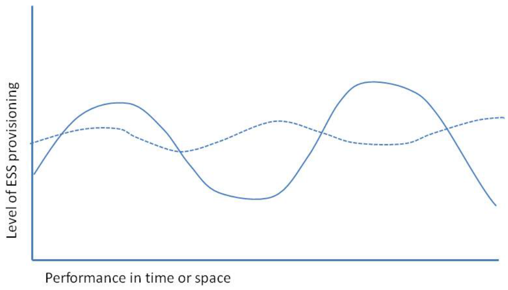


Figure 3: *The solid line illustrates an ecosystem service that is sensitive to disturbances, resulting in large fluctuations in the level of ES provisioning in time or space. The dotted line illustrates an ecosystem service with high reliability, where the level of performance is more constant in time or space.*

The aspect of reliability becomes more important with climate change, as one of the impacts of climate change is that the weather becomes more variable, with larger and more frequent weather extremes, like heavy rain or dry an hot periods (KNMI 2014).

We hypothesize that the relation between reliability of ES performance and species richness will increase with higher levels of species richness, either in a continuous linear fashion, comparable with Figure 2a or towards a saturation level (Figure 2b).

Looking at the different hypotheses for effectiveness and reliability, there is both synergy as well as a trade-off possible between ES reliability and ES effectiveness. In a synergy situation both ES reliability and ES effectiveness increase with growing species richness (see for instance Figures 2a and 2b). While in situation 2c and 2d higher levels of biodiversity will not be positive for effectiveness but do increase reliability. In that case a trade-off could exist between optimal effectiveness and optimal reliability of ES.

In the review we will focus on both effectiveness and reliability and explore whether a relationship exists between ES provisioning and biodiversity and if that is the case which of the above hypotheses might hold for the different ES studied.

Biodiversity

In literature many biodiversity terms are used to describe the relationship between ES performance and biodiversity (see Harrison *et al.* 2014 for an overview). As the focus in this report is on the additional benefits of high levels of biodiversity on ES performance we restricted the study to specific terms (Table 1).

Table 1

The biodiversity terms used to describe high biodiversity levels.

Biodiversity terms

- Species level
  - Species diversity
  - Species richness
  - Species abundance
- Functional group level
  - Functional diversity
  - Trait diversity

One broad and widely used definition of biodiversity is that adopted by the Parties to the Convention on Biological Biodiversity (CBD): ‘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 included diversity within species, between species and of ecosystems’. We restrict our review to biodiversity between species. The aspect of diversity of ecosystems is also tackled in the analysis of the relationship between nature areas and ecosystem service provisioning (see Section 2.1.2). The diversity within species, which is also an important aspect of diversity, is too detailed for the purpose of this study.

2.1.2 Relationship between nature areas and ecosystem service provisioning

According to our conceptual framework (Figure 1) the effectiveness and reliability of ecosystem service provisioning will increase with a high level of biodiversity, which in its turn depends on the natural system. Based on this conceptual framework, we hypothesise that the spatial cohesion (Opdam *et al.* 2003) of the NNN and the small scaled GI network will contribute to the effectiveness and reliability of ES provisioning. The reason for this is that the species that deliver the services depend for their survival on habitat networks of suitable habitat. As individual populations always have a probability to go extinct (Verboom *et al.* 2001), species need a network of suitable habitat, so that habitats can be recolonized from the surrounding habitats. The survival of metapopulations increase with larger nature areas and well connected habitat patches. In addition the network of GI is expected to be important for some services as it provides a small scaled network of suitable habitat for species that deliver their services at close ranges only. An example is natural elements along agricultural fields that are habitat for pollinators or predators of pest species. Again, the effectiveness of this small scaled network will depend on the density of the GI network and on the coherence with the larger nature areas of the NNN to ensure recolonization after local disturbances (Figure 4).

***Figure 4: Left**: The National Nature Network (NNN) provides spatial cohesion on a regional level, which is important for the long-term survival of species. In the habitat network of the NNN patches that have become extinct can be recolonized from the surrounding habitats. **Right**: Green Infrastructure (GI) provides a small scaled habitat network for species that deliver their services at close range.*

The relationship between the level of service provisioning and nature characteristics can be studied directly (Figure 5, arrow 3). Examples of direct relationships between nature areas characteristics and the provisioning of a particular service are for instance that the effectiveness of a service increases near nature areas or with the size of nature areas, or with the presence of particular habitat types. Studies on this direct relationship between nature characteristics and ES are still rare. In that case we depend on the well-studied relationship between biodiversity and nature characteristics (arrow 1). In the field of nature conservation it is well established that nature characteristics such as habitat area and connectivity and abiotic conditions – including gradients and nature management - are important prerequisites for biodiversity (e.g. Hanski and Gagiotti 2004, Turner *et al.* 2013, Kool *et al.* 2014). The question that remains to be answered then is: what are the specific nature requirement for the species (groups) that provide a particular service.

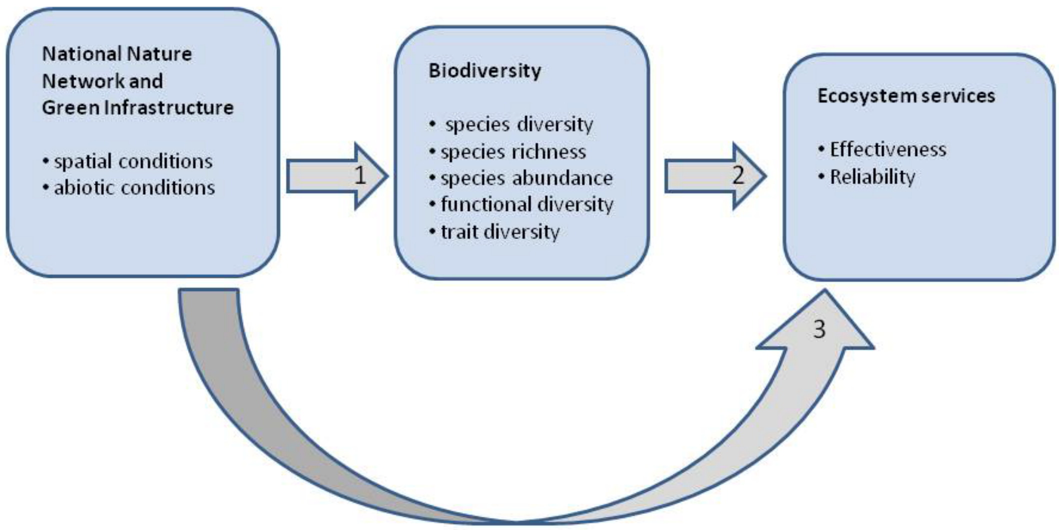


Figure 5: *Examples of different research approaches. Research on the dependence of ecosystem services on biodiversity is the first focus of this review (arrow 2). Studies that directly focus on the importance of nature characteristics for ecosystem services provisioning are rare (arrow 3). A large body of literature exists on the importance of nature characteristics for species diversity (arrow 1).*

We restricted our review on the importance of nature characteristics to those services where a relationship was found between ES performance (effectiveness or reliability) and high biodiversity levels (species richness, species abundance, etc. (arrow 2). For those services we selected studies that are specific on the required characteristics of ecosystems for ES performance (arrow 3). If no direct information was available, we incorporated some general insights, based on the habitat needs of the species (groups) that provide the service (arrow 1). An extensive analysis on this last aspect is outside the scope of this report.

For the management of ES it is relevant to know whether the ES performance depends on the NNN or small scaled natural elements of GI, or both. Therefore we classified the nature terms that came forward, to terms that can be attributed to the NNN and terms that describe GI, the small scaled network of natural elements that form part of multifunctional landscapes (Table 2).

Table 2
Nature terms used in this report can be categorized as being part of the protected National Nature Network (NNN) or part of small scaled natural elements: Green Infrastructure (GI).

National Nature Network:

- Size of nature area
- Distance to nature area
- Habitat type
- Habitat structure

Green Infrastructure:

- Density of GI
- Area of GI
- Distance to GI
- Type of GI (e.g. hedgerows, flower strips, ditches and streams)

2.2 Selection of ecosystem services and review methodology

Selection of ecosystem services
Based on the TEEB ES categories (TEEB 2010) seven services were selected for which biodiversity is likely to play a role in delivering ES (Table 3). The used definitions of TEEB ecosystem services and that of the Millennium Ecosystem Assessment (MEA) differ slightly from those of the CICES classification (Maes *et al.* 2013). The selected services cover regulating, production as well as cultural services. This selection was based on consultation of Alterra experts and Dutch research reports (e.g. Melman & Van Der Heide 2011, Henkens & Geertsema 2013) and several reviews (e.g. Cardinale *et al.* 2012, Mace *et al.* 2012, Isbell *et al.* 2011, and Balvanera *et al.* 2006) as well as a Belgian report on ecosystem services (Meiresonne & Turkelboom 2012). As we focus on the role of natural biodiversity, we focused only on Wild Food, while TEEB, MEA and CICES do not distinguish Wild Food. Water Purification is also referred to as Waste Treatment in TEEB and as Mediation in CICES. Soil Fertility is also called Soil Formation by MEA and CICES. MEA makes a difference between Pest and Disease Regulation while TEEB and CICES define this as one service. We also included Disease Regulation in our definition but most available literature deals with Natural Pest Regulation. We use the term Natural Pest Regulation to distinguish the service from chemical pest regulation. Pollination is referred to as Lifecycle Maintenance by CICES. MA and TEEB use Aesthetic Values as ES, while this is a part of intellectual and representational interactions in the CICES classification. Physical or Mental Well-being is not recognized in existing classifications. Spiritual Values may come close to Mental Well-being.

Selection of most relevant scientific literature
Our aim was to collect the most relevant reviews or meta-analyses for each selected ES. We carried out a keyword driven literature search using Google Scholar and SCOPUS. We wanted to focus on the most relevant and recent literature overviews, instead of carrying out a complete literature analysis. When key word searches delivered large numbers of (irrelevant) results, the search was limited to keywords in the title. Table 3 gives an overview of the used search terms. To focus on the most recent findings, only recent papers were selected: preferably from 2010-2014. During our study the highly relevant review of Harrison *et al.* (2014) was published and added to our study. Besides scientific literature we used publications that were recommended by experts and recent Dutch reports as mentioned above.

We focused on biodiversity attributes reflecting diversity of different natural species (species number, richness, diversity, abundance). We excluded literature focusing on within species diversity or genetic diversity. We also excluded literature studying diversity of agricultural species (crop, cattle). We preferably included literature that is based on areas inside the temperate climate zones and focus on studies that are relevant for the European or Dutch situation.

We also focused on literature containing relevant information on the role of GI and NNN. For this information all types of linear and fine scale habitat was seen as relevant for GI and information on all types of larger natural areas as relevant for NNN. Also we used earlier collected scientific papers on the role of GI on ecosystem services, which was especially available for Natural Pest Regulation and Pollination.

From the (most) relevant studies found, the following information was collected:

- Description of the ecosystem service: what benefits does the service deliver for society, where is it delivered and by what biodiversity is it delivered? How does the relation between biodiversity and service work?
- Main conclusions on the ecosystem service.
- Relevance of selected literature for NL/EU situation: are the conclusions drawn in the studies applicable to the situation in Europe and in the Netherlands?
- Attributes of biodiversity and ecosystem effectiveness/reliability: how is biodiversity, ES effectiveness and/or ES reliability measured in the studies?

- Impact of biodiversity on ES provisioning: do the studies mention impacts of biodiversity and if yes, are the found effects of biodiversity mainly positive or negative or are the effects mixed or unclear? Are effects mostly found on effectiveness or on reliability of the ES?
- Relevance of NNN and GI: is area, structure, connectivity or heterogeneity / quality of GI or of NNN relevant for the delivery of the ecosystem service?

For each ecosystem service, a table was constructed with information of each study on:
- the study: authors, year of publication, type and place of study;
- the found impact of biodiversity (positive, negative, unclear or mixed);
- For ES studied by Harrison *et al.* (2014) the number of biodiversity attributes having a positive, negative or unclear effect was presented;
- the used biodiversity attributes;
- the used effectiveness attributes;
- the used reliability attributes;
- the impact found for GI and NNN.

For each ecosystem service, we added one or two boxes with examples illustrating the effect of biodiversity, GI or NNN on the effectiveness or reliability of ES provisioning.

Table 3
Selected ecosystem services and search terms that were used in Google Scholar and SCOPUS.

Ecosystem Services	Search Terms
Regulating Services	
1. Carbon Sequestration	Diversity/Biodiversity in combination with one or more of the following terms: carbon sequestration, C-sequestration, CO_2 and storage, CO_2 and sequestration, carbon storage, C-storage.
2. Water Purification	Diversity/Biodiversity in combination with one of the following terms: freshwater, de-contamination, nutrient, purification, quality
3. Soil Fertility	Diversity/Biodiversity in combination with one of the following terms: soil, organic matter, fertility, decomposition, nutrient cycling, nutrient retention
4. Natural Pest Regulation	Diversity/Biodiversity in combination with one of the following terms: bio control, biological control, agriculture, agricultural, crop, pest, prey, insects, herbivore, disease, pathogen, infect, illness, epidemic
5. Pollination	diversity/biodiversity in combination with one of the following terms: pollination, flower visit, fruit set
Production Services	
6. Wild Food	Diversity/Biodiversity in combination with one of the following terms: wild crop, wild products, medicine/drug, non-timber products, wild food / edible plants, game, natural products.
Cultural Services	
7. Well-being and Aesthetic Appreciation	Diversity/Biodiversity in combination with one of the following terms: human welfare, aesthetics, perception, appreciation, well-being.

