



# The Doren project: improving the response curves of habitat types to nitrogen deposition

Phase 2

Wieger Wamelink, Hans Roelofsen, Roland Bobbink, Dennis te Beest, Lian Grabijn, Meike Josemans, Han van Dobben, Robert Baayen, Friso van der Zee



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Wageningen Environmental Research  
B-WARE Research Centre, Radboud University, Nijmegen

This research was subsidised by the Dutch Ministry of Agriculture, Fisheries, Food security and Nature (project number BO-5200047647).

Wageningen Environmental Research  
Wageningen, February 2025

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Reviewed by:  
Members of the international scientific steering committee

Approved for publication:  
Dr Joke C. de Jong, Wageningen Environmental Research, leader of the  
Biodiversity & Policy group

Report 3414  
ISSN 1566-7197

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Wamelink, G.W.W., H.D. Roelofsen, R. Bobbink, D.E. te Beest, L.T.P. Grabijn, M.J. Josemans, H.F. van Dobben, R.P. Baayen, F.F. van der Zee, 2025. *The Doren project: improving the response curves of habitat types to nitrogen deposition; Phase 2*. Wageningen, Wageningen Environmental Research, Report 3414. 134 pp.; 49 fig.; 8 tab.; 34 ref.

In 2021 is er een rapport verschenen met responscurven voor habitattypen voor stikstofdepositie, inclusief de curven voor de onderliggende soorten. De curven waren opgesteld door een verband te leggen tussen vegetatieplots uit de EVA-database en gemodelleerde stikstofdepositie door EMEP voor de Atlantische regio. Deze curven konden deels worden gevalideerd met velddata. Hieruit bleek dat dit goed ging voor een groot deel van de typen, maar niet voor alle. Ook vertoonden sommige soorten onverwachte resultaten. In dit onderzoek is geanalyseerd hoe de curven verbeterd konden worden. Dit bleek mogelijk door een verbetering van de kwaliteit van de inputdata en het verzamelen van meer validatiegegevens. Een andere significante verbetering is dat nu ook de onzekerheid in de responscurven wordt aangegeven.

In 2021, a report was published containing response curves for habitat types to nitrogen deposition, including curves for the underlying species. The curves were estimated by linking vegetation plot information from the EVA-database with modelled nitrogen deposition by EMEP for the Atlantic region of Europe. These curves were partly validated with field data. It was found that this worked well for a large part of the habitat types, however, not for all. Additionally, some species showed unexpected responses. The present study analysed how the curves could be improved, primarily by enhancing the quality of the data and collecting more validation data. Furthermore, we are now able to specify a confidence interval for the response curves.

Keywords: nitrogen deposition, critical load, response curves, climate change, soil type, empirical range

The pdf file is free of charge and can be downloaded at <https://doi.org/10.18174/687456> or via the website [www.wur.nl/environmental-research](http://www.wur.nl/environmental-research) (scroll down to Publications – Wageningen Environmental Research reports). Wageningen Environmental Research does not deliver printed versions of the Wageningen Environmental Research reports.

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Wageningen Environmental Research Report 3414 | ISSN 1566-7197

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# Verification

Report: 3414

Project number: 5200047647

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This report was reviewed by members of the international scientific steering committee:

Dr. J. Aherne, Trent University, Canada

Dr. T. Dirnböck, Umweltbundesamt, Austria

Dr. A.M. Kooiman, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, the Netherlands

Dr. T. McDonnell, Oregon Lakes Association, United States of America

Dr. M. Posch, International Institute for Applied Systems Analysis, Austria

Dr. E.C. Rowe, UK Centre for Ecology and Hydrology, United Kingdom

Dipl.-Geogr. T. Scheuschner, Umweltbundesamt, Germany

Dr. H. Siebel, Natuurmonumenten, the Netherlands

Dr. B. van der Veen, Department of Mathematical Sciences, Norwegian University of Science and Technology, Norway

Prof. Dr. W. de Vries, Earth Systems and Global Change, Wageningen University, The Netherlands

Prof. Dr. M.J. Wassen, Copernicus Institute of Sustainable Development, Utrecht University, the Netherlands

Approved by the team leader responsible for the contents,

name: Dr J.C. de Jong

date: 4-2-2025



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# Preface

Following the initial report concerning a modernised methodology for modelling response curves for nitrogen deposition (the Doren project), we present the second report. We looked into some of the problems identified in the response curves and concerns that were raised. We also implemented the new empirical critical load ranges and critical loads for the Netherlands. Much work still can be done to improve the response curves for nitrogen deposition for habitat types further, partly by applying the recommendations from this report.

The Doren-2 project resulting in this report was guided by a steering committee. The committee consisted of Martin Wassen, Annemiek Kooiman, Bert van der Veen, Julian Aherne, Ed Rowe, Todd McDonnel, Thomas Dirnböck, Wim de Vries, Max Posch, Henk Siebel and Thomas Scheuschner. We thank them all for their valuable input, especially at the end of the project, by improving the draft version of this report. We thank Max Posch also for providing the EMEP data.

Wieger Wamelink



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# Summary

In 2021, a report (Doren-1) was published containing response curves for habitat types to nitrogen deposition, based upon the response curves for the characteristic species per habitat type. Species response curves were based on vegetation plots and nitrogen deposition computed by the EMEP model. Response curves for habitat types were based on the response curves of individual characteristic species for the habitat types. These curves were partly validated with field data. Most of the 61 habitat types had a reliable response curve. However, some curves were considered unreliable by expert judgment. Additionally, some species showed an unexpected response to nitrogen deposition.

*Doren is an acronym for the Dutch 'Dosis responsecurven voor stikstofdepositie N' which translates into dose-response curves for nitrogen deposition.*

In this study we analysed how the curves could be improved. This was primarily done by enhancing the quality of the data and collecting more validation data. We also developed a method that provides more insight into the underlying database of vegetation plots which revealed some issues with the data. A solution to solve these problems was given.

Validation of the response curves is of utmost importance to provide confidence that they can be used for forecasting. To this end, additional validation data were collected from literature. To improve quality assurance, the programme that handles the data and estimates the response curves was translated from the programming package Genstat into R.

One of the options we considered for curve improvement was using clay content of the soil instead of soil types. However, inspection of the European soil map (from ISRIC) revealed that clay content probably will not improve the estimation of the response curves. Using the available data could introduce a too large uncertainty. For this reason, we decided to keep using the soil types. However, also the soil type map has a large uncertainty and in general it is better to use measurable quantities such as clay content.

Already from the start of the previous Doren-1 project, it was clear that the species composition of the habitat types would largely influence the outcome of the response curve per habitat type. Therefore, in Doren-2 (this report), four different species lists were tested for the outcome of the habitat type response curve. The alternative species lists, based on 'Red List' criteria or Dutch typical species, did not generate more reliable response curves. Furthermore, the minimum number of ten characteristic species was not always achieved for the alternative species lists. Therefore, we decided to keep using the original list, but without the displacement species, since this provides more reliable response curves. Displacement species are here defined as species belonging to the habitat type, but that profit from nitrogen deposition, and thus show an increasing response to nitrogen deposition, thereby replacing other species.

To further improve the validity of the curves, the uncertainty in the response curves is now also provided. To this end, we included a bootstrap procedure in the program. Results revealed that some parts of some curves are highly uncertain, especially at very high deposition levels where few data were available. This resulted sometimes in an unrealistic (steep) increase of the curve at the highest deposition levels. For this reason, we did not include any extrapolation in response curves beyond the deposition levels at which the habitat types were found in the field. For now, this is only done based on the data available for the habitat type responses and not for the species responses. In future, extrapolation per species should also be avoided. However, this complicates the estimation of the curves for the habitat types.

It was hypothesized that summed nitrogen deposition might be a better indicator than the five-year average deposition, for impact of nitrogen deposition on the vegetation. Therefore, the summed nitrogen deposition over the period from 1880 up to and including year of plot survey was calculated for each vegetation plot, but no actual curves were estimated yet.

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Finally, we reassessed the results from the previous Doren-1 project which were based on previous empirical ranges and critical loads with more recent data. We reassessed the response curves with new ranges and critical loads of 2022 and 2023 that became available and used these. This led to a significant improvement. Note that this new assessment does not include the improvements made in this project, it reflects only the effect of the changed empirical CL and CL. The curves already qualified as 'good' showed an improved agreement with the new empirical ranges and critical loads. Moreover, two habitat types were now qualified as 'good' instead of fair and two types improved from the category 'poor' to 'fair'. If the improvements from this are also taken into account, then eight habitat types go from fair to good, four habitat types from poor to fair, five habitat types from poor to good and one habitat type from good to fair. Thus 49 habitat types are now judged as good, 6 as fair and 4 as poor.

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# 1 Introduction

## 1.1 General introduction

In 2021, the Doren-1 project was finalized (Wamelink et al. 2021). The goal of the project was to estimate response curves for nitrogen deposition for habitat types occurring in the Netherlands. Estimation of response curves was constrained to habitat types enlisted as vulnerable for nitrogen deposition and identified to suffer from exceeding a certain nitrogen level, i.e. the critical load (CL, Van Dobben et al. 2012, 2014). Vegetation data and nitrogen deposition data were collected for the Atlantic region and used together with information about climate (temperature and precipitation) and soil type to estimate the response curves. Doren-1 succeeded in estimating response curves for 60 out of 61 vulnerable habitat types. All response curves per habitat type and underlying species responses were evaluated and partly validated on independent data (Wamelink et al. 2024). This revealed that, for most habitat types, the response curve agreed with the field data and/or agreed with expectations (which means that a downward response curve with increasing nitrogen deposition was identified for vulnerable habitat types). Moreover, response curves were in line with the CL and empirical critical load ( $CL_{empN}$ ) (Bobbink & Hettelingh 2011). However, for a minority of the habitat types, response curves deviated from what was expected by experts or based on empirical critical loads and critical loads. In the current report (Doren-2 project), we present new analyses in an attempt to improve response curves and gain a better understanding of constructing responses for habitat types based on plant species.

In total thirteen potential solutions were formulated at the beginning of the present project to explain and possibly improve the unexpected response curves. Five of them were investigated:

1. In Doren-1, many choices and assumptions were made. It therefore does not come as a surprise that some response curves (for species and/or habitat types) gave unexpected results. Was the curve itself wrong or were the assumptions invalid? The curves were derived from datasets that were not specifically collected for our purpose. These different and varying goals may influence the curves. Therefore, several selections were made to limit uncertainty and bias on the EVA-database (Chytrý et al. 2016). The EVA-database contains European vegetation plots. After the selections, still some puzzling effects remained. Visualizing the raw data in Doren-2 may give insight into the reasons for some of the unexpected responses.
2. In Doren-1, we collected data from empirical nitrogen deposition gradient studies in Europe for the validation of the response curves. In Doren-2, we added new data.
3. In Doren-1, we hypothesized that the effect of nitrogen deposition is soil type dependent. Soil types were derived from the European soil map. The 26 different soil types (FAO, 2015) were clustered into five main types: sand, clay, young soils, peat and water. The soil type was used as a covariate for the response curve. In Doren-2, we investigated using clay ('lutum') content of the soil as a covariate as an alternative for the (clustered) soil types. Lutum is the Dutch term for soil fraction below 2  $\mu\text{m}$  diameter. When lutum content of the soil exceeds 8% the soil is called 'zavel' and beyond 25% it is considered 'clay'. This topic was briefly evaluated, results are given in Appendix 1.
4. In Doren-1, response curves for species and habitat types were used without assessing their uncertainty. In Doren-2, via a bootstrap method, we gained insight in the uncertainty of the responses. This could also reveal the reliability of for instance the sometimes-small increases of the responses at very high deposition levels.
5. In Doren-1, five-year averages were calculated for N-deposition. It is also possible to estimate the summed deposition. As a starting year we chose 1880. The sum of the deposition is the deposition summed over the years till the year the vegetation plot was recorded. It can be argued that an ecosystem is not so much influenced by the deposition in recent years, but rather the accumulation over a longer time period. As more nitrogen accumulates in the system, a larger effect may be expected. The advantage of this method is that unequal variation in deposition over years between plots, or sudden increases or decreases are leading to cumulative values that can be compared between plots. In other words, it no longer matters whether one gets a lot of deposition for a short time or a little bit for a long time, the accumulation counts. Preparations for testing a potential effect of cumulative values were carried out in Doren-2. They were not tested in full due to a lack of funding (for a description, see Appendix 2).

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In 2022, the empirical critical loads were updated (Bobbink et al. 2022) and consequently the critical loads for the Netherlands in 2023 (Wamelink et al. 2023). In Doren-1, the response curves were evaluated based on the old empirical critical loads and critical loads. In Doren-2, we reevaluated the response curves using the new empirical critical loads and critical loads for the Netherlands.