3 Main findings on the role of biodiversity and the National Nature Network

3.1 General findings

Review papers show that there is a considerable amount of information available on the role of species diversity and ES provisioning, illustrating a growing research effort in the last decade. The majority of studies on biodiversity and ecosystem services focus on regulating services, while little information is available on Well-being and Aesthetic Appreciation. Also Wild Food as a production service is hardly studied in temperate climate zones and results can therefore not be extrapolated to the European situation.

Especially from the recent systematic reviews and meta-analyses it can be concluded that species diversity has predominantly a positive impact on ES effectiveness. There is insufficient knowledge to draw conclusions on the exact relationship between effectiveness of ecosystem services and biodiversity but a saturating relation is most likely. Many found relations in individual studies could reflect a part of a logistic S shaped relationship (Figure 6), where at low and medium biodiversity levels effectiveness increases, until a saturation point is reached, where additional species no longer leads to an increase in service level.

The main focus in the reviewed literature lies on the role of species diversity for the effectiveness of ES. The role of biodiversity for reliability of ES is much less studied and therefore no general conclusion can be made. There are however some exceptions. For Carbon Sequestration and Soil Fertility, some studies concluded that biodiversity is important for delivering services at longer time scales, while for Water Purification and Pollination there is evidence that biodiversity ensures delivery of services under different conditions or environmental disturbances.

The role of natural habitat (either GI or NNN) for the ES provisioning is not studied well, or only in an indirect manner when studies are combined on the relation between biodiversity and ecosystem functioning and on the relation between biodiversity and natural habitat (Figure 5). The findings are mostly of a qualitative nature and do not render clear guidelines for the required amount and spatial configuration of the NNN and of GI for optimal service provisioning. There are however a few good exceptions when looking at Natural Pest Regulation and Pollination (see Section 3.5). Carbon Sequestration and Water Purification seem to depend more on area and type of NNN and GI, while Natural Pest Regulation, Pollination and Well-being and Aesthetic Appreciation depend also on structure and distance to GI or NNN.

3.2 The role of biodiversity in ecosystem service provisioning

Biodiversity has a key role in ecosystem delivery (Mace *et al.* 2012), either to ensure the regulating ecosystem processes (e.g. Soil Fertility) or to provide a product or cultural service (e.g. Wild Food or Aesthetic Appreciation). Mace *et al.* (2012) conclude that, although on the short-term species composition (effective key species) and biomass may be more important, biodiversity has a key role in ecosystem service delivery. Regulating ecosystem services are quite well studied, while production and especially cultural services are less studied (Cardinale *et al.* 2012).

In the large majority of cases a positive relationship is found between species diversity and ES provisioning. Harrison *et al.* (2014), Cardinale *et al.* (2012) and Balvanera *et al.* (2006) conclude that there is sufficient evidence that biodiversity positively affects effectiveness or reliability of ecosystem services. Biodiversity per se either directly influences (experimental evidence) or is strongly correlated with (observational evidence) certain production and regulating services. Also, in some studies mixed effects of biodiversity on ecosystem services have been found, which can be caused by complex interactions between service delivering species. For instance, in some cases the effectiveness of Natural Pest Regulation decreases with increasing biodiversity because the added species predate other pest controlling species or added species form alternative prey so that the aimed pest species is predated less (see also Box 5.4-1, Letourneau *et al.* 2009). Mixed effects can also be caused by focusing on aspects of biodiversity and services that are not directly or clearly linked to each other. For instance, Ricketts *et al.* (2008) found that pollinator visitation rate was positively affected by biodiversity of pollinators, but fruit set was not. Fruit set is probably affected by more aspects than visitation of pollinators.

For some services specific functional traits or even specific key species are important (Harrison *et al.* 2014) as found for Carbon Sequestration (leguminous species in grasslands, long-lived trees in forests), Natural Pest Regulation (species-specific parasitoids) and Pollination (wild bee species).

Decline of species may already be affecting the effectiveness of ES, before species have actually disappeared from the species pool (Isbell *et al.* 2011). Looking at the logistic curve of Figure 6, we might be in the increasing part of the curve and no longer in the saturated part of the curve, because of the loss of biodiversity which has already occurred. Indeed, Harrison *et al.* (2014) conclude that especially for Natural Pest Regulation, Pollination and cultural services (species-related recreation) abundance of certain species (functional groups) is often linked to effectiveness of ecosystem services. For example, a higher number of insectivorous birds had a positive effect on Natural Pest Regulation (Koh 2008).

3.3 Effectiveness and reliability

Effectiveness

The majority of studies focused on effectiveness of ecosystem services and revealed a positive relation with biodiversity. However, only a few of the studies we encountered explained the type of relation between effectiveness of ecosystem services and biodiversity. For Carbon Sequestration and Water Purification in homogenous habitats a saturating curve was found. For Water Purification in heterogeneous habitats a linear relation is found, as was also found for Soil Fertility and Well-being and Aesthetic Appreciation. Looking at our hypothesis on the relationship between biodiversity and the effectiveness of a service, these results may support a logistic curve, which corresponds with Figure 2b from our conceptual framework (Figure 6 in this chapter) and was also suggested by Cardinale *et al.* (2012). Initial losses of biodiversity in diverse ecosystems have relatively small impacts on ecosystem service provisioning but increasing losses lead to accelerating rates of reduced service provisioning.

Although review papers also indicated that negative or unclear or mixed relations have been found between effectiveness and biodiversity, we found only one author that suggested that Pollination effectiveness could be reduced slightly at highest species richness (Albrecht *et al.* 2012) resulting in an optimum like in Figure 2c.

However, clear guidelines of how many species should be maintained within certain ecosystems or thresholds under which ecosystem services are in danger are not available from these literature sources.

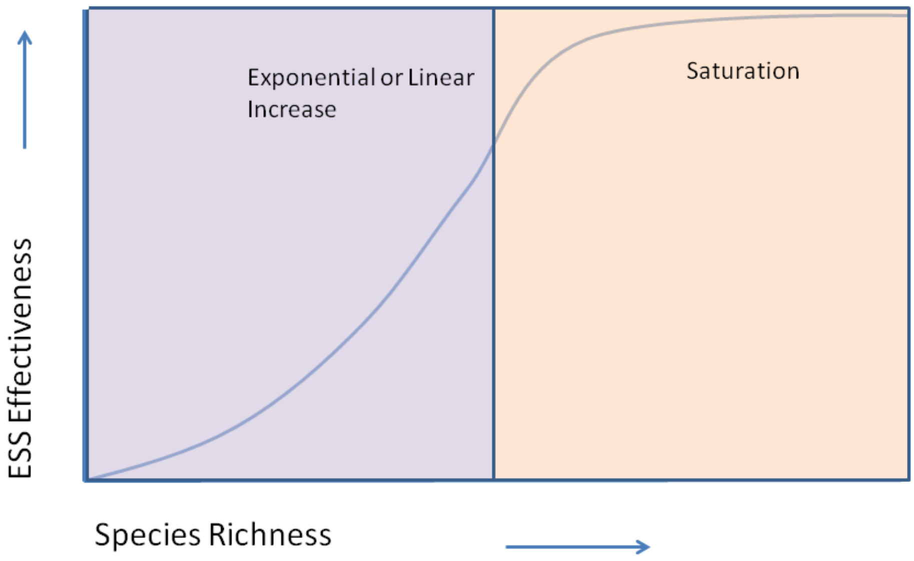


Figure 6 *The relationship between species diversity and ES effectiveness is for most ES best described by a logistic S-shaped curve. At low and intermediate levels of biodiversity ES effectiveness increases in a linear or exponential fashion, until an saturation point is reached, where additional species no longer lead to an increase in service level.*

Reliability

Reliability is taken into account in a limited number of studies only. As a consequence we cannot pronounce upon the type of relation between reliability of ecosystem services and biodiversity. For Pollination Winfree (2013) states that single context relations (at a specific abiotic condition, time or place) often appear to be logarithmic, while in multiple contexts the relation becomes more and more logistic, conform Figure 6.

Isbell *et al.* (2011) stated that even within one context (place, time, condition, service), an increasing species pool in grassland systems already increases ecosystem delivery. However, when focusing on different contexts, different sets of plant species are needed. The more aspects change, the larger the species pool needed to deliver ecosystem services. Cardinale *et al.* (2012.) found the same results focusing on temporal stability of ecosystem services. Mace *et al.* (2011) state that biodiversity buffers ecological systems against future environmental disturbances. The impacts of environmental disturbances on ecosystem services might however be nonlinear, hard to predict and/or irreversible. Balvanera *et al.* (2006), focusing on supporting services as nutrient cycling and primary production, already found diverse ecosystems to be more resistant to nutrient perturbations and invading species.

Therefore, although species may appear functionally redundant when one function is considered under one set of environmental conditions, many species are needed to maintain multiple functions at multiple times and places in a changing world.

In the selected studies we found that for Carbon Sequestration and Soil Fertility, biodiversity is especially important for delivering services at longer time scales, while for Water Purification and Pollination there is evidence that biodiversity ensures delivery of services in under different conditions and environmental disturbances.

Guidelines for how many species should be maintained to ensure reliability of ecosystem services are not available from selected literature.

Effectiveness or reliability

Isbell *et al.* (2011) state that, according to the precautionary principle, all species should be conserved because we cannot be certain which species actually provide ecosystem services. Species that seem to have low effectiveness can be important for reliability. In some studies a trade-off was found between effectiveness and reliability. For example, the experimental study of Water Purification in model streams of Cardinale *et al.* (2011) shows such a trade-off. In this study nitrogen uptake increases with algae diversity. However, in homogeneous conditions this relation is saturating and the highest nitrogen uptake is delivered by one most effective species, while in heterogeneous conditions this relation is linear and highest nitrogen uptake is delivered by a high diversity of species. Also the mentioned trade-off between preserving old-growth forest (with a long-term carbon standing stock and less vulnerable for diseases) and young plantation forest (with a higher carbon flux but with higher vulnerability) is in fact a trade-off between reliability and effectiveness respectively.

3.4 The role of the National Nature Network and small natural elements in ecosystem service provisioning

From the selected literature it appears that Carbon Sequestration and Water Purification depend on size and habitat type of NNN and GI: the larger the area of NNN or GI the larger the ES provisioning. For Carbon Sequestration it was found that specific habitat types were especially important for effectiveness: old growth forest and permanent grasslands were the most effective. The location of these nature areas is not important for the delivery of the service. For Water Purification also specific habitat types were important for effectiveness: wetlands, grasslands and aquatic habitats (algae or (sea) weed beds) were most effective in water. It seems relevant that water is purified in places where contamination is most severe and/or in places where clean water is most relevant, but we have found no information on this aspect in the selected literature.

For Natural Pest Regulation and Pollination there is some evidence that the spatial configuration of the nature areas is important for the ES delivery. The service becomes more effective with a short distance to GI or NNN. Also the spatial configuration between the natural elements and the location where the service is needed is important. The GI network should therefore be fine scaled as effects of GI on these services have been found on short distances, often within 1 kilometre or at least within a few kilometres of the crops studied (Bianchi *et al.* 2006, see Box 5.4-2). There is some evidence that the level of functioning of GI for Pollination and Natural Pest Regulation is supported by the NNN like woods and species-rich grasslands, but so far only few studies have focused on this aspect, and this is not quantified.

For Wellbeing and Aesthetic Appreciation landscape structure is important and distance to nature areas like natural parks. Smaller elements like meadows or linear elements can only be appreciated if they can be experienced, for instance if located next to (touristic) roads. For Well-being and Aesthetic Appreciation not only individual elements are important, but also landscape structure.

There is hardly any literature available on the total amount and spatial configuration of the natural habitat that should be preserved for optimal ecosystem service delivery. An exception is Natural Pest Regulation where several authors mention that 9-20% of the agricultural landscape should consist of semi-natural habitat. It is also stated that in absence of robust elements (NNN) within 1 km, a fine network (every 100-150 m) of linear elements should be present.

There was no information found in the selected literature on the role of NNN or GI on Soil Fertility or Wild Food.

3.5 Main conclusions per ecosystem service

The results are summarized in Table 4. See Chapter 5 for a detailed description of the results per ecosystem service.

Carbon Sequestration
The relation between Carbon Sequestration/Storage and biodiversity is relatively well studied, where the relation between above ground biodiversity and above ground sequestration is quite consistently positive (Table 4). Only a few studies focus on the relation between below ground biodiversity and (long-term) storage in the soil and here results are still less consistent.

Effectiveness. The effectiveness of above ground sequestration increases with species diversity. There seems to be a saturation effect (logarithmic), where after an increase in effectiveness at low levels of biodiversity, additional biodiversity does not further increase effectiveness.

Reliability. Species diversity in relation to the reliability of the service has not been an explicit object of study so far. There are however studies that found that longevity of species increases the reliability of Carbon Sequestration in time as short-lived trees release carbon again when they die. One study found a positive relation between biodiversity and long-term (> 10 year) carbon storage in the soil. These results indicate a trade-off between long-term (> 100 year) storage of old growth forest and short-term (< 40 years) flux of young plantations.

NNN and GI. There is a clear relation with the area of nature areas, but not with distance. Especially (old growth) forests and (permanent) grasslands are most effective.

Water Purification
The relation between biodiversity and Water Purification is relatively well studied, both in terrestrial vegetation (nature, crops and grassland) as in aquatic systems such as (artificial) ponds. The found relation is quite consistently positive, but also mixed or unclear results have been found (Table 4).

Effectiveness. In a large majority of the studies the effectiveness of Water Purification increases with biodiversity, but also mixed or unclear results have been found. Effectiveness increases linearly or saturating (logarithmic) with biodiversity. Specific species can be more relevant in species complexes, like non-leguminous species.

Reliability. The fact that biodiversity is more relevant in heterogeneous conditions and in certain species complexes, like non-leguminous species, implies that biodiversity supports reliability of Water Purification.

NNN and GI. The effectiveness depends on the size and type of the NNN and GI (e.g. wetlands or grasslands, algae vegetation and weed in ponds, streams and rivers and in the sea).

Soil Fertility
The relation between biodiversity and Soil Fertility is often studied, but besides (non-)leguminous vegetation mostly soil biodiversity is studied. Results are quite mixed, depending on the way Soil Fertility is studied and what soil organisms are studied. In general, if the trophic distance between the studied organism and soil nutrients is larger, relations are less clear.

Effectiveness. The majority of studies found a positive effect of below ground species diversity on Soil Fertility. This impact of below ground diversity on Soil Fertility seems to be linear.

Reliability. One of the selected studies reveals that a higher (soil) biodiversity leads to a higher reliability of Soil Fertility on longer time scales. This effect was not found for different abiotic conditions.

NNN and GI. The relation between Soil Fertility and the NNN and GI is not studied, but we assume that a fine-scaled GI network in agricultural landscapes is more important than the NNN.

Natural Pest Regulation
The relation between biodiversity and effectiveness is well studied as well as the role of GI/NNN, this holds not for the reliability. The results are quite consistently positive, as the large majority of studies found an increase in Natural Pest Regulation with species diversity.

Effectiveness. The majority of studies found an increase in Natural Pest Regulation with species diversity. However there are also examples where higher levels of biodiversity have negative impacts, because of complex species interactions. The review of Harrison *et al.* (2014) however revealed that studies with positive effects clearly prevail.

Reliability. We expect that high species diversity is positive for the reliability (compare Pollination) but this is not assessed in the considered studies.

NNN and GI. This ES depends on the GI network supported by the NNN, especially flower rich grasslands and woody vegetation. Figures of 9 to 20% of non-crop habitat has been mentioned to ensure effective Natural Pest Regulation. The size and structure of natural areas is important, but also the distance between crops and surrounding GI (within 1 km). The relationship between Natural Pest Regulation and amount of habitat is assumed to have a logistic curve.

Pollination
This ES depends especially of flower rich grasslands and woody vegetation. The relation between Pollination effectiveness and biodiversity and also the relation with GI/NNN is relatively well studied and results are mostly consistently positive.

Effectiveness. Fruit set increases with higher species diversity, also cross pollination between plants occurs over larger distances. The relation between effectiveness and biodiversity is saturating, maybe even an optimum.

Reliability. Species diversity increases the reliability with wind disturbance, where wild pollinator species remain more effective than honey bees at higher wind speed.

NNN and GI. This ES depends on the GI network supported by the NNN. The vicinity of natural habitat near agricultural fields is positive for flower visits in crops. The number of flower visits decreases exponentially with the distance to natural habitats and drops below 50% at distances over 1300 m.

Wild food
There is insufficient information available to draw conclusions for the European situation. Studies on Wild Food focussed on developing countries related to the nutritional value it delivers. It is hardly studied in temperate climate zones and results can therefore not be extrapolated to the European situation. Perhaps not the nutritional but the cultural value of Wild Food is a better way of approaching the value of Wild Food in the European context.

Well-being and Aesthetic Appreciation
This ecosystem service is already quite often studied, although different studies focus on different aspects of Well-being and Aesthetic Appreciation. Positive effects of biodiversity have been found in several studies, but this effect depends strongly on the ability of people to observe differences in biodiversity.

Effectiveness. Results so far indicate a mostly positive effect of species diversity on Aesthetic Appreciation. However there are also studies where no effects were found, as differences in species diversity were not recognized by visitors.

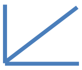
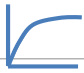
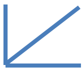
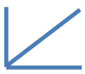
Reliability. None of the studies focused on reliability of Well-being and Aesthetic Appreciation.

NNN and GI. There is an indication that the appreciation increases linearly with the size of nature areas, which illustrates the importance of the NNN.

Table 4

Summary of the main conclusions for the studied ecosystem services.

- *For the relation between ES effectiveness and biodiversity, the (dominant) type of effect is shown, the species groups that are most important for delivering the ES and the shape(s) of the relation that has/have been found.*
- *For the role of GI/NNN for delivering ES, the types of GI/NNN are presented that are most important as well as information on size, location or scale of GI/NNN.*
- *For reliability of ES it is presented if biodiversity contributes to reliability of ES delivery on longer time scales, different abiotic conditions or environmental disturbances.*

Ecosystem service	ES effectiveness – biodiversity			GI/NNN		ES - Reliability
	Effect	**Species**	**Curve-types**	**Size location scale**		
Wild Food	-	-	-	-	-	-
Carbon Sequestration	positive	long-lived species		(old growth) forest, (permanent) grassland	area stand age	long-term
Water Purification	positive	non-leguminous species algae, weeds	 	wetlands, grasslands, ponds, streams, rivers	area stand age	heterogeneous conditions
Soil Fertility	positive, mixed	soil biodiversity, (non-) leguminous plants		grasslands, crops	-	long-term
Pest Regulation	positive	pest parasitizing wasps, predating insects, birds mammals	-	flower rich and woody vegetation	area structure proximity (1-2 km)	-
Pollination	positive	(wild) bees, hoover flies, butterflies		flower rich and woody vegetation	area structure proximity (1-2 km)	wind disturbance
Aesthetic Appreciation	positive	appealing and charismatic species		(old) forest and natural grassy vegetation	area structure proximity	-

-: no information available

4 Towards the further implementation of ecosystem services: Conclusions and knowledge gaps

Species diversity is important for ecosystem service effectiveness
The first aim of this study was to clarify the relationship between species diversity and the effectiveness and reliability of ES provisioning. Our review showed there is evidence that in the large majority of studies high biodiversity does increase the effectiveness of the ES studied. A predominately positive relationship was found for the following ecosystem services: Carbon Sequestration, Water Purification, Soil Fertility, Natural Pest Regulation and Pollination. For the service Wild Food insufficient information was available to draw any conclusions for the European situation. For the service Well-being and Aesthetic Appreciation there are indications that species diversity has a positive impact. This result implies that species loss might lead to a reduction of the ES effectiveness. In addition to species loss also a decline in species abundance seems to be an important factor reducing ES effectiveness.

In a minority of studies no effects or even negative effects of higher biodiversity levels were found. It is suggested these results can occur when the study focuses on aspects of biodiversity and services that are not directly linked to each other (Balvanera *et al.* 2006) or it can be caused by complex interactions between service delivering species (Harrison *et al.* 2014). For instance the effectiveness of Natural Pest Regulation might decrease with higher biodiversity when added species predate other pest controlling species or added species form alternative prey so that the aimed pest species is predated less (see also Box 5.4-1, Letourneau *et al.* 2009).

Our results cannot be extrapolated to all ES. It is possible that there are ES for which a high level of biodiversity does not improve ES provisioning. However we studied seven different ES belonging to three different categories of services (regulating, production and cultural services) so it can be concluded that high biodiversity levels are important for at least a substantial part of the ES.

Food production has for instance been mentioned as an exceptional service where high biodiversity levels not necessarily enhance production. Although our review has shown that agriculture related services such as Soil Fertility, Natural Pest Regulation and Pollination do profit from high species diversity, stimulating these ES has not been a priority in conventional agriculture (Grashof-Bokdam *et al.* 2013[4]). In fact conventional farming methods have been focussed on optimizing the production function, while at the same time minimizing other ES (Power 2010, Galic *et al.* 2012). Conventional farming methods optimize food production on the short term, but on the long term there is a trade-off with other ES (Raudsepp-Hearne *et al.* 2010, Turner *et al.* 2013). This trade-off is problematic in so far that it does not contribute to the goal of the Dutch government to preserve and enhance our natural capital, including the ES it provides (Ministry of Economic Affairs 2014).

Knowledge gap: finding a better balance between optimal food production and other ecosystem services
Regarding optimal food production there is a need to take the societal costs and benefits for all ecosystem services into account. There is a need to find a better balance between optimal food production on the one hand while minimizing the trade-off for other ES on the other hand, thus preserving and enhancing our natural capital on the long term.

[4] *Internal note:* Grashof-Bokdam, C.J., A.M. van Doorn and J.F.F.P. Bos (2013). Perspectief GLB voor verduurzaming landbouw. Interne notitie 63, WOT Natuur en Milieu, Wageningen UR, Wageningen

Reliability is not well studied

The main focus in the reviewed literature is on the role of species diversity for the effectiveness of ES. The impact on reliability is much less studied. However there are some cases where it is indeed illustrated that high species diversity increased the reliability during environmental disturbances. Examples are Water Purification in an experimental setup with different water discharge levels (Cardinale 2011, see Section 5.2). Another example is pollination of tree blossom during variable wind conditions where some species still visit flowers exposed to windy conditions and others do not (Brittain *et al.* 2013, see Section 5.5). These results are in accordance with the principles of resilient ecosystems, where a high species richness or functional diversity is important for ecosystem functioning (Gunderson 2000, Elmqvist *et al.* 2003). In species rich systems disturbances have a smaller impact on ecosystem functioning, because of the redundancy factor, or insurance factor (Yachi and Loreau 1999, Isbell *et al.* 2011). Extrapolating this principle to the provisioning of ecosystem services implies that if multiple species perform a similar service, but differ in their sensitivity to disturbances, this is an insurance for the reliability of the service. The aspect of reliability becomes more important with climate change, as one of the aspects of climate change is that the weather becomes more variable, with larger and more frequent weather extremes, like heavy rain or dry an hot periods (KNMI 2014).

Knowledge gap: The importance of species diversity for ecosystem service reliability

There is a need to quantify the importance of species diversity on the reliability of service provisioning in time. Especially because a trade-off could exist between effectiveness and reliability, in those cases where some key-species might be highly efficient in a service under controlled conditions, but do not perform well when disturbances occur (see example Water Purification (Cardinale 2011, see Section 5.2).

Nature areas are important for Ecosystem Services, but concrete guidelines are still missing

The second aim of this study was to clarify to what extent these services depend on the NNN and the network of small natural elements (GI) in the landscape. If this dependence between nature areas and ES is the case, one would expect that the effectiveness or reliability of a service would improve with the size of and distance from the NNN and the density of GI in the surrounding landscape.

It can be concluded that the NNN and GI are an important backbone for the providing of ES. But it is not yet possible to derive concrete guidelines for the amount and spatial configuration of NNN and GI needed for the optimal provisioning of different services. Our literature review shows, that the quantification of the importance of nature areas and GI for the provisioning of services has rarely been a direct object of study. Studies on the services Natural Pest Regulation and Pollination come closest to defining requirements for the spatial configuration of the NNN and GI. These services become more effective with a short distance to GI or NNN. Effects of GI on these services have been found on short distances, often within one kilometre or at least within a few kilometres of the crops studied (see Box 5.4-2), declining with distance (Bianchi *et al.* 2006). There is also some evidence that the level of functioning of GI for Pollination and Natural Pest Regulation is supported by the NNN like woods and species-rich grasslands, but so far only few studies have focused on this aspect, and this is not quantified.

Multiple hierarchical scales

There appear to be several hierarchical scales in the required level of interconnectedness between nature areas of the NNN, the small scaled natural elements of GI and the locations where ES provisioning is required (Opdam *et al.* 2014). On an (inter) national and regional scale the NNN forms the basis for maintaining high levels of biodiversity in space and time. Thus, the NNN forms the backbone for preserving our natural capital as it functions as a buffer against climate change and other disturbances. On a regional scale the NNN functions as a source for biodiversity in the GI in the multifunctional landscape. For the services that contribute to agricultural production GI and the agricultural fields need to be interwoven on a local scale. Here the closer the better, especially for Soil Fertility but this is also the case for Natural Pest Regulation and Pollination. For Pollination it was found that the total area within a radius of a few kilometres from the field determines the effectiveness of the service.

On the other hand there are also services such as Carbon Sequestration where the service takes place in the nature area itself. The effectiveness of the services clearly increases with the size of the nature area or the length of GI, but the location where this occurs has no influence on the service effectiveness. To some extent this also holds for Water Purification, however it could be important to purify water on specific locations, for instance in a buffer zone surrounding natural areas, or near drinking water locations or close to the source of pollution. For the Aesthetic appreciation and Wild Food services it is important that these areas are near areas where the potential users are based. The service needs to be within the distance one is willing to travel.

Knowledge gap: Spatial requirements of nature areas and GI for Ecosystem Services
For the effective management of ES in the landscape national governments are already obliged to map and assess NNN for the delivery of ecosystem services, which could also give indications for the implementation for GI (Maes 2013, 2014). In the present situation however, policy targets for the NNN are focussed on natural values only represented by specific target species, without incorporating requirements for optimal ES provisioning. Therefore, there is a need for the further quantification of the optimal ecosystem types, size and configuration of NNN and required GI density in relation to the locations where these services are required. As insufficient information is available in literature on the direct relationships between the configuration of nature areas and the GI network and the effectiveness and reliability of ecosystem services.

We propose to derive the spatial requirements in an indirect way, based on the requirements of the species that provide the services (see Figure 5, arrow 1 and 2). With this approach it would be possible to develop spatial requirements for different ES. This approach is in line with the ecoprofile approach that formed the basis for the spatial requirements of the NNN (Vos *et al.* 2001, Verboom and Pouwels 2004, Opdam *et al.* 2008). The species that provide a service are grouped in ecoprofiles with similar traits: e.g. the type of habitat they use, the individual area requirements and their dispersal capacity. Based on the spatial requirements of the ecoprofiles per ES, it becomes possible to define spatial guidelines per ecosystem service giving for instance the habitat type, size and configuration of the NNN and GI.