Doren is an acronym for the Dutch 'Dosis responsecurven voor stikstofdepositie N' which translates into doses response curves for nitrogen deposition.

In the following paragraphs, each of the five topics is introduced separately.

## 1.2 EVA-database

For the Doren-1 calculations, several choices and assumptions had to be made. It therefore is not surprising that some response curves (for species and/or habitat types) yielded unexpected response curves. The question is subsequently, was the curve wrong or are the expectations wrong? The datasets used for the estimation of the response curves had their limitations. They were not collected for this project, and all projects had their own specific research goals. Not all data available in the EVA-database (Chytrý et al. 2016) were used, selections were made (see Wamelink et al. 2021 and Chapter 2 of this report) and covariables were added to minimize noise and bias as much as possible. It never will be ideal given the different goals of the data sets present in EVA, but the goal was to systematically work towards an optimal selection for this project.

A thorough review of the data selected may reveal some anomalies explaining some of the unexpected results. To be able to do this with such a large data set, we designed several visualisation methods that could reveal outliers. A limited number of concrete cases were investigated, so that artifacts and other misinterpretations could be identified.

## 1.3 Additional empirical relationships between atmospheric nitrogen deposition and plant species richness: a visual inspection

An important approach for studying effects of N deposition – besides N-addition experiments – is through exploring changes in ecosystem structure and/or functioning along a N-deposition gradient (e.g. Bobbink et al. 2022). Such (targeted) N-gradient studies may provide information on longer-term responses of increased N-deposition and serve to demonstrate that responses observed in experiments are also found in the real-world. Most of such studies used species richness of the vegetation – or specific components thereof – as a bioindicator. Based upon these data, dose-response curves for N-deposition can be estimated.

In Doren-1, a new methodology was developed to estimate habitat dose-response curves based upon the European database of vegetation plots (EVA) and modelled N-deposition values (Wamelink et al. 2021). The resulting dose-response curves for N-sensitive habitats were validated – where possible – by the empirical outcome ('dose response curve' via visual inspection) of published N-gradient studies in the same habitat type. This comparison has been done from nine field studies within nitrogen gradients. Despite the limited amount of empirical validation data, validation was possible for 35% of the habitat types with a response curve. The main aim of this part of the current study (Doren-2) is to analyse newly published N-gradient studies from additional habitats to enlarge data-pool for validation of the habitat curves.

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## 1.4 Evaluation of the response curves from Doren-1

Building on the improved database (Chapter 3), we recalculated the species and habitat types response curves. A determining factor for the response curve, is the degrees of freedom for the spline, i.e. the number of knots or 'inflection points'. In Doren-1, the number of degrees of freedom was set at 2. However, earlier research (Wamelink et al. 2005) showed that allowing more degrees of freedom gives sometimes a more reliable spline. Therefore, the goal here was twofold, i.e. to evaluate the response curves and to investigate the effect of the number of degrees of freedom on the response curve. For three different species, the number of degrees of freedom was varied to investigate the effect on the response curve. The evaluation was done to test the R-program, but also to test the changes we implemented based on the review of the database (Chapter 3) and the application of the new empirical critical load and CL. The new curves were compared with the curves from the Doren-1 project and reassessed.

## 1.5 Species composition of habitat types

In Doren-1, a species list per habitat type was compiled by linking vegetation records from the 'Vegetation of the Netherlands' (Schaminee et al. 1995-1998) database to habitat types. Further selection based on fidelity and coverage of a species for a habitat type were made, utilizing several threshold values resulting in a list of characteristic species. A question that arose was: what is the minimum number of constituent species in a habitat for building a reliable nitrogen deposition response curve for a habitat type? A second and even more urgent question was: which species are eligible for inclusion in the species list per habitat type?

In Doren-1, some habitat types contained many species (e.g. up to 158 species for Alkaline fens). This could be genuine, but it might also be better to tighten the criteria for species selection. Besides that, it is important to note that characteristic species exist which benefit from deposition and thereby influence the overall response of a habitat type. This may result in unexpected positive response of the habitat type on nitrogen deposition. Or it may result to a curve that is insensitive for nitrogen deposition whilst the habitat type does contain N-sensitive species and the habitat type itself is also known to be sensitive to nitrogen deposition.

Examples of this can also be found in the results of Doren-1, such as the response for Wet heathland (4010A) on sandy soils. Here the new calculation resulted in a slightly increasing response for nitrogen deposition based on a limited number of characteristic species. Some of these decreased with higher nitrogen deposition, as expected, whilst others proved to increase with increasing deposition. This resulted in an increasing trend for nitrogen deposition. In contrast, the same habitat type on lowland peat (4010B) did show the expected decrease.

Therefore, the goal was to evaluate variations in habitat-type species lists compiled on different criteria, mostly being a subset of the lists used in Doren-1. This also provided an opportunity to quantify the sensitivity of the dose-effect relationship of a habitat type to the species choice.

## 1.6 Confidence interval

A simple bootstrap method was implemented to estimate the statistical uncertainty on the basis of the presence/absence data. The aim was to visualize the uncertainty of the curves based on the bootstrap method. It may reveal why some curves show unexpected behaviour. The bootstrap method was applied to the habitat type and the underlying species response curves.

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## 1.7 Reassessment of the response curves from Doren-1 solely based on the empirical range from 2022 and the critical load from 2023

In Doren-1, the habitat type response curves for nitrogen deposition were assessed based on the empirical critical load ranges of Bobbink & Hettelingh (2011), as well as the critical load by van Dobben et al. 2012). Since the release of the Doren-1 report, both the empirical critical load range (Bobbink et al. 2022) and the critical load (Wamelink et al. 2023) for Dutch habitat types were revised and updated. This chapter gives the assessment of the old response curves from Doren-1, but now considering the updated empirical ranges and critical loads by the first author.

Some habitat type response curves were additionally validated against field data. The plotted figures are now also available including the critical load (Wamelink et al. 2023) and the empirical critical load range (Bobbink et al. 2022). They are given here as well (Appendix 8). The assessment by five experts did not change since neither the empirical range nor the critical load played a role in the validation. Note that this assessment deviates from the one mentioned here above, which referred to responses judged and evaluated by the first author only, whereas here the validation is carried out on independent field data, assessed by five experts and a statistical test (Lin's test of concordance, Lin 1989). Although more field data were collected in this research, they were not yet used for validation because of lack of time.

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## 2 Material & methods

To clarify the coming chapters, we here include the material and methods section from Wamelink et al. (2021). The work carried out to improve the response curves described in this report comprised deviations of that original method. These deviations are described in the following paragraphs.

### 2.1 Method to estimate response curves for nitrogen deposition for species and habitat types: material and methods from Doren-1

Directly describing the quality of a habitat type as a function of nitrogen deposition based on vegetation plots is currently not possible. There is no tool available to assign vegetation plots to habitat types on a European scale. Therefore, we derived the response of a habitat type to nitrogen deposition from response curves for the characteristic species associated with the habitat type. These response curves, i.e. the probability of occurrence of a species as a function of nitrogen deposition, were estimated on the basis of vegetation plots. The steps required for this are described in detail below.

#### 2.1.1 Characteristic species for the habitat types

In this project, the response curve of a habitat type for nitrogen deposition is derived from the response curves for the plant species associated with the habitat type. This section describes how the list of so-called characteristic species for a habitat type was created. A list of typical species has been drawn up for each Dutch habitat type (<https://www.natura2000.nl/beschermde-natuur/habitattypen>). However, this list has the following disadvantages:

- Typical species are not available for every habitat type;
- The number of typical species is limited. Species not mentioned in the list of typical species are sometimes very diagnostic for the habitat type, i.e. their presence determines the quality of the habitat type;
- Partly as a result of nitrogen deposition, a habitat type can change, and other species can become characteristic of a habitat type. The question is whether they should be included at all in the list.

Because of these disadvantages, a list of characteristic species has been drawn up based on the principles and database behind the reference textbook *De vegetatie van Nederland* (Schaminée et al. 1995). Two criteria were used: (1) the percentage occurrence of a species, or simply the presence; and (2) the degree of fidelity of a species (see also Rowe et al. 2016), or the extent to which a species is tied to a plant community which means that the species is quite uniquely diagnostic for that community. The fidelity rate can be calculated on the basis of attendance, fidelity presence, or on the basis of the coverage, fidelity coverage. The latter is calculated based on the average cover of a species in a plant community. Characteristic species then meet at least one of the following five conditions, as calculated on the basis of the database belonging to *De vegetatie van Nederland* (SynBioSys):

1. Presence  $\geq$  10% and fidelity presence  $\geq$  7%;
2. Presence  $\geq$  10% and fidelity coverage  $\geq$  7%;
3. Presence  $\geq$  4% and fidelity presence  $\geq$  30%;
4. Presence  $\geq$  2% and fidelity presence  $\geq$  85%;
5. Presence  $\geq$  85%.

These conditions are based on Smits et al. (2016) and adjusted for this project, with conditions 4. and 5. being added because otherwise a number of typical species would not have been selected. Even then, some typical species, which are deemed as typical by experts, were not selected. These have been added manually

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afterwards. Because the species list has been determined by means of an algorithm, all habitat types have been checked to assess whether all selected species are indeed 'quality indicative'. Species were removed based on the following rules:

- It is a tree species (see below);
- A species occurs frequently in other habitat types and is not characteristic of the type in question (low fidelity);
- Whether or not the species occurs has no influence on the quality of the habitat type (expert knowledge);
- A species is indicative of disturbance;
- It is a species that could not be identified; an example of this is *Agrostis canina/vinealis*.

Tree species form a separate category because they have a long lifespan and therefore may be poor indicators of the effects of nitrogen deposition. In addition, trees are often planted in the Netherlands, but also in many places abroad, and therefore do not always provide a good indication of the natural situation or their natural distribution area. To prevent the disturbing influence of trees, they have not been included as indicative species for a habitat type, not even in forests. An exception was made for willow species which are generally not planted.

The electronic appendix in Wamelink et al. (2021, file "Characteristic species and displacement species.xlsx") contains the resulting characteristic species for 67 habitat types mentioned in Appendix 2 of Wamelink et al. These are coded with a 1 or a 2, with a 2 indicating that the species is both a characteristic and a displacement species. The species coded with a 3 are pure displacement species that are not characteristic; these species are discussed and analysed in Wamelink et al. (2021).

In this study, displacement species are defined as species that profit from nitrogen deposition, and thus show an increasing response to nitrogen deposition, and replace other species. Displacement species may 'invade' habitat types because of the nitrogen deposition and thus not be typical or normal absent in the habitat type. However, invasive species can also be typical for the habitat type and increase due to nitrogen deposition, e.g. *Deschampsia flexuosa* in dry heath.

### 2.1.2 Classification of habitat types into structure types

Many plant species occur in different habitat types. This applies, for example, to black crowberry (*Empetrum nigrum*), which occurs in both "Dune heaths with black crowberry (moist)" and in "Moist dune valleys (decalcified)". Because the response curve for a habitat type is based on the response curves of the associated characteristic species, it is important to make the response curve for a species as specific to a habitat type as possible. It is therefore desirable to estimate separate response curves for black crowberry in "Dune heath with black crowberry (moist)" and for black crowberry in "Moist dune valleys (decalcified)". To this end, all vegetation plots used to estimate species response curves should be assigned to a habitat type. However, no link has yet been established between vegetation plots and habitat type on a European scale. We solved this issue by dividing both plots into 11 so-called vegetation structure types (Table 1), as well as dividing the habitat types into the same structure types. The roughness factor is an additional relevant measure for structure (forests have a high roughness and potentially capture more atmospheric deposition). The derivation of a response curve for a habitat type, with a certain structure type, is then based on the estimated response curves based on the vegetation plots of the same structure type. The classification of habitat types into structure types is given in Appendix 2 of Wamelink et al. (2021). Note that some habitat types are linked to two structure types. The linking of vegetation plot to structure type is described in section 2.1.4.

**Table 1** Structure types, the corresponding abbreviations used in figures and the roughness factor. The abbreviations are based on the Dutch names of the structure types.

Structure type	Abbreviation	Roughness
Dry dwarf shrubs	D-DS	low
Dry grassland	D-G	low
Dry deciduous forest	D-B	high
Dry shrub	D-S	high
Swamp	MOE	low
Wet dwarf shrubs	N-DS	low
Wet grassland	N-G	low
Wet deciduous forest	N-B	high
Water streams	SWAT	low
Water	WAT	low
Salt	ZOU	low

### 2.1.3 Selection of vegetation plots, the EVA-database

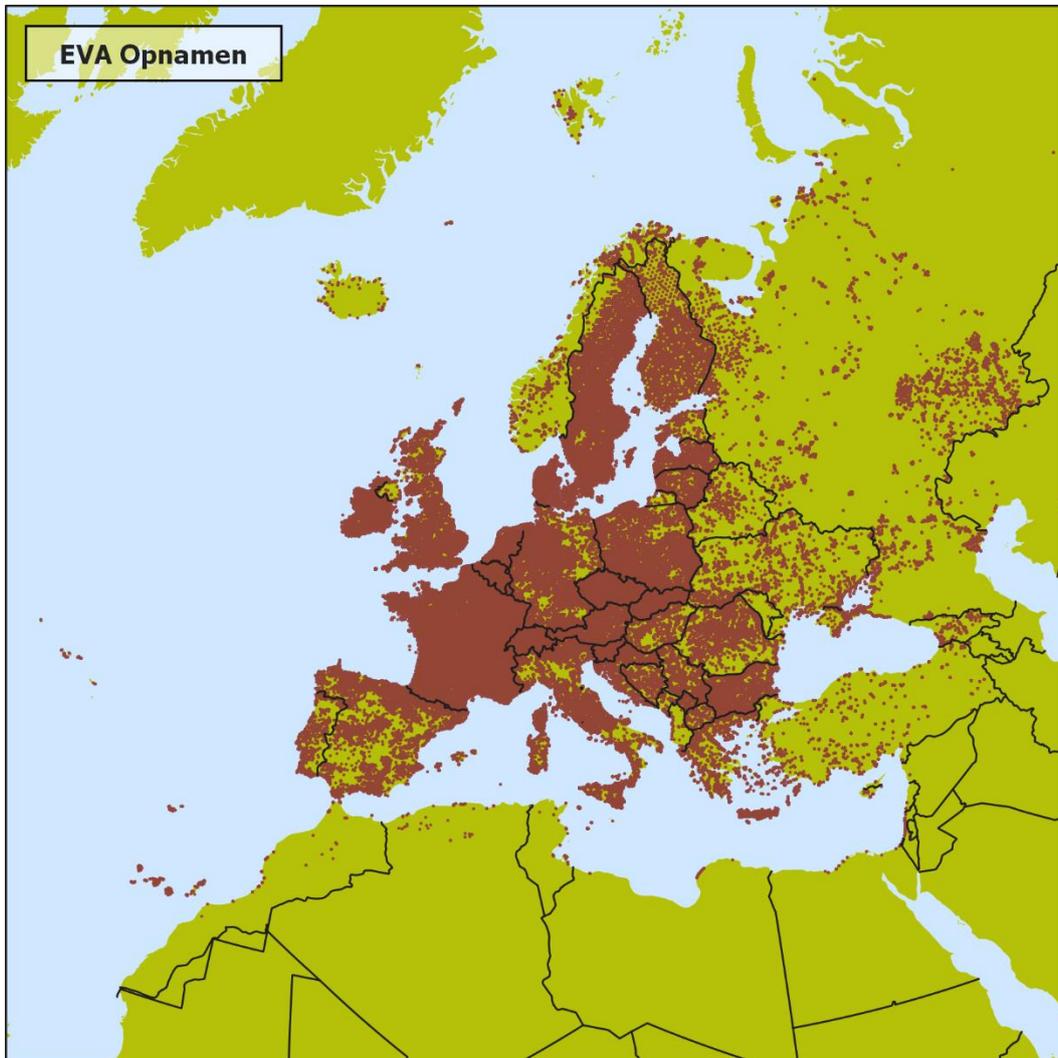
Response curves for species are estimated based on vegetation recordings (plots) from the EVA database (version 2018; Chytrý et al. 1996), see Figure 1. The EVA database is maintained by the European Vegetation Survey (EVS), a Working Group of the International Association for Vegetation Science (IAVS). The database consists of European vegetation plots (European Vegetation Archive; <http://euroveg.org/eva-database>). Use of the database is free, but a proposal has to be submitted to EVS and database contributors have the option to block the use of their own data.

In this project, the effect of nitrogen deposition on habitat types in the Netherlands is studied. It is important to (1) use plots with the widest possible range of nitrogen depositions in order to properly estimate response curves, especially for low depositions; and (2) only use plots obtained under comparable environmental conditions to the ones in The Netherlands. Criterion (1) implies that not only recent plots in the Netherlands, with high deposition values, should be used, but that the search area and the year of plot should be expanded. Criterion (2) implies that restrictions must be imposed on this expansion.

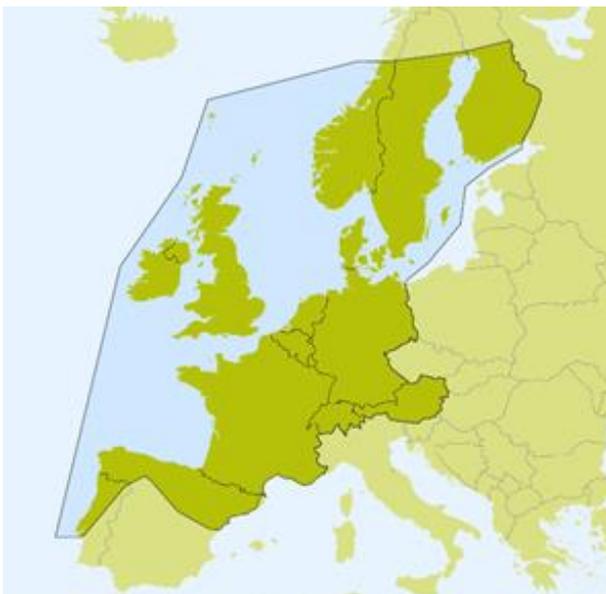
The chosen compromise between (1) and (2) is formed by using vegetation plots from 1950 onward in the area shown in Figure 2. Only plots with a known latitude and longitude have been selected so that a link with the nitrogen deposition and the altitude of the plot was possible. The selected area consists of the so-called Atlantic zone supplemented with Germany, the lower parts of Austria and Switzerland and France. Towards the north, plots above the Arctic Circle were not selected because of different climatic conditions. To prevent the climatological differences with the Netherlands from becoming too large, only plots below an altitude of 500 m were selected (based on a European covering altitude model; U.S. Geological Survey, 1996). Above that, the climatic conditions will deviate too much. By also using early plots, i.e. from 1950 onwards, we succeeded in adding more plots with low deposition values, however with the disadvantage that nitrogen deposition in the (distant) past is less well known.

For the Atlantic region 1,356,335 plots were available, of which 158,597 were missing at least one essential parameter, leaving 1,197,738 plots that could be used.

The selection of plots from the EVA database and linkage to covariates was performed in program language Python. The code can be consulted online. An automatically generated report of the procedure is available by emailing the first author.



**Figure 1** Location of the vegetation plots available from the EVA database. Only plots from the Greater Atlantic area (see Figure 2) have been selected.



**Figure 2** Area from which plots were selected for estimating nitrogen response curves of plant species.

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#### 2.1.4 Classification of vegetation plots into structure types

Section 2.2.2 describes how response curves for a species were estimated on the basis of vegetation plots belonging to one, sometimes two, structure types. To this end, it was necessary to link plots to structure types. The classification by structure type is based on EUNIS types (European Nature Information System, EUNIS). Using expert rules (Chytrý et al. 2020), all selected plots in the database were assessed and, where possible, assigned to an EUNIS type. The EUNIS types available for the Atlantic region have subsequently been translated into structure types (Appendix 3, Wamelink et al. 2021). For the plots that could not be classified by the expert rules, an earlier classification was used that was already linked to some of the plots (Appendix 4, Wamelink et al. 2021). For some plots no EUNIS type could be assigned; these plots were not used.

#### 2.1.5 Nitrogen deposition of the vegetation plots

For the nitrogen deposition, we used the computational estimates as made by the “European Monitoring and Evaluation Programme” (EMEP, [www.emep.int](http://www.emep.int)). Within this program, nitrogen deposition is estimated (modelled) in a uniform manner for the whole of Europe. EMEP makes a distinction between NO<sub>x</sub> and NH<sub>y</sub> concentrations in the air and also in the depositions derived from them. In principle, separate response curves can be estimated for both forms of nitrogen. Previous research shows that plant species can respond differently to NO<sub>x</sub> and NH<sub>y</sub> and that the ratio between the two molecules could be important (Stevens et al. 2011). In this study, however, both depositions were added together to form the total inorganic atmospheric nitrogen deposition, expressed in kmol/ha/yr or in kg/ha/yr.

For the period 2000-2017, EMEP provides the nitrogen deposition for the whole of Europe per year on a grid of 0.1° × 0.1° (Tsyro et al., 2018, 2019). The depositions were generated within EMEP with so-called “source receptor matrices” (SRMs). These SRMs were applied, among other things, in the GAINS evaluation model (Amann et al. 2011). For the years before 2000, the deposition is only available for 5-year intervals (1995, 1990, ..., 1945) and for a coarser grid (0.50° × 0.25°). These earlier depositions are based on calculations as described in Schöpp et al. (2003). The deposition of the five intermediate years for the period 1945-2000 have been estimated by means of linear interpolation.

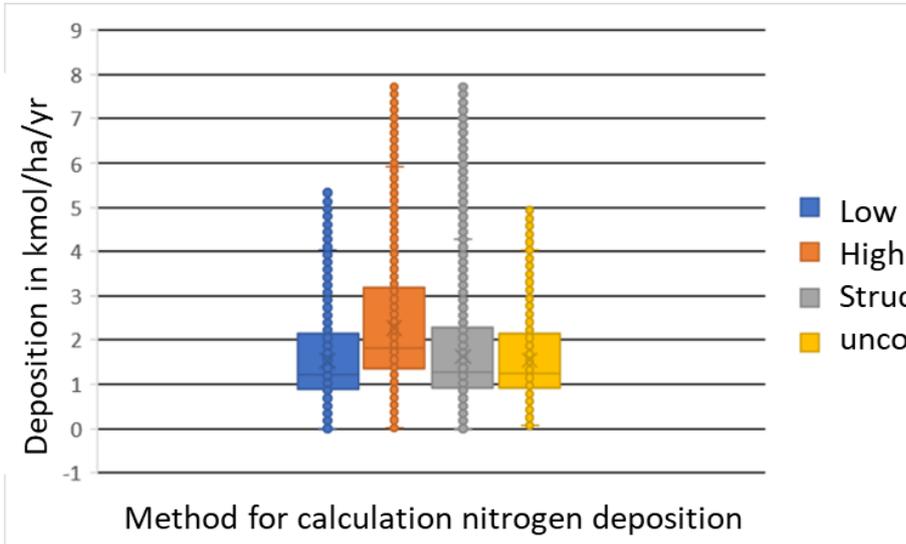
The deposition of a plot is calculated, based on its latitude and longitude, via bilinear interpolation on the grid, see Appendix 5 (Wamelink et al. 2021). This was carried out for the year of the plot and for the four years before, after which the average over these five years was assigned to the plot. Annual species are mainly affected by the deposition that falls in their year of growth, while long living species are related to the deposition over a much longer period. The five-year average is assumed by us seems a reasonable compromise. The same period was used in the PROPS model (Wamelink et al. 2019), however, Rowe et al. (2017) use the much longer period of 30 years.

It is clear that the uncertainty in the calculated deposition is larger further in the past. This is due to the fact that (1) depositions from before 2000 were calculated with an older model, (2) depositions from before 2000 are available on a coarser grid, which makes the interpolations more uncertain, and (3) older deposition calculations are simpler, especially before 1960, based on only a few data and cannot be validated. The resulting uncertainty has currently not been mapped.

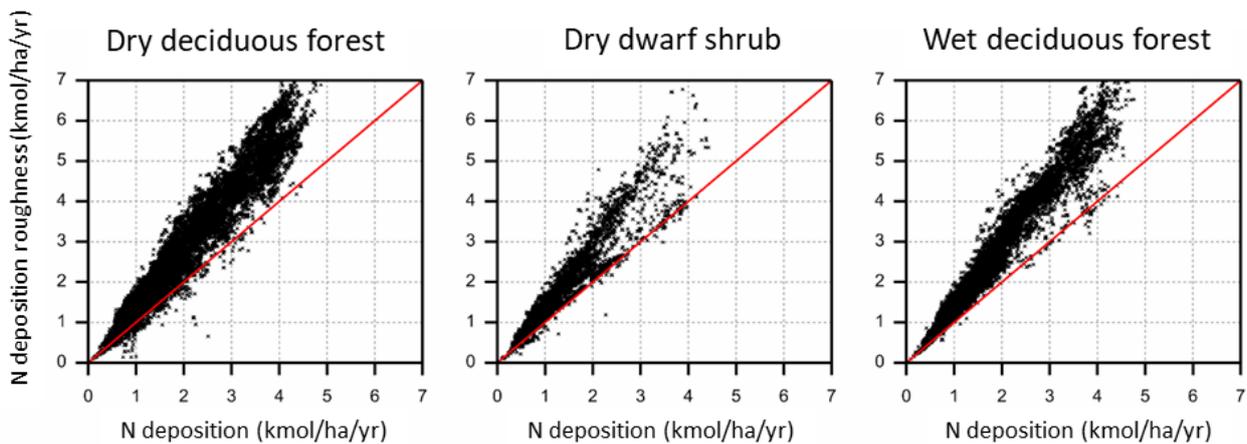
The deposition for a plot is not only dependent on atmospheric conditions at the location (such as wind speed and direction), but also on so-called roughness factors. The roughness is largely determined by the shape and height of the vegetation. The roughness is taken into account in the EMEP MSC-W atmospheric transport model by using a vegetation map. This improved model takes roughness into account and by calculating a low deposition for plots with a low roughness and a higher deposition for plots with a high roughness. The roughness factor of a plot is defined by the structure type, see Table 2, of the plot. The EMEP MSC-W is described by Simpson et al. (2012, 2014) and in the annual updates of the EMEP calculations ([www.emep.int/mscw](http://www.emep.int/mscw)).