Implementation of Ecosystem Services in local landscape planning is lagging behind

Synergy between Ecosystem Services and Natura 2000 goals
This literature review has shown that the effectiveness of the studied ecosystem services does benefit from high species diversity, which in its turn is supported by the NNN and GI, although this last aspect is still insufficiently quantified. The suggestion that a basic level of biodiversity is sufficient for ES provisioning (Veeneklaas 2012), does not hold for a substantial part of the ES. As the Natura 2000 goals also focus on high biodiversity levels, of characteristic species for targeted ecosystems, it is to be expected that the targets for the optimal functioning of Natura 2000 areas and for optimal ES provisioning for a considerable part coincide. These results bring the aims of the human oriented approach of ES and the nature oriented approach of the Natura 2000 Network closer together and could therefore enhance the societal support for the NNN and the Natura 2000 network within.

Ecosystem services or technological alternatives
A recent study on ES provisioning (De Knegt 2014) shows that a substantial part of the ES in the Netherlands is being supplied by technological alternatives or is imported from outside the Netherlands (Figure 7). Technological means may offer a cost-effective and reliable alternative. For instance Water Purification using a water purification plant, takes much less space compared to purification by ecosystems. Especially in urbanized areas where space is scarce technological systems can be more effective than ES. However the same natural elements often provide multiple services, which might change the balance between technological and natural solutions. Also it is clear that technological alternatives may be more costly or have unfavourable side-effects, such as crop protection agents that affect the quality of surface waters (De Knegt 2014).

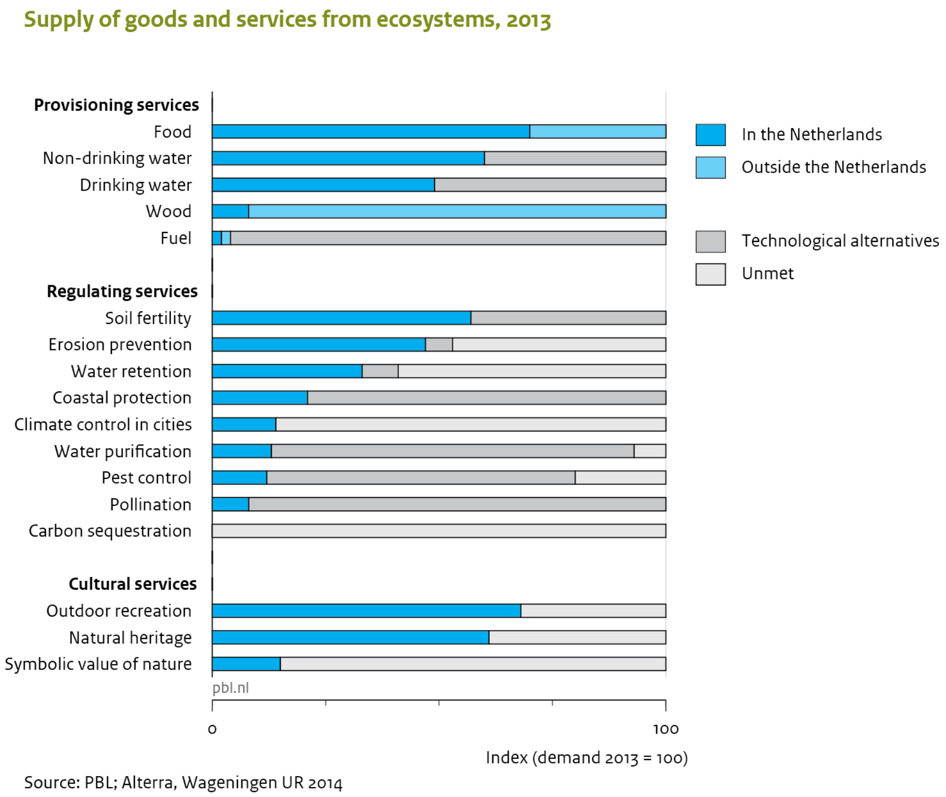


Figure 7 *The supply of services by Dutch ecosystems is supplemented by imports from ecosystems in other countries or by using technological solutions. Some types of demand remain unmet (Source: De Knegt 2014).*

Implementing ecosystem services in planning and decision-making
Despite the growing knowledge of the relevance of ES for society the actual mainstreaming and implementation of ES in practical planning and decision-making are still lagging behind (Albert *et al.* 2014). Applying the ES concept is considered most promising in multi-sectorial planning contexts (Sitas *et al.* 2014). The perceived added value of applying the ES concept in local planning lies in communicating the contributions and values of ecosystems and biodiversity to the well-being of different stakeholder groups. Nature areas and the network of GI often provide multiple services. Putting emphasis in the multiple benefits provided by the same natural structure in the landscape stimulates coalitions and cooperation in the planning area (Steingröver *et al.* 2010, Opdam *et al.* 2015). Also the surplus value of working together with your neighbours, for instance by increasing the total density of GI in the landscape, stimulates cooperation and contributes to the social cohesion between actors. The implementation of ES then becomes predominantly a landscape design and governance task.

Knowledge gap: Effective tools for the implementation of Ecosystem Services.
The contribution of ES to collaborative landscape planning is still hardly studied (Opdam 2013). Yet the potential seems considerable, as the concept stimulates coalition building and collective action (Opdam *et al.* 2015). Existing knowledge on the relation between desired ES , species diversity and spatial structure of nature areas and GI needs to be translated so that it better fulfils the information needs and requirements of groups of local actors and decision-makers. For instance, design tools are needed so that local groups know whether and where additional nature elements are needed for the provisioning of the desired services. Furthermore local governance arrangements are needed to bring together the providers of services and the demanders for these services.

PART 2 Detailed Results

5 Systematic results ecosystem services

Reading guide

From the (most) relevant studies found, the following information was collected:

- Description of the ES: what benefit does the service deliver for society, where is it delivered and by what biodiversity is it delivered? How does the relation between biodiversity and service work?
- Main conclusions for each ES?
- Relevance of selected literature for NL/EU situation: are the conclusions drawn in the studies applicable to the situation in Europe and in the Netherlands?
- Attributes of biodiversity and ES effectiveness/reliability: how is biodiversity, ES effectiveness and/or ecosystem reliability measured in the studies?
- Impact of biodiversity on ES: do the studies mention impacts of biodiversity and if yes, are the found impacts of biodiversity mainly positive or negative or are the effects mixed or unclear? Are effects mostly found on effectiveness or on reliability of the ES?
- Relevance of GI and NNN: are area, structure, connectivity or heterogeneity / quality of GI or of NNN relevant for delivery of the ES?

For each ES, a table was constructed with information of each study on:

- the study: authors, year of publication, type and place of study;
- the found impact of biodiversity (positive, negative, unclear or mixed); the number of biodiversity attributes having a positive, negative or unclear effect was presented based on Harrison *et al.* (2014, Figure 5.1);
- the used biodiversity attributes;
- the used effectiveness attributes;
- the used reliability attributes;
- the found impact of GI and/or NNN.

For each ES, we added one or two boxes with examples illustrating the effect of biodiversity, GI or NNN on effectiveness or reliability of that ES.

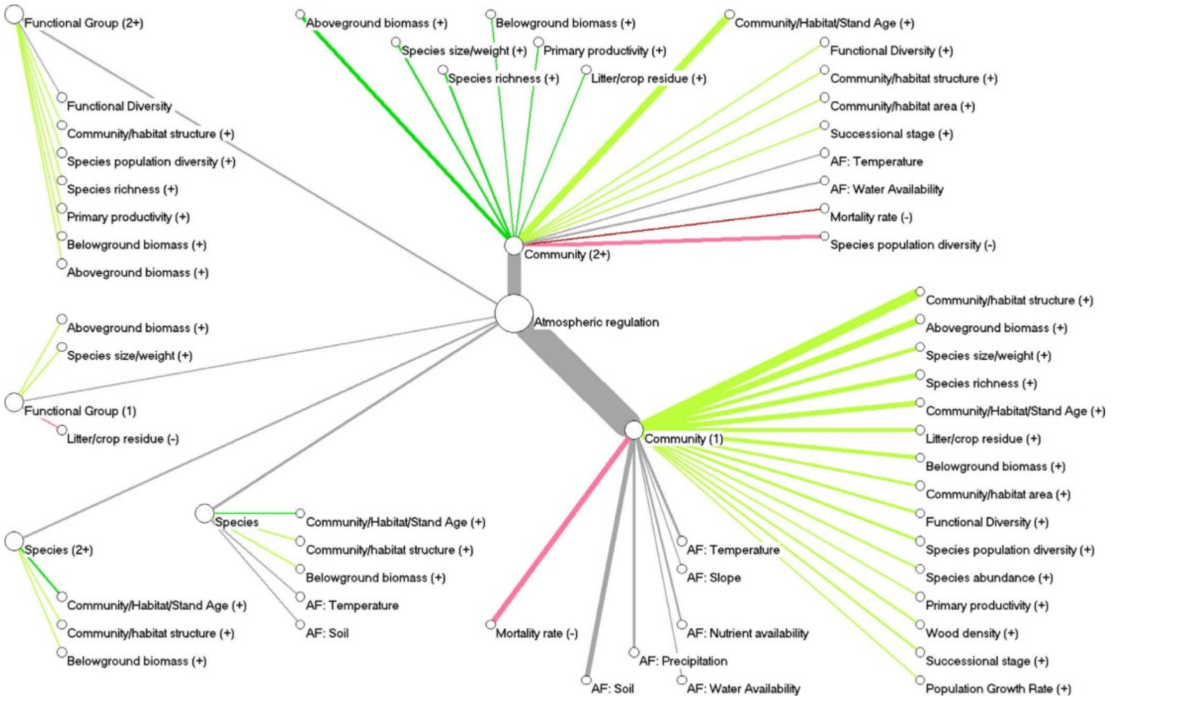


Figure 5.1 *Example of network diagram presenting positive (green), negative (red) or unclear (grey) relations between Natural Pest Regulation and different biodiversity attributes. Width of lines indicates the number of papers showing that relation, while depth of colour indicates the strength of the found relation (from: Harrison et al. 2014).*

5.1 Regulating Service: Carbon Sequestration

Description of the ecosystem service
Carbon Sequestration refers to the binding of carbon either aboveground (in the vegetation) or belowground (in soil complexes). Also the term 'storage' is used, sometime as equivalent of sequestration and sometimes to indicate binding of carbon to stable soil complexes over longer time scales. The term 'flux' is sometimes used to indicate the process of storage per time unit, while storage then refers to the existing supply of stored carbon. Carbon Sequestration decreases the concentration of greenhouse gasses like CO_2 in the air. CO_2 is taken up from the air by plants during photosynthesis. It is released again during decay of dead plants and animals and is taken up by soil complexes. It is delivered in and by natural vegetation like forests and peat land, but also by grasslands and crops.

Main conclusions Carbon Sequestration
The relation between Carbon Sequestration/Storage and biodiversity is relatively well studied, where the relation between aboveground biodiversity and above ground sequestration is quite consistently positive, see Table 5.1. Fewer studies focus on the relation between aboveground biodiversity and (long-term) storage in the soil and here results are less consistent. The effectiveness of above ground sequestration increases with species diversity. There seems to be a saturation effect, where, after an increase in effectiveness at low levels of biodiversity, additional biodiversity does not further increase effectiveness. Species diversity in relation to the reliability of the service was not an explicit object of study. Some studies found that longevity of species increases the reliability of Carbon Sequestration in time, as short-lived species release carbon again when they die. One study found a positive relation between biodiversity and long-term carbon storage (>10 years) in the soil. Results indicate that there is a trade-off between long time (> 100 year) storage of old growth forest and short-term (< 40 years) flux of young plantations. There is a clear relation with the area of nature areas. Especially (old growth) forests and (permanent) grasslands are most effective.

Relevance selected literature for NL/EU situation
The cited meta-analyses use literature sources from all over the world, but the individual studies used are all carried out in European countries. Although quantities of sequestrated carbon in boreal (coniferous) forests and evergreen oak forests may differ from those in Dutch (mixed) forests, the found relations are not expected to be very different in Europe.

Attributes of biodiversity and ecosystem service effectiveness/reliability
Most studies focus on biodiversity attributes of aboveground plant species. Aboveground biodiversity is measured by species richness or diversity, often of tree species or grassland species. Some studies focus on diversity of specific functional groups, such as legumes. Wardle *et al.* (2012) also use diversity of aboveground consumer species as biodiversity attribute as these organisms take up carbon by eating vegetation. Harrison *et al.* (2014) refer to studies that use size or weight of species as biodiversity indicator, as the amount of carbon sequestrated increases with the amount of biomass in the aboveground vegetation. They also report that mortality rate is used as an attribute of biodiversity. A higher mortality rate indicates a higher release of carbon and is therefore negatively related to Carbon Sequestration. In other words, the life span of species is positively related to Carbon Sequestration.

In most cases, effectiveness of Carbon Sequestration is measured as the amount of carbon stored in biomass per ha of a certain vegetation type or by certain functional groups in a certain vegetation type. Also Carbon Sequestration in the soil is studied. Cardinale *et al.* (2012) related biodiversity also to long-term storage of carbon (> 10 years) which gives more information on reliability of Carbon Sequestration.

Impact of biodiversity on Carbon Sequestration
Most literature sources find a positive relation between biodiversity attributes and effectiveness of Carbon Sequestration. Harrison *et al.* (2014) present positive effects of 39 biodiversity attributes and only 2 negative and 1 unclear effect. Woodall (2011) states that carbon storage in USA forests decreases if stands are progressively occupied by one species. Also Wardle *et al.* (2012) state that aboveground sequestration increases with species richness of plants and aboveground consumers.