Typically, EMEP provides deposition in three ways: grid average, semi-natural, or woodland per grid. The effect of these three ways on the calculated deposition is given in Figure 3. In theory, the use of the roughness factor results in a deposition that is more accurately representing the actual deposition on that habitat. However, overall, the differences between the uncorrected deposition and the deposition corrected for roughness appeared to be not large (Figure 3). However, differences at plot level were observed. For

plots with a high roughness factor, the differences are shown in Figure 4 with clearly higher depositions when roughness is taken into account. For plots with a low roughness factor in Figure 5, the differences are smaller, and it is striking that low uncorrected depositions often become even lower after correction for roughness. In an earlier calculation in this project, with estimated response curves for species without a breakdown by structure type, the response curves with uncorrected and corrected deposition were compared. This showed that there were small differences. Since, we think that deposition based on the roughness factor better matches the local situation and especially the relevance for the vegetation, we decided to use these in this study.



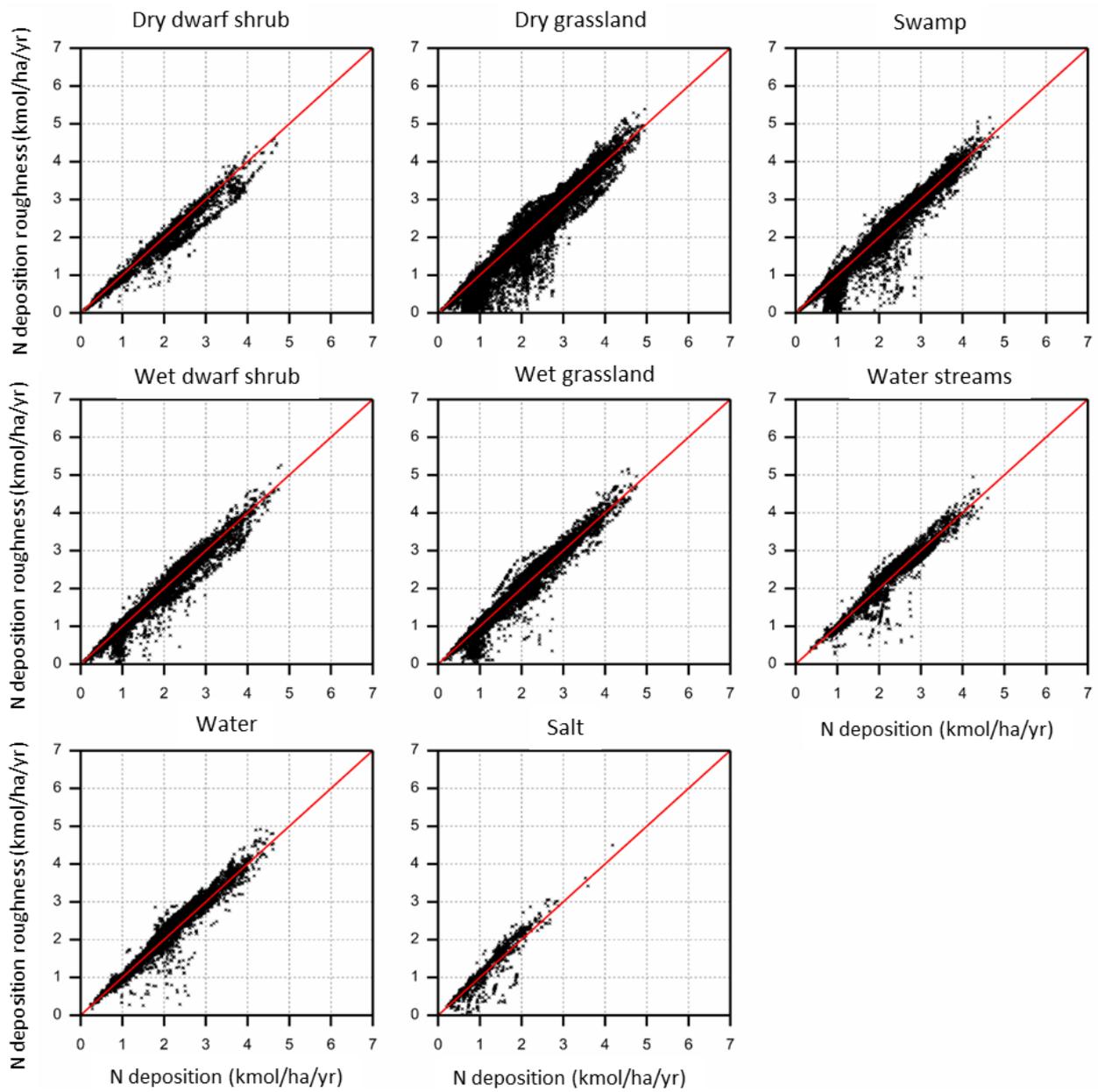
**Figure 3** Box plot for the uncorrected deposition (yellow; not used in this research), the low deposition for all plots (blue, not used in this research) and the roughness-corrected deposition based on the structure type of each plot (grey).



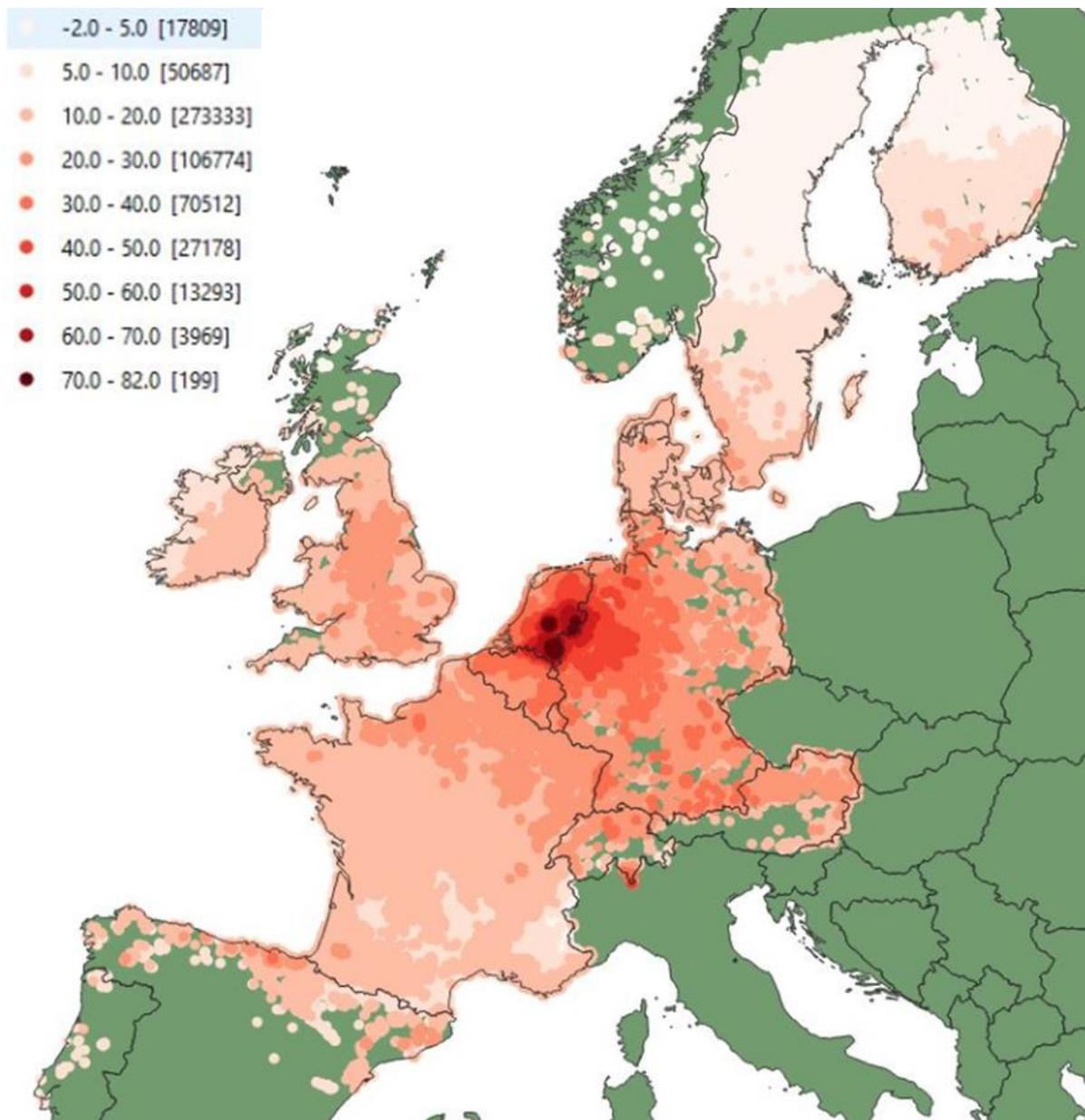
**Figure 4** Nitrogen deposition corrected for the roughness factor of a plot versus the uncorrected nitrogen deposition for vegetation types with a high roughness factor.

The spatial visualization of the roughness-corrected nitrogen deposition per plot is given in Figure 6. The deposition of more recent plots is plotted over that of older plots so that adjacent depositions can come from different years. It appears that the highest depositions occur in the Netherlands and parts of Germany. Figure 7 shows the number of plots per year for which a deposition is available. There are relatively few plots from before 1970, while most plots are from after 2000. Figure 8 shows that most depositions are in the categories between 0.6 and 1.3 kmol/ha/yr. Very high values, larger than 4 kmol/ha/yr, occur only sporadically. In a limited number of cases the interpolated deposition is negative or zero, which of course

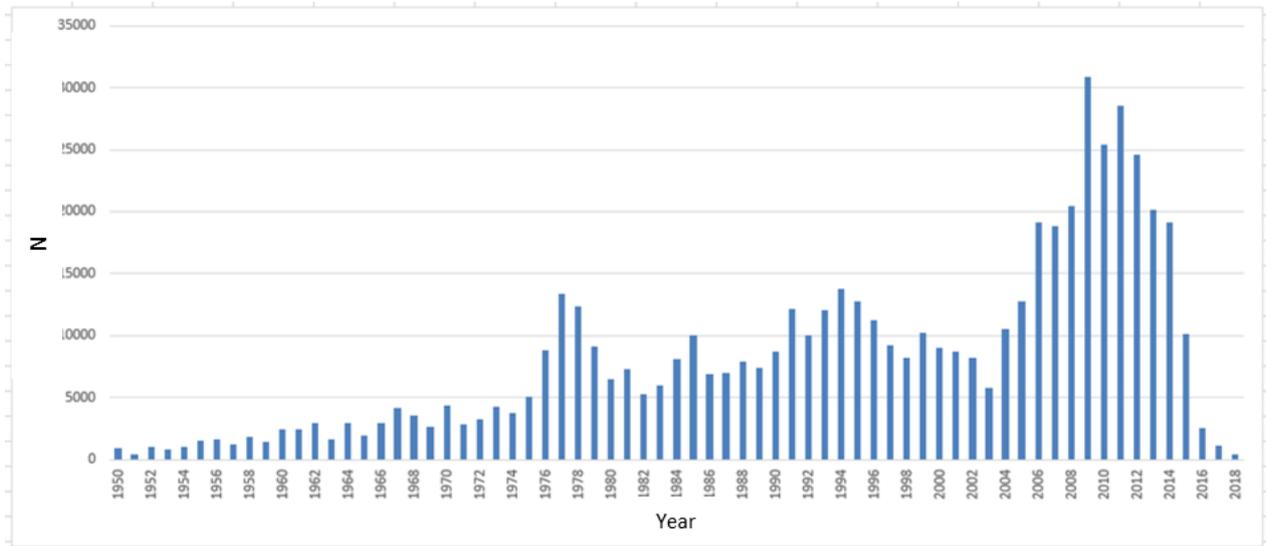
does not make sense, these plots have been deleted. This is expected to apply to a limited number of plots and therefore is assumed to have only a minor influence on the results.



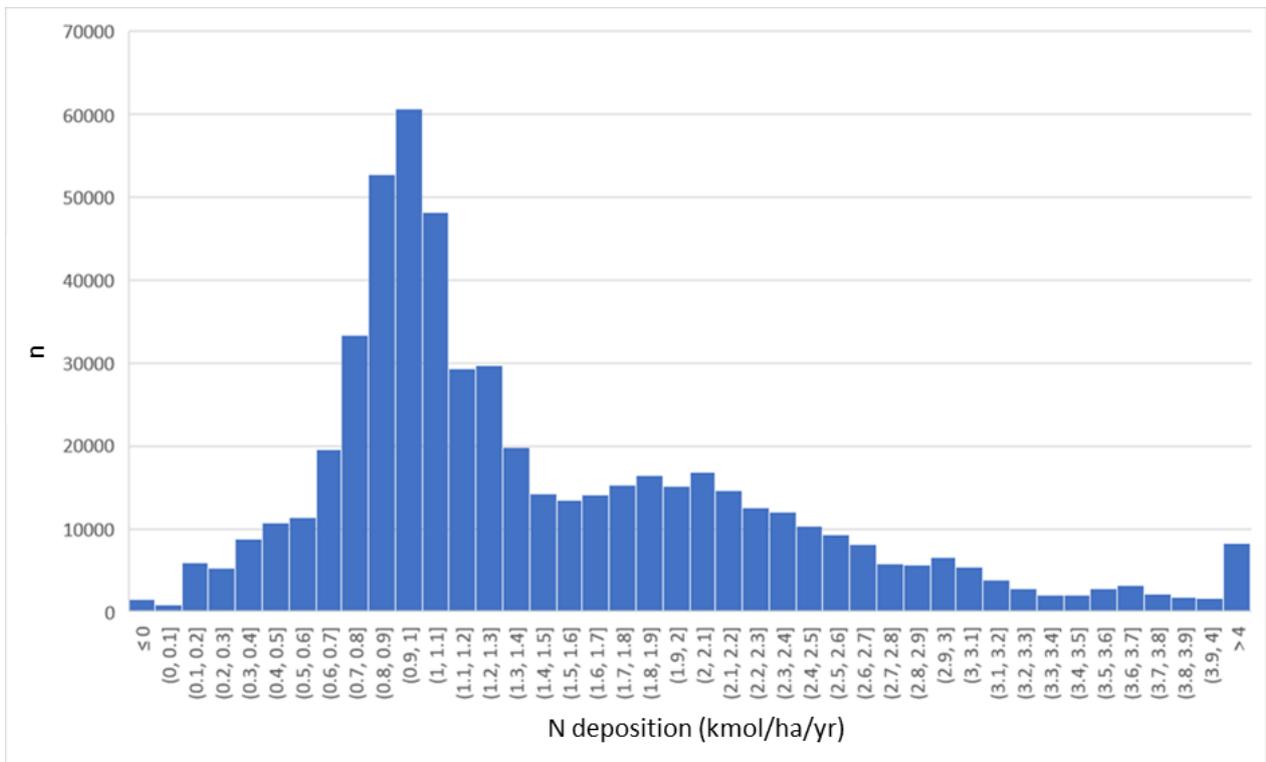
**Figure 5** Nitrogen deposition corrected for the roughness factor of a plot versus the uncorrected nitrogen deposition for vegetation types with a low roughness factor.



**Figure 6** Five-year average nitrogen deposition (kg/ha/yr) modelled with EMEP after correction for the roughness factor for the selected plots in the period 1950-2018. Note that adjacent points can come from a different period. If multiple plots were available at the same location, the highest depositions were taken. The different colours represent deposition classes with the number of observations in brackets. Plots with negative or zero deposition values were not used in deriving the response curves.



**Figure 7** Number of plots per year with a nitrogen deposition value.

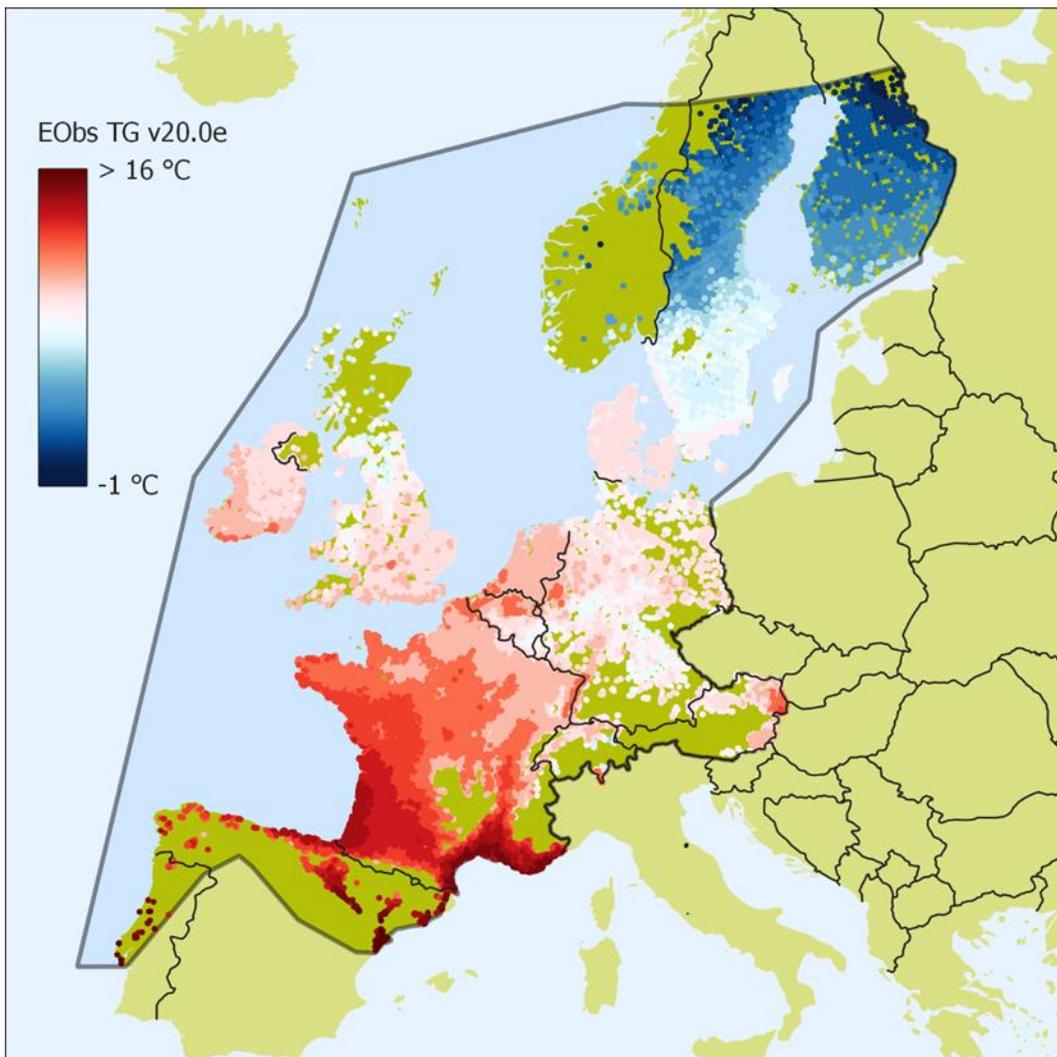


**Figure 8** Number of plots per nitrogen deposition class (class size of 0.1 kmol/ha/yr).

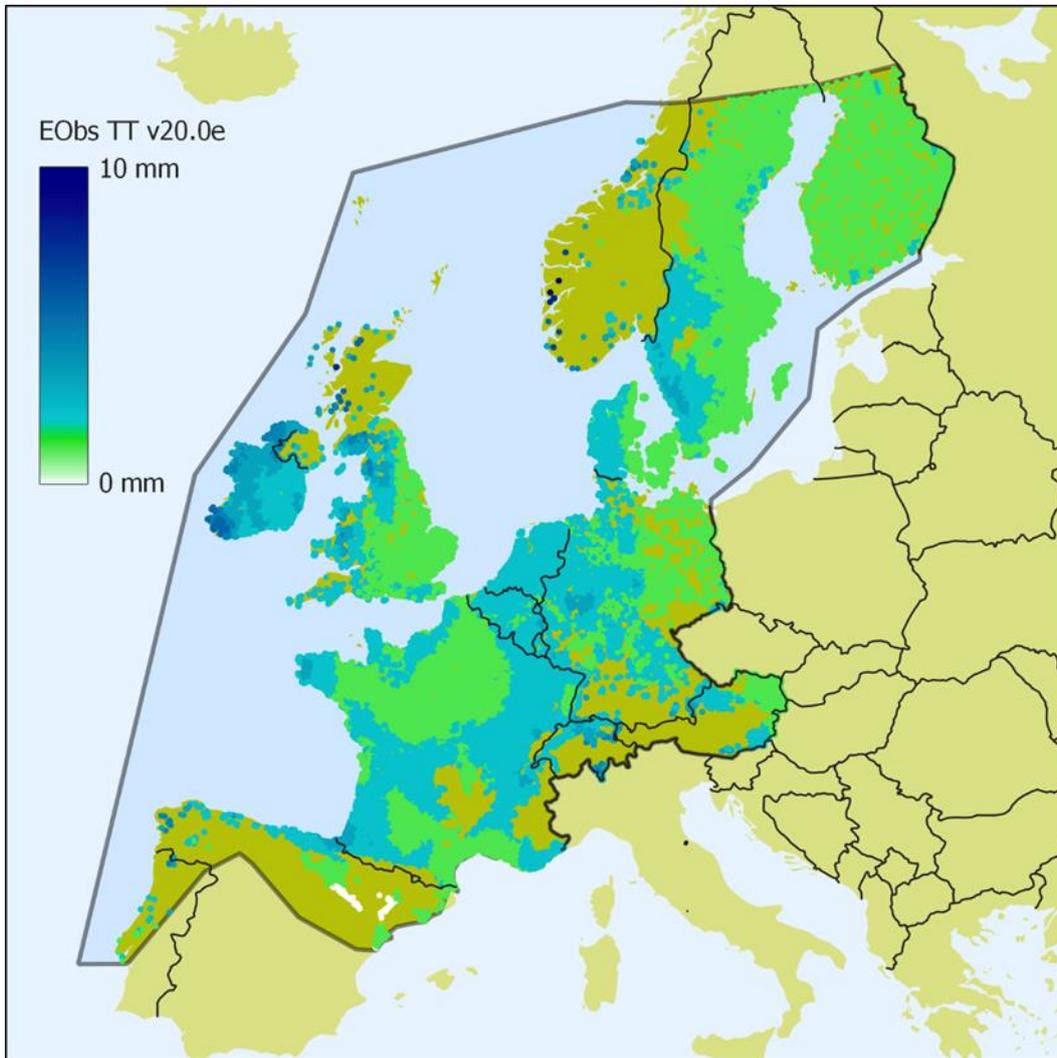
## 2.1.6 Temperature and precipitation for vegetation plots

Temperature and precipitation data were collected for the European plots based on data from weather stations. For temperature and precipitation data, use was made of the E-OBS dataset from the EU-FP6 project UERRA ([www.uerra.eu](http://www.uerra.eu)), the Copernicus "Climate Change Service" and data from the ECA&D project ([ecad.eu](http://ecad.eu), Cornes et al. 2018). The "Ensemble Mean 0.1 deg regular grid" version 21.0e of the daily mean temperature (TG) and daily precipitation sum (RR) were downloaded and processed into separate "geospatial" grids for each year.

For each plot, the temperature and precipitation grids were sampled based on the plot coordinates in the year of plot plus the four previous years. The average of these five temperature/precipitation values was assigned to the plot. This is analogous to the calculation of the deposition and the calculation in PROPS (Wamelink et al. 2019). A spatial visualization of the average temperature and precipitation per day thus obtained is given in Figure 9 and Figure 10.



**Figure 9** Average annual temperature of the plots. Some of the plots (dots) are not visible due to the large number of plots. Average temperature of areas above an altitude of 500m are not shown.



**Figure 10** Average precipitation in sum per day (in mm) for the plots. Some of the plots (dots) are not visible due to the large number of plots. The dark brown spots within the Greater Atlantic area are spots without selected plots.

In the logistic regression model for estimating the response curves, temperature and precipitation are used as covariates. The annual sum (mm) is used for precipitation instead of the average per day. The formula to calculate the response curve contains covariables. So, to be able to calculate a response curve for the Netherlands, a value must be entered for the covariables temperature and precipitation. To this end, the average was taken over the period 2007-2017 for De Bilt (the Netherlands), being 10.6 °C and 876 mm respectively, see Table 2.