However, they remarked that there is little experimental or observational evidence for a positive relation between belowground biodiversity and Carbon Sequestration in the soil. Specific species enhance sequestration, as found for leguminous species in grasslands (e.g. *Trifolium pratense*, De Deyn *et al.* 2011) and long lived trees (Harrison *et al.* 2014). Cong *et al.* (2014) also found positive effects of species richness in former arable fields in absence of legumes. Harrison *et al.* (2014) also found negative effects of mortality rate implying positive effects of species with a long life span. Ruiz-Benito *et al.* 2014 found the relation between tree species richness and above ground carbon storage to be saturating (Box 5.1).

Not all studies find positive effects of biodiversity on effectiveness of Carbon Sequestration. The study of (Onaindia *et al.* 2013) reveals that both biodiversity hotspots and species poor (pine/eucalyptus) plantation forests contribute comparably to carbon storage, implying that there is no effect of biodiversity on effectiveness of Carbon Sequestration. However, biodiversity hotspots may be preferred as plantations may have negative effect on conservation value en can cause environmental problems. Moreover, as plantations consist of relatively short-lived species, we expect reliability of Carbon Sequestration of plantations to be lower than that of biodiversity hot-spots considering the found negative effects of mortality by Harrison *et al.* (2014). Cardinale *et al.* (2012) found mixed effects of biodiversity on reliability of Carbon Sequestration. The authors state that only few studies did focus on reliability and that Carbon Sequestration is the outcome of complex processes like photosynthesis and decomposition.

Relevance of Green Infrastructure and National Nature Network
Nature areas, especially trees in forests, form the largest above ground CO_2 stocks, determined by size and age of trees. Peat soils have large stocks of below ground CO_2. Also GI, grassland vegetation and crops contribute to Carbon Sequestration. Harrison *et al.* (2014) presented several positive effects of community and habitat area and structure on Carbon Sequestration. Stand age has positive effects on Carbon Sequestration, suggesting that old-growth forest and permanent grassland improve this ES compared to plantation and rotation grasslands. Also the results of Wardle *et al.* (2012) showing that total sequestration increases with time without fire disruption (stand age), suggest that old-growth forest maximizes biodiversity and Carbon Sequestration. Harmon *et al.* (1990) found that carbon storage decreases after conversion of old growth forest to young forest and not restored until at least 200 years. This could be related to the positive effect found of higher organic matter and of improved soil structure by De Deyn *et al.* (2011) and of litter/crop residue quality on Carbon Sequestration (Harrison 2014). These results could indicate a trade-off between long time (> 100 year) storage of old growth forest and short-term (< 40 years) flux of young plantations (Luyssaert *et al.* 2008). No effects of distance to NNN or GI have been noted. Carbon Sequestration is produced and delivered in nature areas and therefore distance is probably not an issue.

Box 5.1 Effectiveness of Carbon Sequestration depends on forest diversity (Ruiz-Benito *et al.* 2014)

Carbon storage (Carbon Sequestration) increases with functional species diversity following a saturating curve. For some forest systems (e.g. planted mountain pine) carbon storage only increases strongly with biodiversity in very species poor situations, but not anymore when an ecosystem is relatively species rich. For other forest systems (e.g. deciduous forest) carbon storage increases gradually with biodiversity.

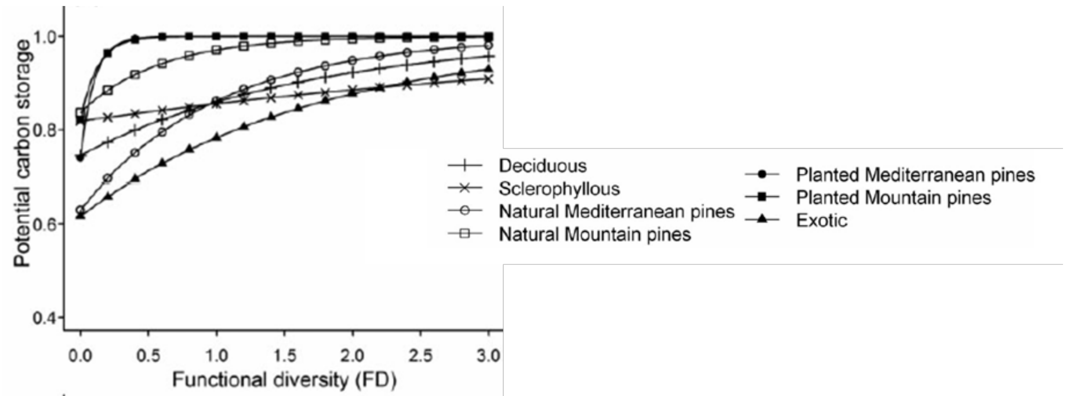


Table 5.1

Information found in scientific literature on the impact of biodiversity on effectiveness and/or reliability of Carbon Sequestration. The numbers in Harrison et al. (2014) refer to the number of times the effect was found for one of the biodiversity attributes in de selected studies.

No.	Study	Impact of biodiversity	Biodiversity attribute	Effectiveness attribute	Reliability attribute	Impact of GI/NNN
1	Cardinale *et al.* 2012 (review, global, various crop and nature types)	positive mixed	plant species diversity	C sequestration (in plants)	 C storage (in plants and in soil long-term > 10 years)	
2	De Deyn *et al.* 2011 (experiment, meadows UK)	positive	biodiversity restoration practices	C storage (in vegetation and soil)		
3	Ruiz-Benito *et al.* 2014 (forest data analysis, Spain)	positive	(functional) tree species diversity	C storage (in trees), tree productivity		
4	Onaindia *et al.* 2013 (mapping and interpolation analysis, coastal and evergreen ecosystems, Basque country)	no clear effect	diversity of tree species	C storage (in soil and trees)		
5	Wardle *et al.* 2012 (experiment, boreal forest islands, Sweden)	positive	species richness of plants and aboveground consumers	total C storage (in soil and vegetation)		
6	Harrison *et al.* 2014 (meta-analysis global, various crop and nature types)	positive (39) negative (2) unclear (1)	pop/species/functional richness/ diversity size/weight/density biomass/productivity life span (= - mort rate) successional stage population diversity functional diversity	C sequestration		community / habitat area/structure stand age
7	Cong *et al.* 2014 (experiment former arable fields, the Netherlands)	positive	species richness of non-legume plant species	C stock in the soil		
8	Woodall *et al.* 2011 (analysis of forest inventory data across USA)	positive	tree diversity as inverse of species purity ration	standing tree carbon stock		

5.2 Regulating Service: Water Purification

Description of the ecosystem service
Water Purification is the ability of vegetation to absorb pollutants to prevent leaching into surface water of rivers, streams and ditches and groundwater. It can concern non-natural pollutants that are produced by industrial activity or traffic, but also natural occurring nutrients (nitrogen and phosphorus), mainly added by (intensive) agriculture. Large quantities of nutrients in surface or ground water cause environmental problems, like dominance of fast growing species in water bodies causing algae bloom. Water Purification is delivered in and by green or blue infrastructure, nature areas as well as grassland and crops.

Main conclusions Water Purification
The relation between biodiversity and effectiveness of Water Purification is relatively well studied, as well in terrestrial vegetation (nature, crops and grassland) as in (artificial) ponds, see Table 5.2. In a large majority of the studies the effectiveness of Water Purification increases with biodiversity, but also mixed or unclear results have been found. Effectiveness increases linearly or saturating (logarithmic) with biodiversity. Biodiversity may be more relevant in heterogeneous conditions and in certain species complexes, like non-leguminous species. The fact that biodiversity is more relevant in heterogeneous conditions and in certain species complexes, like non-leguminous species, implies that biodiversity supports reliability of Water Purification The effectiveness depends on the size and type of the NNN and GI (e.g. wetlands or grasslands, algae vegetation and weed in ponds, streams and rivers and in the sea).

Relevance selected literature for NL/EU situation
The found literature sources are meta-analyses using sources all over the world, or lab or pond experiments under controlled conditions outside Europe. Therefore we should be careful to conclude upon specific situations in Europe or the Netherlands.

Attributes of biodiversity and ecosystem service effectiveness/reliability
The meta-analysis of Harrison *et al.* (2014) refers to several attributes, such as species richness as well as size/weight of species and productivity and biomass. They also refer to species diversity of functional groups. Other studies also use species groups that are known for their ability of filtering pollutants from water, like macrophytes, algae and filter feedings organisms.

Effectiveness is measured by nutrient uptake rates, the amount of removed nutrients and pollutants per unit water or the amount that is taken up by units of vegetation. The study of Cardinale (2011) also measures reliability of Water Purification by looking at nutrient uptake rates in different habitat niches of streams.

Impact of biodiversity on Water Purification
Almost all studies find positive effects of biodiversity on effectiveness of Water Purification. Harrison *et al.* (2014) listed positive effects of 19 biodiversity attributes and 5 unclear effects. Engelhardt & Ritchie (2001) explained that competition between macrophyte species in aquatic habitat is high. In their pond experiments, it appeared that effective species like crisped pondweed and attached algae can only survive in species rich vegetation and are competed out by the less effective sago pondweed in species poor situations. They found a linear relation between biomass and binding of phosphate. Only the meta-analysis of Cardinale *et al.* (2012) did not find positive effects. They give some explanations, for instance that the service depends on very specific species. Scherer-Lorenzen *et al.* (2003) indeed found that a positive effect of biodiversity was only found in grasslands for non-leguminous species, as legumes increase N leaching to the groundwater. Cardinale *et al.* (2011) found a linear relation in heterogeneous conditions, where high species diversity is more effective than the best single species. In constant abiotic conditions, the relation is saturating and the best single species is more effective than high species diversity (Box 5.2). These results imply an effect of biodiversity on reliability of service provision. The fact that different salt marsh plant species have a higher nutrient uptake from (sea) water in different abiotic conditions also supports this implication (De Lange and Paulissen 2014).

Relevance of Green Infrastructure and National Nature network

Only the meta-analysis of Harrison *et al.* (2014) focused on habitat or community area and structure of the habitat type under concern, having a positive effect on purification effectiveness of that habitat type. Also stand age appeared to have a positive effect, indicating that old growth forests and permanent grasslands have an added value compared to early-successional forest and rotational grasslands. No studies focused on distance between the location where water is purified and where clean water is needed.

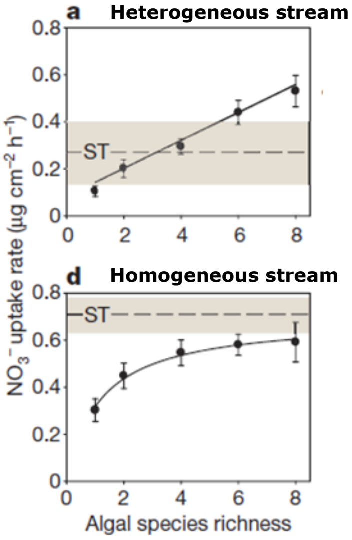
Table 5.2

Information found in scientific literature on the impact of biodiversity on effectiveness and/or reliability of Water Purification. The numbers in Harrison et al. (2014) refer to the number of times the effect was found for one of the biodiversity attributes in de selected studies.

No.	Study	Impact of biodiversity	Biodiversity attribute	Effectiveness attribute	Reliability attribute	Impact of GI/NNN
1	Cardinale *et al.* 2012 (review, global, various crop and nature types)	unclear	species diversity of algae and filter-feeding organisms	removal of nutrient pollutants		
2	Cardinale 2011 (lab experiments, California)	positive	algae species diversity	nitrogen uptake rates	nitrogen uptake rates in different habitat niches or streams	
3	Scherer-Lorenzen *et al.* 2003 (experi-ments, semi-natural grasslands Germany)	positive	plant species and functional group diversity	preventing N leaching to groundwater		
4	Engelhardt & Ritchie 2001 (experi-ments in artificial ponds, Utah, USA)	positive	macrophyte species diversity	preventing P loss		
5	Harrison *et al.* 2014 (meta-analysis global, various crop and nature types)	positive (19) unclear (5)	species/functional richness/ abundance/ size/weight/density biomass/ productivity species diversity size/weight biomass pop growth rate	various attributes		community/habitat area/structure stand age

Box 5.2 Reliability of Water Purification increases with biodiversity (Cardinale 2011)

In this example study, habitat heterogeneity in streams is simulated by varying stream velocities and disturbance rates in a model stream. In heterogeneous model streams different forms of algae dominate each unique habitat (niche). Here, nitrogen uptake rates (a) increases strongly (linearly) with algae species diversity to a rate that is much higher than the rate achieved by the most efficient single species (ST dashed lines). In uniform streams however, the algae community tends to collapse to one single species regardless of the initial species diversity. In this case nitrogen uptake (d) increases less strongly (saturating) with algae species diversity to a rate that is lower than the most efficient single species (ST dashed lines). These results imply that in homogenous systems Water Purification is most efficient using one species that is most efficient in that specific condition. However, in variable systems with disturbances or heterogeneous systems Water Purification is most efficient at a high diversity of species.



5.3 Regulating Service: Soil Fertility

Description of the ecosystem service

Soil Fertility depends on stimulating the nutrient cycle in the soil that ensure that basic elements like nitrogen (N), phosphorus (P) and carbon (C) become available from stabile soil complexes for uptake by crops. Soil (micro)-organisms like fungi, bacteria and earthworms play different roles in the complex nutrient cycle. They are responsible for biological and chemical processes or influence soil structure. The service is consequently delivered in agricultural systems, but can be influenced by natural systems.

Main conclusions Soil Fertility

The relation between biodiversity and Soil Fertility is often studied, besides (non-)leguminous vegetation mostly soil biodiversity is studied, see Table 5.3. Results are quite mixed, depending on the way Soil Fertility is defined and what soil organisms are studied. In general, if the trophic distance between the studied organism and soil nutrients is larger, relations are less clear. The majority of studies, however, did find a positive effect of below ground species diversity on effectiveness of Soil Fertility. This impact of below ground diversity on Soil Fertility seems to be linear. One of the selected studies reveals that a higher (soil) biodiversity leads to a higher reliability of Soil Fertility on longer time scales. Reliability for different abiotic conditions was not found. The relation between Soil Fertility and the NNN and GI is not studied, but we assume that fine-scaled GI network in agricultural landscapes is more important than the NNN.

Relevance selected literature for NL/EU situation

The meta-analyses and reviews focus on literature sources throughout the world and individual studies focus on grassland systems in Switzerland and UK. For European grassland these may be illustrative, but Dutch grassland systems are much richer in nutrients and intensively used and fertilized. Moreover, the grasslands are studied in experimental model systems.

Attributes of biodiversity and ecosystem service effectiveness/reliability

Cardinale *et al.* (2012) measure biodiversity by species richness or diversity, but they do not specify whether this concerns aboveground or belowground species or both. Other studies focus on diversity or composition of functional groups, like mycorrhizal and soil fauna species groups or species groups of different trophic levels.

As nutrient cycles are a complex of different processes, effectiveness attributes differ considerably, varying from mineralisation and decomposition rates, amount of (available) nutrients produced to the amount of soil organic matter in the soil. Balvanera *et al.* (2006) refer to stability or insurance indicators, referring to reliability of Soil Fertility, measured by temporal stability of effectiveness attributes or higher resistance to external forces as nutrient perturbations, drought, consumption, variable natural conditions or invading species. De Lange *et al.* (2013) found that species richness in earthworms leads to better resilience in ecosystem functioning under flooding conditions, but this was not specifically attributed to Soil Fertility.

Impact of biodiversity on Soil Fertility

The majority of studies found a positive effect of (belowground) biodiversity on Soil Fertility attributes. Cong *et al.* (2014) found also relations between aboveground (also non-leguminous) species richness and N stocks in the soil in Dutch former arable fields. Wagg *et al.* (2014) found a linear relation between biodiversity and Soil Fertility, combining all measured attributes of Soil Fertility into one attribute (see Box 5.3). However, also no or mixed effects were found. Bradford *et al.* (2002) for instance, found that microbial and root biomass, decomposition rate, and mycorrhizal colonization where all differently affected by soil species composition, so that the final net primary productivity was not markedly affected. Balvanera *et al.* (2006) stated that effects of biodiversity on Soil Fertility are weaker with higher trophic distance, if biodiversity levels are less well controlled and if studies focus on ecosystem and population level rather than on community level. Balvanera *et al.* (2006) also stated that higher biodiversity leads to higher reliability of Soil Fertility when looking at temporal stability, but not when variable abiotic conditions are taken into account. However, the review of Brussaard *et al.* (2007) showed that soil biodiversity stimulates resilience against (a)biotic disturbance and stress, for instance after fire, storms or insect outbreaks.

Relevance of Green Infrastructure and National Nature Network

None of the literature sources related Soil Fertility to natural habitat. Harrison *et al.* (2014) did focus on these aspects, but did not take Soil Fertility into account. This aspect may be underexposed due to the fact that Soil Fertility is delivered in crop systems and therefore studies focus on effects of agricultural management on the agricultural fields themselves, but not on the effects of (nearby) GI or NNN.

Box 5.3 Effectiveness of Soil Fertility: different responses to biodiversity (Wagg et al. 2014)

Different aspects of Soil Fertility (plant diversity, net productivity, Carbon Sequestration, litter decomposition, nitrogen turnover, N_2O emission, Phosphorous and Nitrogen leaching) all respond differently to soil biodiversity, but the overall effect of biodiversity on the combination of all these attributes together is positive in two model grassland ecosystems (open and closed circles).

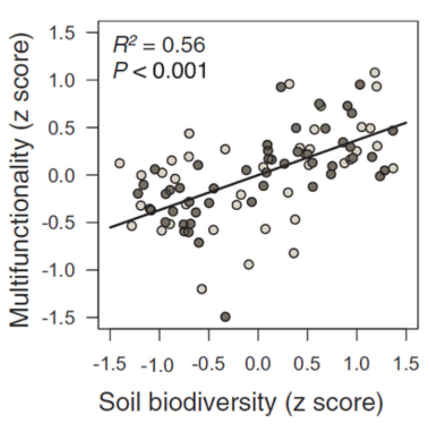


Table 5.3
Information found in scientific literature on the impact of biodiversity on effectiveness and/or reliability of Soil Fertility.

No.	Study	Impact of biodiversity	Biodiversity attribute	Effectiveness attribute	Reliability attribute	Impact of GI/NNN
1	Cardinale *et al.* 2012 (review, global, various crop and nature types)	positive	plant species richness/diversity	soil nutrient mineralization, soil organic matter		
2	Brussaard *et al.* 2007 (review framework global)	positive	mycorrhiza and soil fauna species diversity	nutrient use effectiveness	resilience against abiotic disturbance and stress	
3	Bradford *et al.* 2002 (experiments in model grassland ecosystems, UK)	mixed	soil faunal community composition	primary and net productivity		
4	Wagg *et al.* 2014 (experiments in model European grasslands)	mixed positive	soil biodiversity	plant diversity, net productivity, carbon sequestration, litter decomposition, nitrogen turnover, N_2O emission, Phosphorous and Nitrogen leaching combination of all of above attributes		
5	Balvanera *et al.* 2006 (meta-analysis, global, various crop and natural systems, mostly grasslands)	no or positive	biodiversity attributes not specified	decomposer activity, plant nutrient concentration, nutrient supply from soil	stability indicators	
6	Cong *et al.* 2014 (experiment former arable fields, the Netherlands)	positive	species richness of non-legume plant species		long-term N stock in the soil	
7	Handa *et al.*2004	positive	functional diversity of decomposer		cycling of litter carbon and nitrogen	

5.4 Regulating Service: Natural Pest Regulation

Description of the ecosystem service

Natural Pest Regulation is the ability of natural ecosystems to control pest species in order to reduce damage of arable crops and of fruit by these pest species. Pest species are herbivores feeding on or infecting crops or weed plant species competing with crops. The service is delivered by populations of natural enemies (e.g. insects, spiders, small mammals or birds) that eat, infect or parasitize pest species. The different ways in which natural enemies affect pest species are called functional traits or functional groups. The added value of this service is a decreased use of chemical pesticides and consequently lower pollution of the environment. The service is delivered in crop systems. It is produced however by biodiversity of natural habitat.

Main conclusions Natural Pest Regulation

For results of individual literature resources see Table 5.4. The relation between biodiversity and effectiveness is well studied as well as the role of GI/NNN, but reliability is not. The results of effectiveness studies are quite consistent, as a large majority of studies found an increase in Natural Pest Regulation with species diversity. However, there are also examples where higher levels of biodiversity have negative impacts, because of complex species interactions. The review of Harrison *et al.* (2014) however revealed that studies with positive effects clearly prevail. We expect that high species diversity is positive for the reliability (compare Pollination) but this is not assessed in the considered studies. This ES depends on the GI network supported by the NNN, especially flower rich grasslands and woody vegetation. Figures of 9 to 20% of non-crop habitat have been mentioned to ensure effective Natural Pest Regulation. The size and structure of natural areas is important, but also the distance between crops and surrounding GI (within 1 km). The relationship between Natural Pest Regulation and amount of habitat is assumed to have a logistic curve.

Relevance selected literature for NL/EU situation

We used several meta-analyses and reviews for which Natural Pest Regulation was one of the studied ES. These studies used literature from over the whole world and also included all kinds of crop systems and natural systems. Only the review of Bianchi *et al.* (2006) focused on agro-ecosystems of North America and Europe. The study of Baveco and Bianchi (2008) specifically addressed the situation of arable Dutch farms on clay soils. We added one specific model and experimental study in the Netherlands. Therefore we expect that the found results are relevant for the Dutch and European situation.

Attributes of biodiversity and ecosystem service effectiveness/reliability

In the meta-analyses, Natural Pest Regulation is related to biodiversity, mostly of natural enemies parasitoids like parasitic wasps or pathogens, in total or of different functional groups/traits. Harrison *et al.* (2014) do not specify what species are mentioned in the reviewed studies, but refer for example to predator species like insectivorous birds (Koh 2008). Biodiversity is measured at the species level (abundance, richness) or at the level of functional species groups or traits. Harrison *et al.* (2014) also include size and weight, biomass and productivity, natality rate and successional stage as biodiversity attributes. Most studies focus on effectiveness of natural pest control. Effectiveness is measured as attributes of pest species (density, abundance, mortality) where a lower pest abundance or density implicates a higher level of Natural Pest Regulation. Effectiveness is also measured by attributes of natural enemies. Measuring higher natural enemy activity implies higher effectiveness of Natural Pest Regulation, but this approach measures the suppliers and not the service itself.

Impact of biodiversity on Natural Pest Regulation

Most studies show positive effects of biodiversity on Natural Pest Regulation. For instance, diverse assemblages of natural enemies (predators, parasitoids and pathogens; generalists as well as specialists) are frequently more effective in reducing the density of herbivorous pests (Denoth *et al.* 2002). Several studies find mixed or negative effects of biodiversity on Natural Pest Regulation. This may be due to complex feedback loops between predators and pests, like predators feeding on alternative (non-pest) herbivore prey Oelbermann & Scheu (2009), or predators being eaten themselves by other predators (Vance-Charcraft *et al.* 2007, Letourneau *et al.* 2009, Xu *et al.* 2011; see also see Box 5.4-1). According to the review of Letourneau *et al.* (2009) positive effects of biodiversity dominate the negative effects on pest suppression. Only Harrison *et al.* (2014) quantified

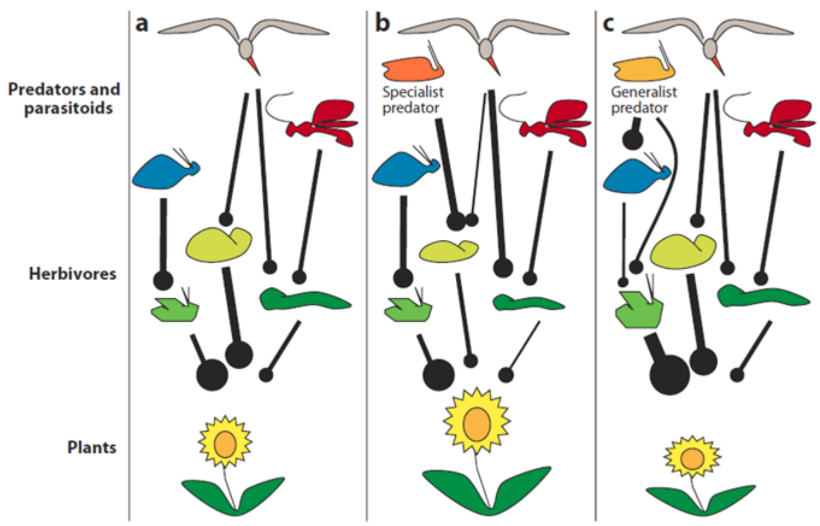
the number of studies with positive, mixed or negative effects and showed that effects of almost all biodiversity attributes on Natural Pest Regulation are positive (37), while only one negative effect on productivity is found. The effect of biodiversity differed somewhat between the used attributes, both species richness as biomass or productivity have strong effects on Natural Pest Regulation.
We expect that high species diversity is positive for the reliability (compare Pollination) but this is not assessed in the considered studies.

Relevance of Green Infrastructure and National Nature Network
The service is delivered in crop systems and is produced by biodiversity of surrounding GI and NNN. This effect of natural habitat on (gathering behaviour) of pest regulating species is quite well investigated. It is often not clear, however, how landscape structure affects the pest regulating service they deliver (Chaplin-Kramer *et al.* 2011, Bianchi *et al.* 2010). Flower rich grassy vegetation delivers nectar and host plants for regulating species, while woody habitat is also needed for nesting and overwintering. Especially soil dwelling predators need high connectivity between crops and natural habitat (Alebeek & Clevering 2005). In Harrison *et al.* (2014) many studies reveal (strong) positive effects of habitat or community area and structure on Natural Pest Regulation (e.g. Bianchi *et al.* 2010). They did not specify whether this concerned habitat of GI or NNN. Bianchi & Van Der Werff (2003) state that the 9% of the surrounding landscape of crops should exist of natural habitat that is evenly distributed over the landscape, preferably hedgerow elements. Tscharntke *et al.* (2002) however state that it takes up to 20% non-crop area before parasitism levels in the centre of crop fields are as high as in field edges. Steingröver *et al.* (2010) state that robust elements (NNN) are most important for Natural Pest Regulation within 1000 m. of crops. When less robust elements are present , G.I., the network of elements needs to be finer. Den Belder *et al.* (2002) suggested however that pesticides have a higher effectiveness on onion thrips in the Netherlands than surrounding woodlots. On the other hand, woodlots may deliver a higher reliability, but this was not investigated. The review of Bianchi *et al.* (2006) shows that the relation between crop injury of oil seed rape and the amount of non-crop habitat in Germany (Thies & Tscharntke 1999) is logistic, suggesting that adding habitat is most effective near the infliction point. Baveco and Bianchi (2008) mapped the predicted parasitation rate in crop fields assuming a logistic relation between amount of forest in the surroundings and parasitation rate (Box 5.4-2).

Box 5.4-1 Effectiveness of biodiversity for Natural Pest Regulation depends on species (Letourneau et al. 2009)

In an experiment, increasing natural enemy diversity by introducing a specialist predator (b) that feeds only on herbivores can improve the pest suppression on crop plants (compare a and b). However, introducing a generalist predator (c) that not only feeds on herbivores but also on other natural enemies may limit pest suppression (compare a and c).