**Table 2** Average temperature and precipitation for De Bilt (the Netherlands) over the period 2007-2017.

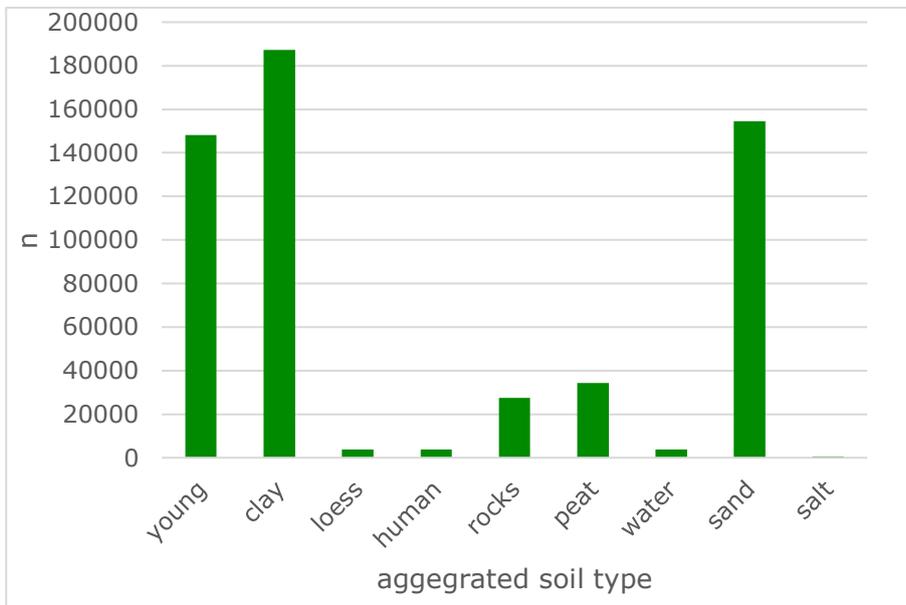
Year	Average temperature (°C)	Precipitation sum (mm/y)
2007	11.2	985
2008	10.6	886
2009	10.5	805
2010	9.1	878
2011	10.9	845
2012	10.3	944
2013	9.8	804
2014	11.7	824
2015	10.9	925
2016	10.7	812
2017	10.9	924
Average	10.6	876

### 2.1.7 Soil type for plots

In the logistic regression model for estimating the response curves, soil type was used as a covariate. The soil type is required for each plot and the Soil Atlas of Europe was used for this purpose (Jones et al. 2005; World Reference Base for Soil Resources). The soil type was selected from the soil map based on the coordinates of each plot. This resulted in too many different soil types and also soil types that do not occur in the Netherlands. Plots on soil types that do not occur in the Netherlands were not used. The remaining soil types were combined into nine main types (Table 3, Figure 11). Of these, the rocky and anthropogenic (man-made) types were not used. The few plots on loess were added to the sand soil type, and salt has been added to the soil type clay. Note that salt is distinguished through the vegetation structure types, where salt is a separate category. The soil type 'water body' also contains few plots, but this has not been deleted, it could also contain shores. In this way we keep five categories: sand, clay, young, peat and water. The category young give young soils, sometimes man-made, which do not show particular soil formation yet. The logistic regression model corrects for soil type. To obtain one response curve for the Netherlands and not per soil type (which is also an option), so only as a function of deposition, an average was made over the soil types. This was done in proportion to the number of plots for the different soil types in the Netherlands for the relevant dataset. In case the number of plots in the Netherlands was less than 100, then instead of using Dutch soil data, the European plots were used.

**Table 3** Soil types following Jones et al. (2005) and their categorization in five main types.

Soil type	Short description	Simplified type
Podzol	Podzol, infiltration zone	Sand
Water body	Water	Water
Andosol	Volcanic soil	
Cryosol	Permafrost	Should not be present in our selection
Histosol	Peat	Peat
Rock outcrops	Merged with Regosol	Rocky
Glacier	Ice, if in selection, remove	
Gleysol	Gley, wet, influence of groundwater in NL clay? In the NL they are listed as podzols	Clay
Leptosol	Stony rocky soil, both acid and alkalic	Rocky
Fluvisol	Flood planes of rivers, but also reclaimed land from the sea, but also Acid sulfate soils (so-called 'cat clay')	Clay
Cambisol	Young soils, due to wind, water or decayed rock	Young soil
Albeluvisol	Podzol, this apparently includes loess	Sand (loess)
Arenosol	E.g. former free blown sand and other young sandy soils	Sand
Planosol	Soils have often water holding capacity issues, clayey alluvial and colluvial deposits	Clay
Phaeozem	Organic soils, chalk poor, Phaeozems are formed in eolic deposits like loess, morene or other non consolidated, mostly alkaline material	Sand (loess)
Regosol	Poorly developed mineral soils. Classified as Leptosols (very thin soils), Arenosols (sandy soils) or Fluvisols (recent soils in fluviale, lacustrine or marine sediments). IUSS Working Group WRB: World Reference Base for Soil Resources 2014, Update 2015. World Soil Resources Reports 106, FAO, Rome 2015. ISBN 978-92-5-108369-7	
Chernozem	Organic and chalk rich, develops in loess, in a wet steppe or forest steppe	Sand (loess)
Umbrisol	Acid soils with strong infiltration, with a dark A horizon. With a lot of accumulated organic matter in the soil which influences the soil properties	Sand
Kastanozem	Chalk rich. kastanozems are normally formed in eolic sediments such as loess in a dry hot climate	Sand (loess). Should not be present in our selection
Solonchak	Salty soils where seepage causes strong salination	Sand
Solonetz	Salty clay, due to salt and or clay deposits in the past. Not including present day salt marshes	Clay
Vertisol	Clay soils that dry out quickly	Clay
Calcisol	Very chalk rich soils. Mostly developed in alluviale, colluviale and eolic deposits of base rich materials occurs in very low numbers, therefore not included	
Town	Built up area	Anthropogenic
Unknown	Unknown	
Soil disturbed by man	Stirred soils	Sand
Luvisol	Clayey soils	Clay
Acrisol	Course sand. Strongly degraded soils with a low base saturation. The sub soil is often old clay or old acid rock	Clay
Marsh	Marsh	Peat
Gypsisol	Gypsum (CaSO <sub>4</sub> ) rich sand, only a few in Spain.	Sand
None	Coastal areas where the plot is outside the extend of the soil map, mostly sea	



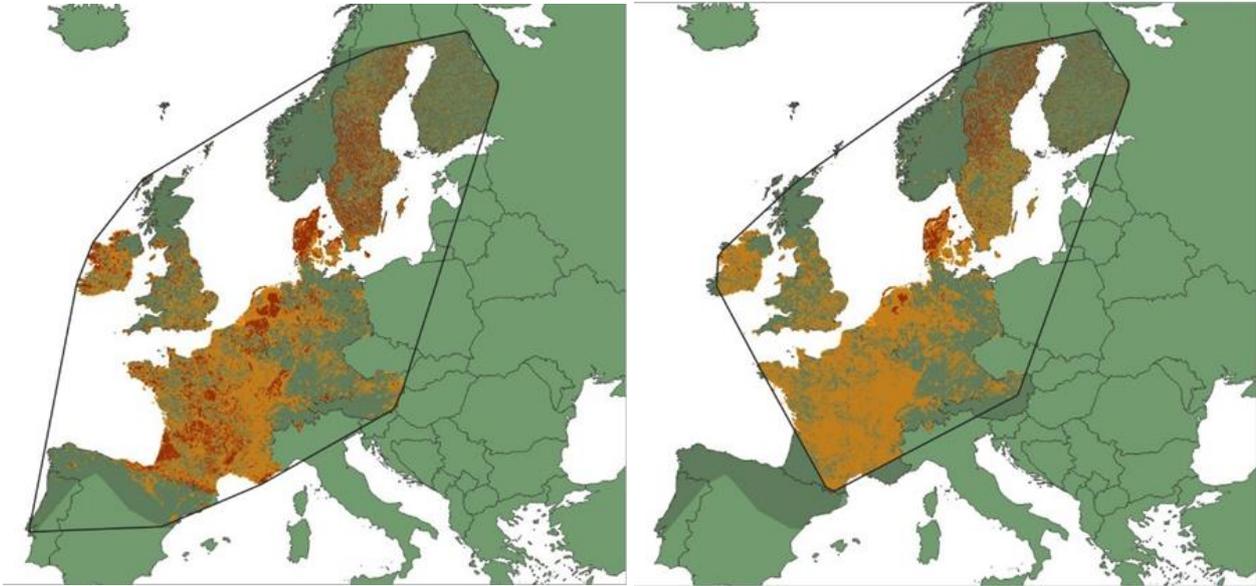
**Figure 11** Number of plots per simplified soil type.

### 2.1.8 Construction of datasets via the range of a species

To estimate response curves, i.e. the probability of occurrence of a species as a function of deposition, in addition to positive observations of a species in plots (coded by ones), plots in which the species does not occur (coded by zeros) were also required. In principle, this allowed to use all selected plots for estimating the response curve. The curve then represented the probability of occurrence in the entire Atlantic part of Europe. There are two disadvantages to this approach. Firstly, plots might be used that are far outside the distribution range of a species, with different natural and climatic conditions than where the species occurs. For example, for the response curve of salt-loving species, zero observations in fresh conditions would also be used, or for species that mainly occur in warmer conditions, zero observations would also be used in the Scandinavian countries. Such null observations, in plots where the species cannot occur, are undesirable in deriving the response curve because they provide no information about factors other than the factor which prevents occurrence. A second disadvantage of using all plots is that zero plots were used in all vegetation types, including zero plots in vegetation types where the species can never occur. An example of this is the marsh orchid, which only occurs in wet grasslands. Without selection, null plots in forests would also be selected. This could also improperly influence the curve. A method is therefore needed that uses the distribution area of a species. This problem was overcome by using structure types (see 2.1.4).

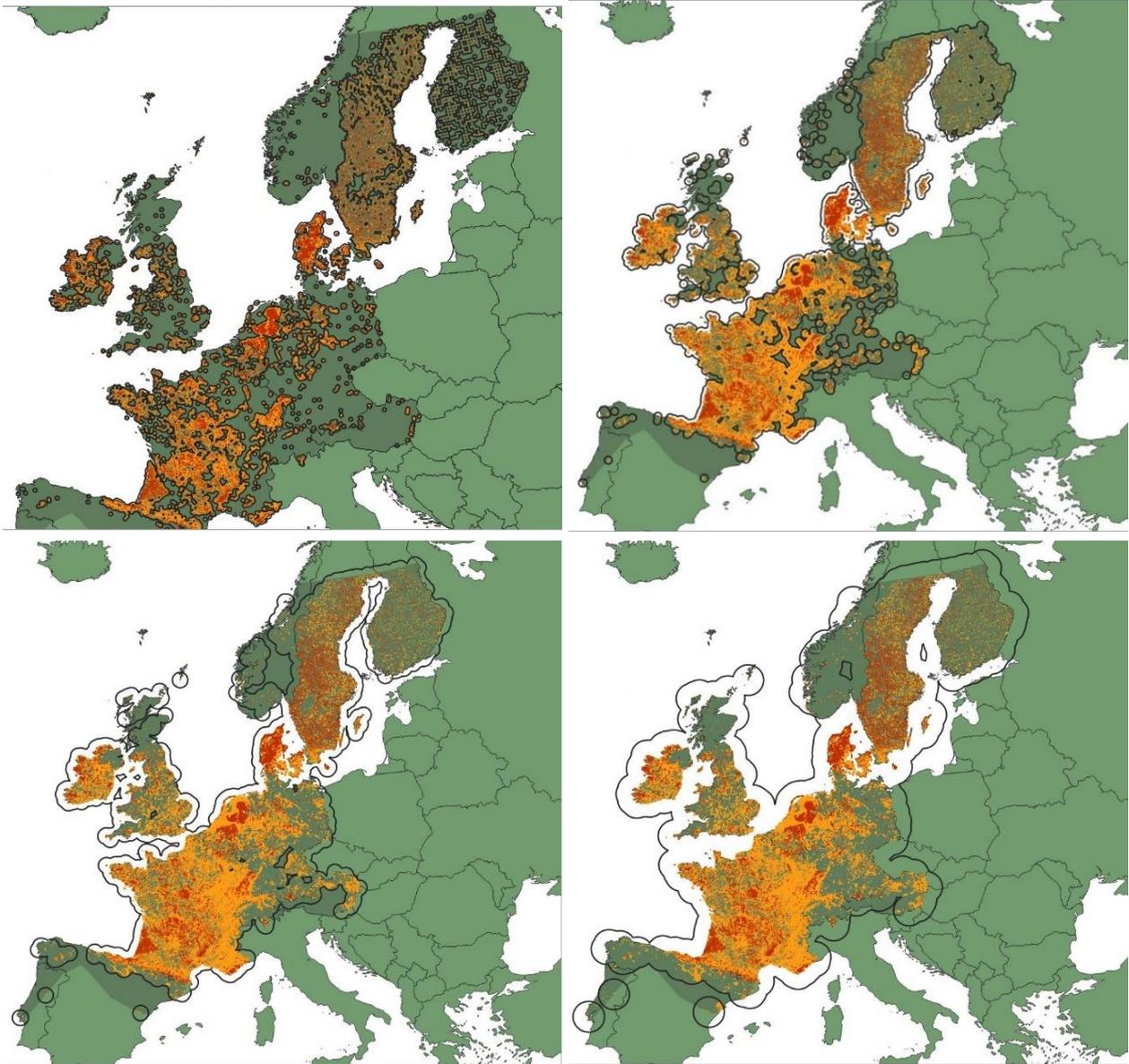
Unfortunately, distribution maps for all species are not available digitally. Therefore, the following two methods have been investigated to determine the distribution area of a species: (1) determining a global demarcation based on vegetation surveys where a species occurs; and (2) by determining a much more specific area per vegetation survey where the species occurs.