However Harrison et al. (2014) found that in almost all reviewed cases a higher enemy diversity leads to higher suppression of herbivores and thus to higher crop production (b), and that the number of cases leading to lower suppression of herbivores and thus to lower crop production (c) is negligible.



Box 5.4-2 GI/NNN contributes to Natural Pest Regulation (Baveco & Bianchi 2008)

The predicted rate of Natural Pest Regulation (parasitism on pest species) in the neighbourhood of forest lots in a randomly selected landscape (Zuid-Flevoland, the Netherlands). The Natural Pest Regulation on the field varies from low (pink) to high (red), depending on the amount of forest in the surrounding landscape (forest density increases from light green to dark green).

(Figure b is a detail from Figure a).

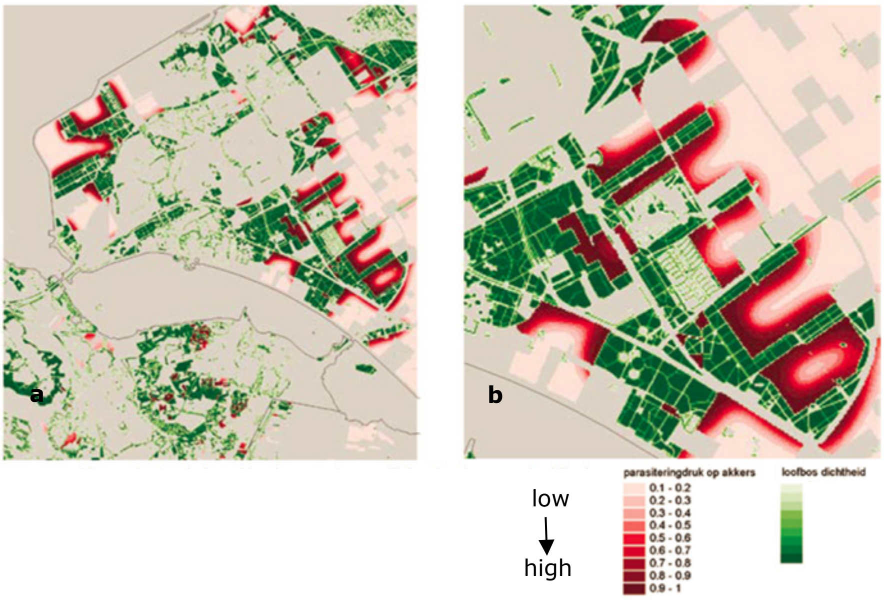


Table 5.4
Information found in scientific literature on the impact of biodiversity on effectiveness and/or reliability of Natural Pest Regulation. The numbers in Harrison et al. (2014) refer to the number of times the effect was found for one of the biodiversity attributes in de selected studies.

No.	Study	Impact of biodiversity	Biodiversity attribute	Effective-ness attribute	Reliability attribute	Impact of GI/NNN
1	Harrison *et al.* 2014 (meta-analysis global, various crop and nature types)	positive (37)	pop/species/functional abundance/richness/ diversity size/weight behavioural traits pop growth rate biomass/productivity natality rate	several, e.g. pest abundance of pest diversity		community/ habitat area/structure stand age
		negative (1)	successional stage productivity			
2	Cardinale *et al.* 2012 (meta-analysis global, various crop and nature types)	mixed	diversity of functional groups (predators, parasitoids, pathogens)	several, e.g. herb pest abundance, density		

No.	Study	Impact of biodiversity	Biodiversity attribute	Effective-ness attribute	Reliability attribute	Impact of GI/NNN
3	Bianchi *et al.* 2006 (review, agro-ecosystems in N-America and Europe)	mainly pos (70-80% of studies)		natural enemy activity		herb or woody habitats, landscape patchiness
4	Letourneau *et al.* 2009 (meta-analysis, global, various crop and nature types)	mixed (185 studies pos, 80 negative)	species richness of natural enemies	herbivore density and mortality		
5	Baveco & Bianchi 2008 (model and field experiments on cabbage fields in Netherland)	positive		parasitism rate of moth caterpillars		area and location of forest within 5 km.

5.5 Regulating Service: Pollination

Description of the ecosystem service

Pollination is the ability of natural ecosystems to pollinate plant species in order to produce fruit and seeds of arable crops (e.g. courgettes, sugar beets), fruits (e.g. strawberries), (fruit)trees and wild plant species. The service is delivered by populations of pollinating species (mostly honey bees, wild (solitary) bees, bumble bees, hover flies and butterflies). The added value of this service is an increased fruit set and a higher level of cross pollination over larger distances. This leads to improved exchange of genetic material of plant species and decreased labour costs of manual pollination. The service is delivered in agricultural crops, but is produced by biodiversity of natural habitat.

Main conclusions Pollination

This ES depends especially on flower rich grasslands and woody vegetation, see Table 5.5. The relation between Pollination effectiveness and biodiversity and also the relation with GI/NNN is relatively well studied and results are mostly consistently positive. Effectiveness (fruit set) increases with higher species diversity, also cross pollination occurs over larger distances. The relation is saturating, maybe even an optimum. Species diversity increases the reliability with wind disturbance, where wild pollinator species remain more effective than honey bees at higher wind speed. This ES depends on the GI network supported by the NNN. The vicinity of natural habitat near agricultural fields is positive for flower visits in crops. The number of flower visits decreases exponentially with the distance to natural habitat and drops below 50% at distances over 1300 m.

Relevance selected literature for NL/EU situation

We used several meta-analyses/reviews for which Pollination was one of the studied ES and several individual studies including Europe and the Netherlands. These studies used literature from over the whole world and also included all kinds of crop systems and natural systems. Several individual empirical studies are included that studied the effect of the vicinity of natural habitat on Pollination.

These are mainly from Californian almond orchards, but we believe that the conclusions on the behaviour of honey bees and wild bees are useful in Europe and the Netherlands.

Attributes of biodiversity and ecosystem service effectiveness/reliability
Pollination is related to diversity of wild pollinator species, besides cultivated honeybees, like wild bees, bumblebees, butterflies or hover flies. Functional groups/trait are for instance generalists (visiting many plant species) versus specialists (visiting a specific plant species), bees and butterflies with short or long tongues or groups differing in flying distances during nectar collection. Biodiversity is mostly measured at the species level (abundance, richness) or at the level of functional species groups (behavioural traits). Also species weight or size is taken into account (Harrison *et al.* 2014). Most studies focus on effectiveness of Pollination. Effectiveness is sometimes measured as fruit set or flower visitation rate, although the latter attribute is also used as biodiversity attribute. Some meta-analysis studies only specify the used biodiversity attributes, but not the used effectiveness attributes. Reliability is hardly studied, therefore it is difficult to pronounce upon how effectiveness and reliability influence each other for this specific ES.

Impact of biodiversity on Pollination
Most studies show positive effects of biodiversity on Pollination effectiveness, but also studies with mixed or no effects have been found. However, the meta-analysis of Harrison *et al.* (2014) revealed that most studies found positive effects of species diversity (17 times), while only 3 relations were unclear. Many studies also found a positive effect of behavioural traits but mixed effects of species abundance. This can be caused by invasive species (Munoz & Cavieres 2008), while competition between managed honey bees and wild pollinators can lead to unclear relations (Allsopp *et al.* 2008, Shavit *et al.* 2009). Garibaldi *et al.* (2013) found in 41 crop systems over the world that wild bees both increase fruit set in the large majority of studies, and that the effectiveness (increase of fruit set) of wild bees was twice as high compared to that of honey bees. There is little information on how strong effects are or what effect sizes are in the meta-analysis or what the shape is of the ES-biodiversity curve. Harrison *et al.* (2014) illustrated the predominant direction and strengths of biodiversity effects using a quantitative method. They showed that species richness of specific functional groups has the strongest effects on Pollination, but did not explain what functional groups were involved. Winfree (2013) states that the relation between biodiversity and Pollination is saturating or logistic, while Albrecht *et al.* (2012) stated that Pollination may even be slightly reduced again at highest species richness if increasing species richness leads to a lower visitation by more effective pollinator species.

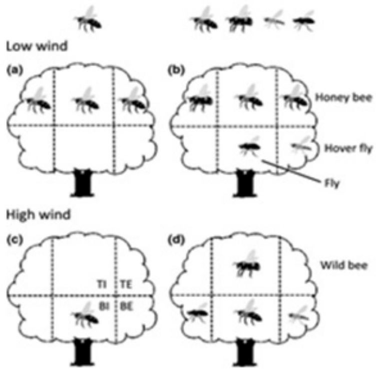
The role of biodiversity for reliability of Pollination is not well studied. One example of biodiversity affecting reliability is the study of Brittain *et al.* (2013) showing that a higher pollinator diversity leads to lower decrease in Pollination effectiveness at increasing wind speeds (see Box 5.5-1). Also, Winfree *et al.* (2007) stated that native bees provide insurance against ongoing honey bee losses.

Relevance of Green Infrastructure and National Nature Network
The service is delivered in crops, but is produced by biodiversity of surrounding GI and NNN. Flower rich grassy vegetation deliver nectar and host plants for pollinating species, while in addition woody habitat is needed for nesting and overwintering. Several reviews, meta-analyses and individual studies found positive effects of the vicinity of natural habitat (NNN) and strips of (semi-)natural vegetation (GI) on effectiveness and reliability of Pollination (see also Box 5.5-2). Effects on fruit set were unclear, however in the review of Ricketts *et al.* (2008), but other studies did find effects of biodiversity on fruit set. Ekroos *et al.* (2013) did not find effects of landscape heterogeneity on Pollination, indicating that this measure may not be specific enough for Pollination. The fact that presence of semi-natural vegetation has an impact on short distances, e.g. within 1 km, shows that processes of Pollination happen on relatively small spatial scales (< 1.5 km Ricketts *et al.* 2008, < 1 km Garibaldi *et al.* 2011), matching insect foraging distances (Kremen *et al.* 2004). This indicates that GI and NNN should be situated close to crops that depend on Pollination. Ricketts *et al.* (2008) found an exponential relation between distance to natural habitat, and found in temperate zones that visitation rate drops below 50% of maximum values at distances over 1300 m.

An important precondition (supporting service) of Pollination diversity is plant diversity. Weed diversity of natural patches within sunflower fields increased flower visitor diversity, hence ameliorating the measured negative effects of isolation from natural habitat (Cavalheiro *et al.* 2011). After establishing natural habitat adjacent to crops with perennial vegetation, it may take several years before flower abundance increases and pollinating insects colonize these habitats (Blaauw & Isaacs 2004).

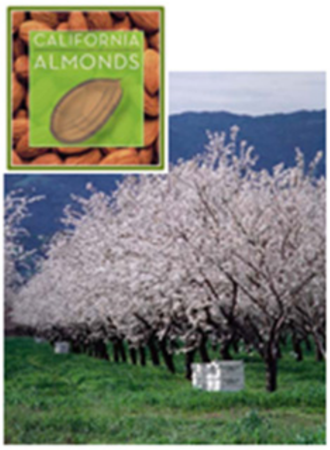
Box 5.5-1 Reliability of Pollination increases with biodiversity (Brittain et al. 2013)

Low diversity Californian orchards contain only or mostly honey bees (a), but high diversity orchards are also visited by other pollinator taxa including wild bees (b). At high wind speeds, total flower visits decrease in low diversity orchards (c) as visits by honey bees visits decrease disproportionately. At high wind speeds the total number of flower visits is much higher in high diversity orchards (d), as the dropping visits by honey bees are buffered by wild pollinators.



Box .5.5-2 Pollination increases with amount of GI/NNN (Klein et al. 2012)

In Californian almond orchards, flower visitation frequency of honeybees (a) decreases with percentage of natural habitat within a radius of 1 km, while that of wild bees (b), hover flies (c) and other visitors (d) increases with percentage of natural habitat. Differences in visitation frequency between conventional (open, dashed line) and organic (filled, solid line) almond orchards are relatively small (each point represents one orchard).



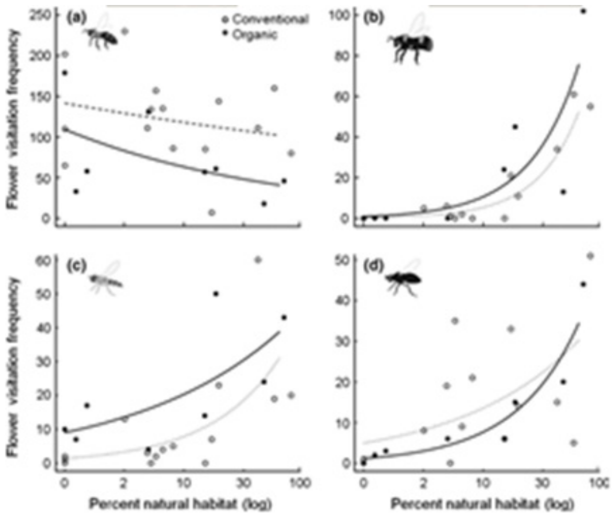


Table 5.5

Information found in scientific literature on the impact of biodiversity on effectiveness and/or reliability of Pollination. The numbers in Harrison et al. (2014) refer to the number of times the effect was found for one of the biodiversity attributes in de selected studies.