The first method uses the so-called "convex hull" to determine the outer limit of the occurrence of a species. The "convex hull" is the line that connects the outer points of a point cloud in such a way that no re-entrant corners are created. Figure 12 gives an example for common heather and black crowberry. This method demarcates a fairly large area, and many plots end up in the potential distribution area that are probably not suitable in the real world. Therefore, this method is less suited to determine the range of a species.



**Figure 12** Distribution of *Calluna vulgaris* (common heather, left) and *Empetrum nigrum* (black crowberry, right) with the potential distribution area around it according to the "convex-hull" method. Dark red points indicate plots within the convex hull where the species is present, orange points indicate plots where the species is absent.

In the second method, a circle is drawn around each plot in which the species occurs. Plots within the circle where the species does not occur are then selected as null observations. The size of the circle is then important. The larger the circle, the more plots are selected and also the larger the potential range of nitrogen deposition. However, if circles are too large, plots may be selected where the species cannot occur. A good example of this are the salty species; at a circle size of 100 km, many non-saline plots are added as null observations, where the species could never occur. Figure 13 gives an example of the effect of the circle size on the potential distribution area of common heather. As the circle becomes larger, the potential distribution area increases and areas are linked together into one large distribution area. Based on the figures for common heath and black crowberry, a circle size of 25 km was chosen. The selected areas then appear to fit well with the distribution areas of the species. At circles of 50 and 100 km, the circles merge into a large area including places where the species is unlikely to occur, such as in Austria. Circles of 10 km create a fine-meshed network that includes relatively few zero observations, which may overestimate the probability of occurrence of rare species.



**Figure 13** Distribution area for *Calluna vulgaris* (common heather) based on circles drawn around a site, with circle size 10 km at the top left, 25 km at the top right, 50 km at the bottom left and 100 km at the bottom right. Dark red points are plots with common heather (the ones) orange points are plots without common heath (the zeros) within the search circle.

In addition to the distribution area, which is defined by circles of 25 km around plots where a species occurs, the habitat type was also taken into account, see also section 2.1.1. A dataset has been derived for all species in a habitat type that is specific to the structure type associated with the habitat type. For example, suppose that habitat type H belongs to structure types S1 and S2 and that species A is a characteristic species for H. The derived dataset for species A then first contains all ones of species A in plots of structure types S1 or S2. The imaginary distribution area of species A (in S1 and S2) is formed by the intersection of the circles of radius 25 km around those plots. Zeros are then added to the data set for those S1 or S2 plots within the imaginary distribution area. Table 4 shows a hypothetical example with 12 plots: 6 plots of structure type S1 and 6 of S2. Suppose further that species A belongs to habitat type H1 of type S1, that A also belongs to habitat type H2 of type S2, and also that A belongs to habitat type H3 of types S1 and S2. The distances from the zero observations to the nearest one observation of S1 and S2 are given by the Distance columns including the minimum of these two distances. The procedure then gives the 0/1 data for species A in the three habitat types H1, H2 and H3.

**Table 4** Construction of the datasets for species A belonging to habitat H1, H2 and H3.

Nr	Struct	A	Distance to S1	Distance to S2	Minimum distance	Data H1 (S1)	Data H2 (S2)	Data H3 (S1 en S2)
1	S1	1	0	10	0	1		1
2	S1	1	0	100	0	1		1
3	S1	0	10	10	10	0		0
4	S1	0	10	100	10	0		0
5	S1	0	100	10	10			0
6	S1	0	100	100	100			
11	S2	1	10	0	0		1	1
12	S2	1	100	0	0		1	1
13	S2	0	10	10	10		0	0
14	S2	0	10	100	10			0
15	S2	0	100	10	10		0	0
16	S2	0	100	100	100			

This method implies that several response curves may have to be estimated per species, specifically for the structure type associated with a habitat type. For example, the species "*Rhynchospora alba*", or "White-beak sedge", occurs in the following four habitat types with associated structure types between curly brackets:

1. 3160 Acid fens {water}
2. 7110B Active raised bogs {wet dwarf shrubs, swamp}
3. 7120 Recovering raised bogs {wet dwarf thickets, swamp}
4. 7150 Pioneer vegetation with bulrushes {swamp}

Three response curves were therefore adjusted for this species, namely for the three (combinations of) structure types mentioned. There were a total of 2735 (species, structure type) combinations for which a response curve was desired. However, curves were only estimated if there were at least 100 plots where the species occurs in the structure type. With that condition, 2254 combinations remained for 1032 single species. This implied that no curve could be estimated for 481 combinations and that these combinations were not included in the calculation of a curve per habitat structure type. When a habitat type was linked to two or more structure types, a response curve was estimated for each combination, based on its own species composition.

### 2.1.9 Response curves for species

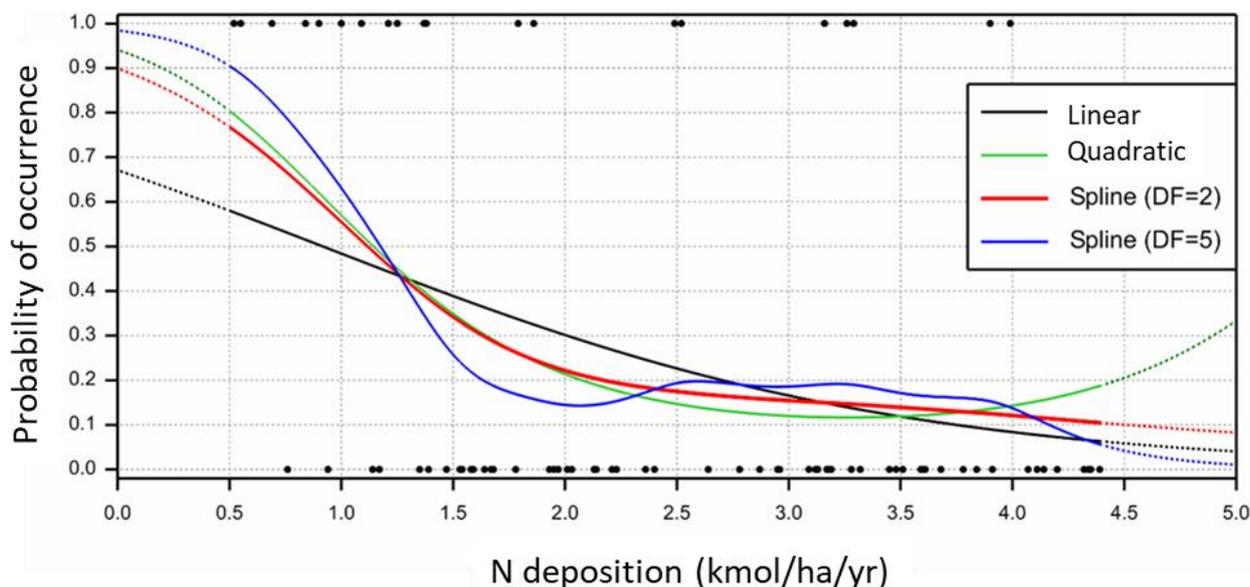
For each species-structure type combination, the probability of occurrence was modelled as a function of nitrogen deposition. Because it concerns 0/1 observations, logistic regression was used for this, in which the relationship with nitrogen deposition is modelled by a smoothing spline with two degrees of freedom (Hastie & Tinshirani 1990).

$$\text{"logit"}(n) = \alpha + \beta_1 \text{"Rain"} + \beta_2 \text{"Temperature"} + \beta_3 \text{"Rain"} \times \text{"Temperature"} + \text{"Soil"} + \text{Spline}(\text{"Ndeposition"; 2})$$

Soil, or better soil type, is here a nominal variable with as many variables as there are selected soil types (see 2.1.7).

A linear or quadratic model could also have been chosen for the relationship with nitrogen deposition. However, a spline is more flexible and is widely used in modelling response curves (see for example Wamelink et al. 2005). The number of degrees of freedom (df) of the spline can be used to set the flexibility of the adjusted curve, more df gives more flexible (wilder) curves. Due to the very large number of observations, a spline with more df generally gives a statistically significantly better curve. However, splines with more df move along with potentially large differences in the probability of occurrence at adjacent deposition values, which can be caused by bias in the data selection used. For these reasons a limitedly flexible spline with 2 df was chosen; this is assumed to provide a good picture of the course of the response over the entire deposition process.

Figure 14 shows, for a hypothetical situation, adjusted curves for 0/1 data for a limited number of plots with different depositions. The black/green line shows the fitted curve for a linear/quadratic logistic model. The disadvantage of the quadratic model is the poor extrapolation outside the observation area for the deposition and at the limits of the observation area. The smoothing spline with  $df=5$  (blue) produces a “wild” curve that responds too much to local differences in the density of ones and zeros. The spline with  $df=2$  (red) is used more generally and is a good compromise here.

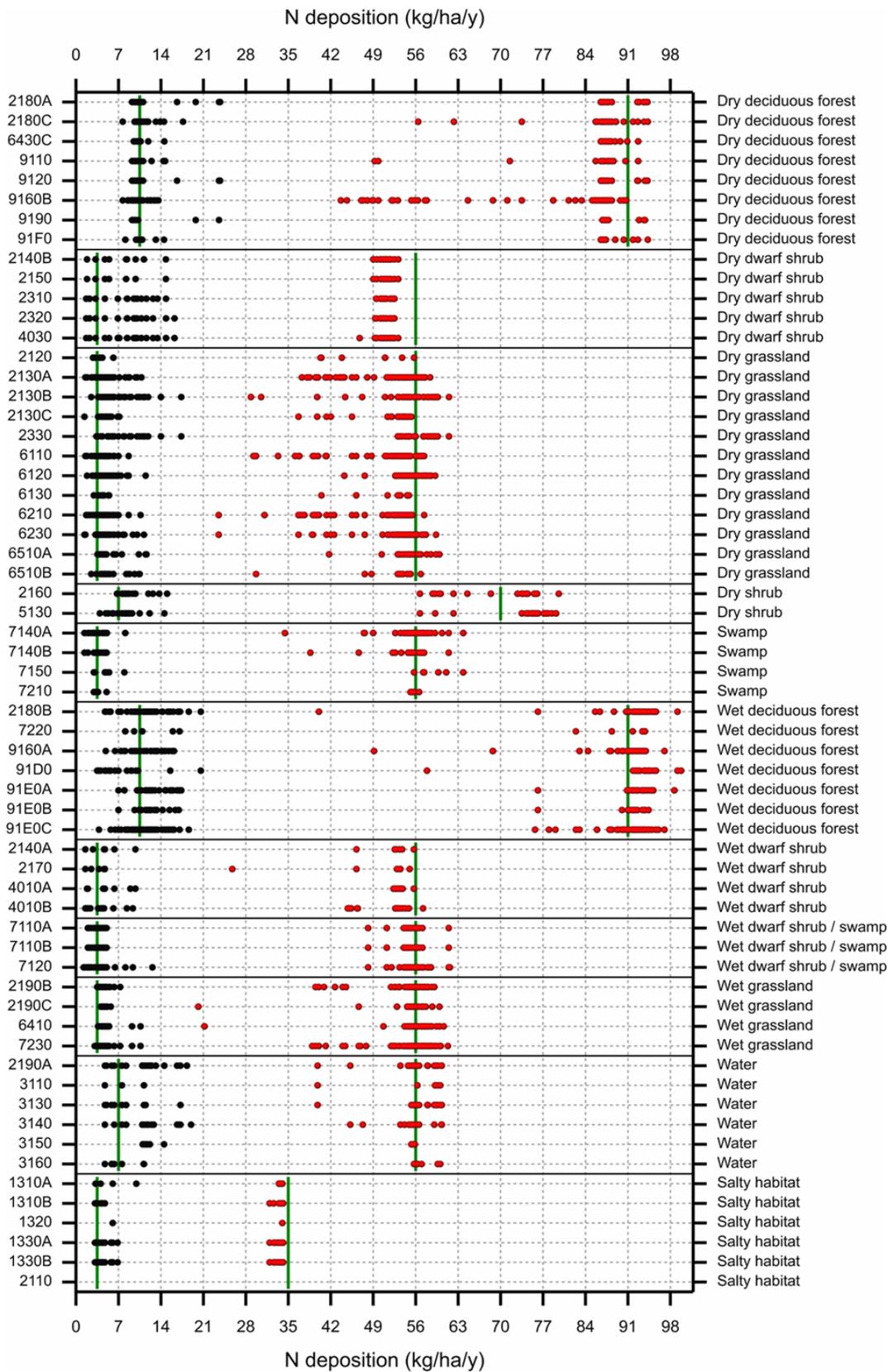


**Figure 14** Example of a dataset with ones (presence) and zeros (absence) of a species in plots with different nitrogen depositions. The lines represent fitted curves for different models with extrapolation shown by dotted lines.