No.	Study	Impact of biodiversity	Biodiversity attribute	Effective-ness attribute	Reliability attribute	Impact of GI/NNN
1	Cardinale *et al.* 2012 (meta-analysis global, various crop and nature types)	mixed	Species diversity	not defined		
2	Garibaldi *et al.* 2013 (review, global)	positive	Flower visitation by wild and honey bees.	Fruit set		
3	Ekroos *et al.* 2013 (empirical, Europe)	Positive No effects	Abundance bumblebees and butterflies in GI			Proximity of semi-natural grassland Landscape heterogeneity
4	Harrison *et al.* 2014 (meta-analysis global, various crop and nature types)	positive (17) unclear (3)	species/ functional abundance/ richness/ diversity Behavioural trait species richness species size/weight	not defined		community/ habitat area/structure community/ habitat area
6	Ricketts *et al.* 2008 (review global, various corps)	positive unclear effects	pollinator richness	native visitation rate fruit/seed set		vicinity natural habitat vicinity natural habitat
7	Kennedy *et al.* 2013 (meta-analysis, global, several crops)	positive	bee abundance, richness			amount of high-quality habitats in surroundings
8	Kremen *et al.* 2004 (empirical, California USA)	positive		pollination effective-ness	pollination reliability	prop. of natural habitat in vicinity of farms within bee foraging ranges
9	Klein *et al.* 2012 (empirical, California, almond orchards)	positive	number of wild bee species	flower visitation rates, fruit set		% semi-natural habitat < 1 km, presence of adjacent semi-natural GI

No.	Study	Impact of biodiversity	Biodiversity attribute	Effective-ness attribute	Reliability attribute	Impact of GI/NNN
10	Brittain *et al.* 2013 (empirical, California, almond orchards)	positive	pollinator diversity		flower visitation at higher wind speeds	
11	Garibaldi *et al.* 2012 (review, global)	positive			spatial and temporal stability of flower visitor richness, visitation rate and fruit set by wild bees	vicinity of florally diverse (semi) natural areas < 1km
12	Blaauw & Isaacs 2004	positive		fruit set, fruit weight and seed set		presence of GI, flower strips, adjacent to blueberry fields

5.6 Production Service: Wild Food

Description of the ecosystem service

Wild Food is the ability to collect or harvest edible products like fruits, nuts, mushrooms but also vegetables and herbs for medicinal purposes. In literature also the term non-timber products is used, but this can also comprise decorative purposes. Consequently, the ES of Wild Food is delivered and produced by natural habitat.

Main conclusions Wild Food provision

There is insufficient information available to draw conclusions for the European situation, see Table 5.6. Studies on Wild Food focussed on developing countries related to the nutritional value it delivers. It is hardly studied in temperate climate zones and results can therefore not be extrapolated to the European situation. Perhaps not the nutritional but the cultural value of Wild Food is a better way of approaching the value of Wild Food in the European context.

Relevance selected literature for NL/EU situation

Most literature related to wild Food consumption focuses on middle and low income countries so relevance for the European or Dutch situation is low. The essay of Honnay *et al.* (2012) has relevance to Belgium (and for the Dutch situation) and the focus of Jones & Lynch (2007) on pacific Northwest forest in the USA may also be useful for the European situation, but none of these studies analyse the relevance of biodiversity for the provision of Wild Food. Most studies focus on the importance of Wild Food to the nutritional value of the diet of local people (e.g. Vinceti *et al.* 2013). Jones & Lynch (2007) revealed the considerable contribution of wild products of US forests, like edible mushrooms, to (local) economy, although emphasis may have shifted from subsistence to commercial and recreational pursuits. This shift may also hold for European countries. These authors also mention the lack of research in this field and stress that current biodiversity conservation management does not take wild food productions into account. In general forest managers see wild food collection as a threat to biodiversity.

Attributes of biodiversity and ecosystem service effectiveness/reliability

No studies focused on the relevance of species richness or diversity for provision of Wild Food. Jones & Lynch (2007) focused on the social relevance of wild food collection. They did mention however, that a large diversity of harvested non-timber wild species represents a considerable subset of the overall terrestrial biodiversity in Pacific Northwest forests. They did not deliver any data however to proof this relation between overall biodiversity and diversity of non-timber species. Honnay *et al.* (2012) supported the importance of species diversity because of the importance of population genetic diversity in crops, for which related wild species needed are needed to breed new crop varieties that are better resistant to diseases or more tolerant to stress. For instance wild potato species are more resistant to *Phytophthora*. They did not analyse this however, but only stressed the need for study on this topic.

Impact of biodiversity on provision of Wild Food

From the available studies no conclusions can be drawn on the impact of biodiversity on the provision of Wild Food. Penafiel *et al.* (2011) stated that local availability of Wild Food is important for human diets, but this has mostly been analysed in highly biodiverse areas in low and middle income countries, but not in urbanized settings in high income countries like the Netherlands. Vinceti *et al.* (2013) mentioned several constraints for optimal use of biodiversity in diets, varying from cultural aspects, lack of sustainable use of Wild Food, lack or organisation or knowledge of non-wood forest products, and forest biodiversity not being managed for multiple benefits.

Relevance of Green Infrastructure and National Nature Network

Wild Food is produced in GI and NNN, but none of the selected literature has related the service to (spatial) characteristics of natural elements.

Table 5.6

Information found in scientific literature on the impact of biodiversity on effectiveness and/or reliability of Wild Food.

No.	Study	Impact of biodiversity	Biodiversity attribute	Effectiveness attribute	Reliability attribute	Impact of GI/NNN
1	Honnay *et al.* 2012 (essay)	not analysed	species diversity of wild plants	plant crop varieties		
2	Jones & Lynch 2007 (essay on Pacific Northwest forests, USA)	not analysed	overall terrestrial biodiversity	diversity of harvested species		
3	Penafiel *et al.* 2011 (review, global)	not analysed	wild plant and animal biodiversity	energy intake, micronutrient intake, dietary diversification		
4	Vinceti *et al.* 2013 (essay)	not analysed	trees and wild plants	sustainable diets		

5.7 Cultural Service: Well-being and Aesthetic Appreciation

Description of the ecosystem service

Diversity of landscapes and species can be appreciated for recreational purposes (walking, cycling) but can also contribute to well-being by improving physical or mental health of people.

Main conclusions Well-being and Aesthetic Appreciation

This ES is already quite often studied, although different studies focus on different aspects of Well-being and Aesthetic Appreciation, see Table 5.7. Positive effects of biodiversity have been found in most studies. However, there are also studies where no effects were found, as differences in species diversity were not always recognized by visitors. None of the studies focused on reliability of Well-being and Aesthetic Appreciation. There is an indication that the appreciation increases linearly with the size of nature areas, which illustrates the importance of the NNN.

Relevance selected literature for NL/EU situation

Many reviews and meta-analyses do mention well-being in general, but do not treat it as a specific ES. These studies were not involved in our study. The selected meta-analysis includes all kinds of studies all over the world. The cited experimental studies focus on European sites, where results found in urban parks and lowland grasslands are more similar to the Dutch situation than results from alpine studies. Moreover, public in urban parks and lowland grasslands are visited probably more by local inhabitants, while in alpine grasslands many tourists from abroad will be involved.

Attributes of biodiversity and ecosystem service effectiveness/reliability

Biodiversity is measured by species abundance, richness, diversity and evenness, in general or of specific species groups (plants, butterflies, pollinators) or functional groups (size/weight). Harrison *et al.* (2014) also included studies using size or weight, natality rate, life span and successional stage. Conspicuously, some studies measured both actual species richness (counted in the field) as perceived richness as estimated by visitors.

Effectiveness is measured by aesthetic appreciation of a specific habitat type or the whole landscape as indicated by visitors themselves. Also well-being (physical or mental) is measured, by visitors themselves or by attributes measured by researchers. Fontana *et al.* (2014) measured functional biodiversity (flower colour and edible or healing plants) as effectiveness measure and linked this to biodiversity in general. Harrison *et al.* (2014) distinguished species orientated recreation and landscape aesthetics.

Impact of biodiversity on Well-being and Aesthetic Appreciation

Most studies reveal a positive effect of biodiversity on Well-being and/or Aesthetic Appreciation. Harrison *et al.* (2014) mention positive effects of biodiversity of 21 attributes on species oriented recreation and only one unclear effect. They mention positive effects of 7 attributes on landscape aesthetics. People's aesthetic appreciation as well as the perceived species richness increased with true species richness, especially when species evenness was high (Lindemann *et al.* 2010). However, also no or no clear effects have been found. There may be several reasons for this. First, in the case of aesthetic appreciation, biodiversity has only a positive impact when measured by traits or attributes that are relevant for human appreciation (Fontana *et al.* 2014). Hall *et al.* 2011 elaborated that not only tree diversity but specific large charismatic flag-ship trees attribute to a high Aesthetic Appreciation of forests, but the authors did not assess whether these trees are more often found in forests with higher species diversity. Probably their occurrence is also linked to forest age.

The type of visitors may also influence results, as Junge *et al.* (2009) found that the visitors of Swiss lowland grasslands were attracted by the naturalness of field margins, unlike farmers in earlier studies, as they are aware of the biodiversity value of natural elements. Lindemann *et al.* (2010) found a linear relation between Aesthetic Appreciation and biodiversity, but slightly different relations for passers-by in Swiss lowlands than for tourists in the mountain near Davos (Box 5.7). Dallimer *et al.* (2011) found, unlike Lindemann *et al.* (2010) no positive relation between estimated and actual species richness by visitors of green spaces in Sheffield, UK. This may be due to the fact that not all types of visitors are able to notice actual differences in species diversity. Shwartz *et al.* (2014) found that visitors of public gardens in Paris, France, were not able to notice actual difference in species diversity without being informed.

In the case of physical or mental Well-being, the absence of a positive effect of biodiversity may be due to the small body of evidence, heterogeneous or unsuitable attributes of biodiversity and of health and the complexity and multidimensionality of links between biodiversity and good health (Lovell *et al.* 2014).

Relevance of Green Infrastructure and National Nature Network
The meta-analysis of Harrison *et al.* (2014) revealed a positive effect of habitat / community area or structure on landscape aesthetics, where effects of structure were found in a larger number of studies compared to effects of area. Lovell *et al.* (2014) however did not find positive effects of landscape diversity or distance to natural parks on perceived species diversity or physical or mental health or on well-being.

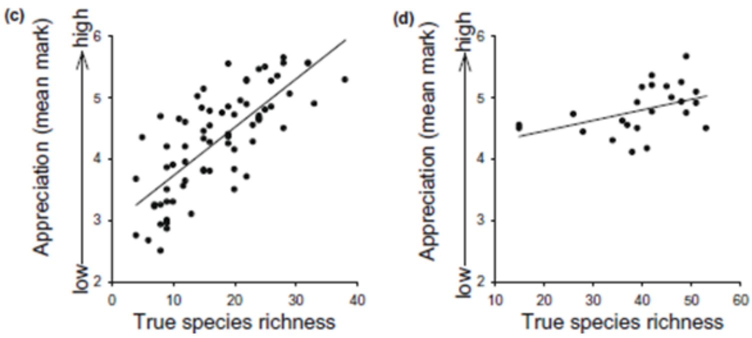
Table 5.7
Information found in scientific literature on the impact of biodiversity on effectiveness and/or reliability of Well-being and Aesthetic Appreciation. The numbers in Harrison et al. (2014) refer to the number of times the effect was found for one of the biodiversity attributes in de selected studies.

No.	Study	Impact of biodiversity	Biodiversity attribute	Effective-ness attribute	Reliability attribute	Impact of GI/NNN
1	Harrison *et al.* 2014 (meta-analysis, global, various crop and nature types)	positive (21)	pop/species/functional abundance/richness/ diversity size/weight natality rate life span (= -mortality rate)	species oriented recreation		community/ habitat area/structure
		unclear (1)	functional richness			
		positive (7)	species richness/abundance successional stage	landscape aesthetics		community/ habitat area/structure
2	Fontana *et al.* 2014 (experimental, Italian alps, grassland)	positive (scenic beauty)	diversity of plant species	functional diversity (flower colour and edible or healing plants)		
3	Lindemann *et al.* 2010 (experimental, Germany and Switzerland, grasslands)	positive	plant species richness, plant species evenness	aesthetic apprecia-tion of way-side meadows		
4	Lovell *et al.* 2014 (review, global)	not clear	various attributes of actual and perceived species diversity	various attributes of physical health, mental health and well-being		various attributes of landscape diversity, distance to national park
5	Junge *et al.* 2009 (experimental, Swiss lowland field margins)	positive	estimated species richness	attractive ness rated by visitors		

No.	Study	Impact of biodiversity	Biodiversity attribute	Effective-ness attribute	Reliability attribute	Impact of GI/NNN
6	Dallimer *et al.* 2012 (experimental, public green spaces of Sheffield, UK)	positive no effect	perceived species richness actual plant, butterfly and bird species richness	mental well-being of visitors		
7	Shwartz *et al.* 2014 (experimental, public gardens in Paris)	unclear	species diversity of plants, butterflies and pollinators	preference rate		

Box 5.7 Effectiveness of species richness for Aesthetic Appreciation depends on type of public (Lindemann *et al.* 2010)

Lindemann *et al.* (2010) found a stronger (linear) effect of true species richness on Aesthetic Appreciation of way-side meadows scored by passers-by in Swiss lowlands (c) than scored by tourists in the mountain near Davos (d). This implies that the effect of biodiversity on Aesthetic Appreciation depends on the type of public. Also the species richness of mountain grasslands is higher than that of lowland grasslands.



Appreciation of 2x2 plots by passers-by near Zurich

Appreciation of 25x1 plots by tourists near Davos

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Verschenen documenten in de reeks Technical reports van de Wettelijke Onderzoekstaken Natuur & Milieu

WOt-Technical reports zijn verkrijgbaar bij het secretariaat van Unit Wettelijke Onderzoekstaken Natuur & Milieu te Wageningen. T 0317 – 48 54 71; E info.wnm@wur.nl

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