On the logistic scale, this model with covariates produces parallel curves for the different soil types. To obtain a response curve for a species for the Netherlands, only as a function of deposition, the average rainfall and temperature over the past 10 years in the Netherlands were entered in the estimated curve, see section 2.1.6. There also was an average over the soil types in proportion to the number of plots in the Netherlands for the soil types in question. In case the number of plots was less than 100, it was weighted by the number of plots in Europe.

To prevent overextrapolation of the response curves, the upper and lower limits within which little or no extrapolation takes place were determined for each structure type. The limits were calculated as the average of the 1 percentiles for the lower limits and 99 percentiles for the higher limits of the data points. Only the portion of the estimated response curves within the lower and upper limits are shown in the figures. The boundaries were determined per structure type, see Figure 15. Identical boundaries have been chosen for habitat types within the same structure type. Upper limits were set at intervals of 0.5 kmol, lower limits at intervals of 0.25 kmol.

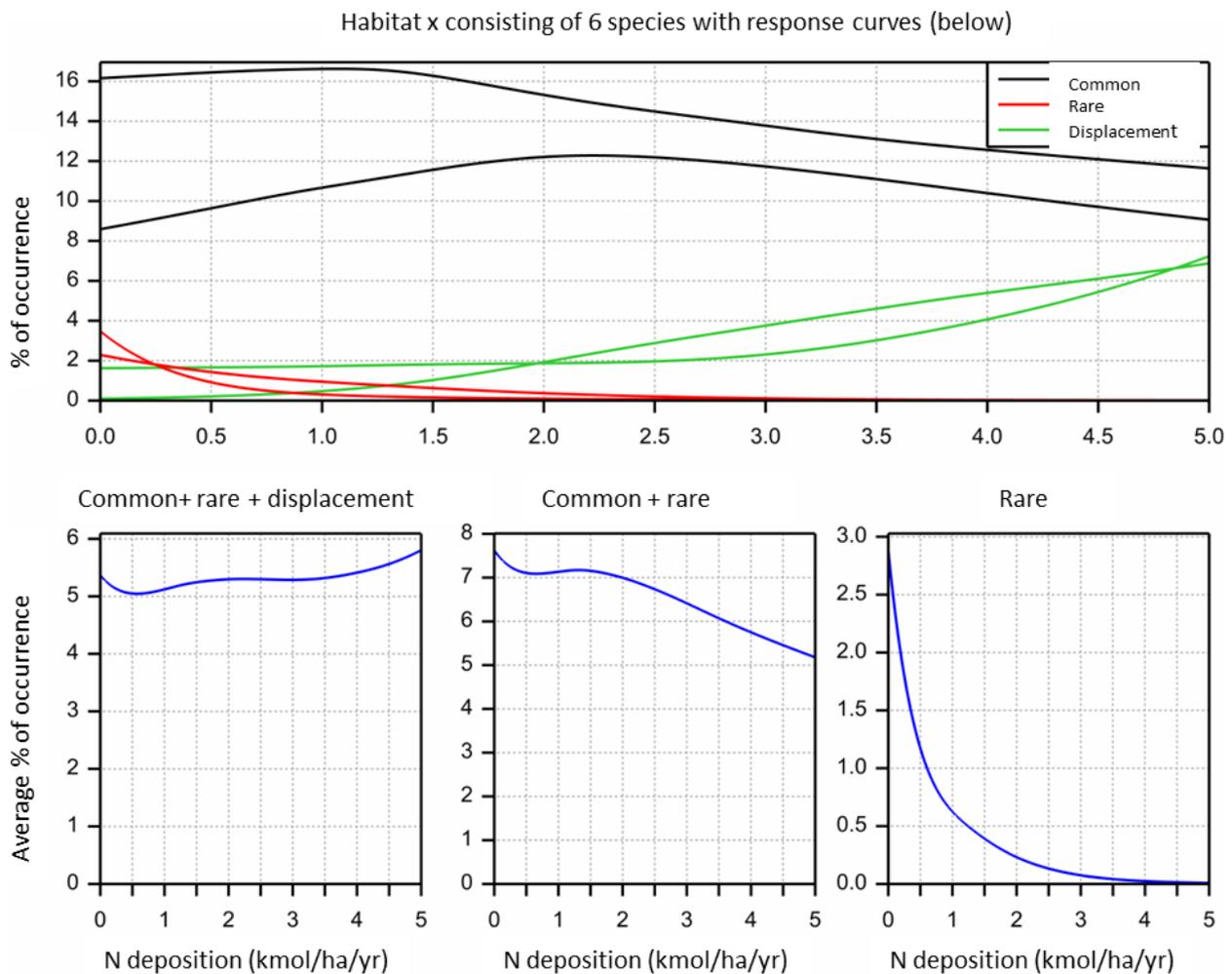
This method was applied for the habitat types, but not for the species. This implies that though for habitat types extrapolation is prevented this still can occur for species. This may lead to undesirable effects caused by the extrapolation for species, such as unrealistically increasing probabilities at extremely high deposition rates.



**Figure 15** For each habitat type, sorted by associated structure type, the 1% percentile (black) and the 99% percentile (red) of the observed nitrogen range of the associated species are given. The green lines indicate the interval where no extrapolation is assumed to occur. The surface normalization of the response curves uses the same range (see 2.1.10).

## 2.1.10 Response curves for habitat types

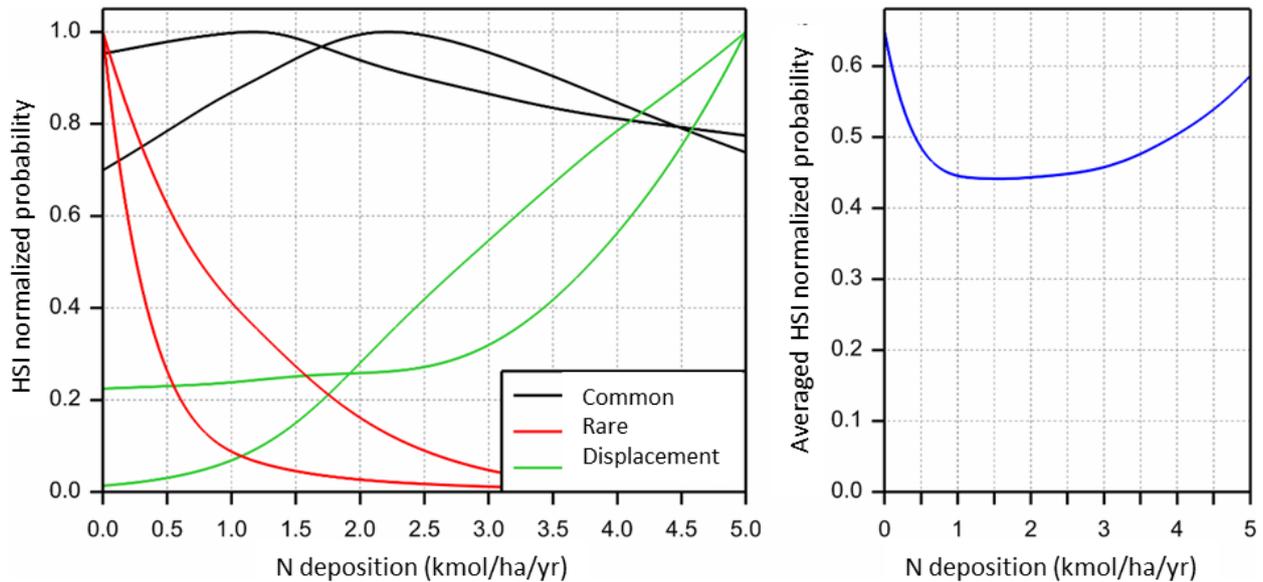
A response curve can be obtained for a habitat type by summing up or averaging over the characteristic species. The summed curve can be interpreted as the average number of expected characteristic species as a function of nitrogen deposition. In summation, common species, with a higher probability of occurrence, carry much more weight than rare species, with a lower probability of occurrence. At higher nitrogen depositions, the sum may be dominated by the increasingly high probability of the occurrence of characteristic displacement species. Figure 16 shows response curves for a fictitious habitat type X consisting of 2 common species, 2 rare species and 2 displacement species. The average probability over all 6 species is dominated by the common and characteristic displacement species. For the displacement species, i.e. species that increase as a result of nitrogen deposition and outcompete other species, there is an increase at higher deposition levels. After omitting the displacement species, the average probability is dominated by the common species. Only averaging over the rare species gives a sharply downward sloping curve.



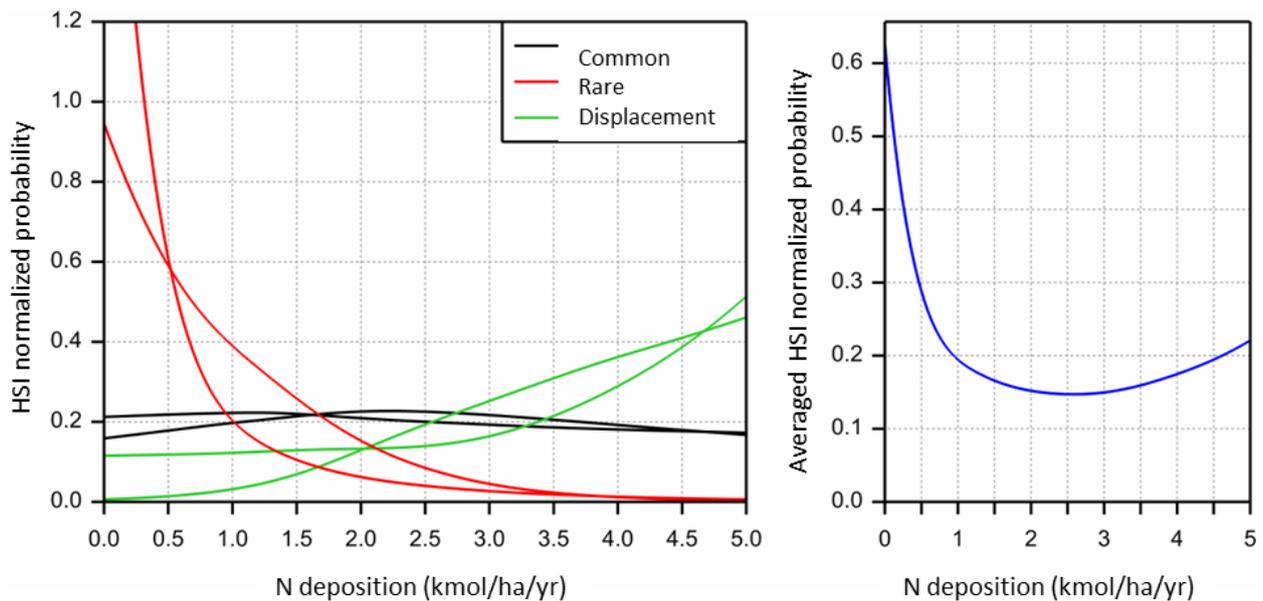
**Figure 16** Response curves (top graph) for a fictitious habitat type with two common species (two black lines), two rare species (two red lines) and two displacement species (two green lines). The bottom graphs show the average response curves for different selections of species. The bottom left graph shows the method we used in Doren-1.

The so-called Habitat Suitability Index (HSI) is based on the occurrence of characteristic or distinctive species. When used in combination with PROPS it normalizes the response curves by dividing by the maximum probability of occurrence (Figure 17). The HSI response of a species can be interpreted as the relative probability of occurrence compared to the maximum probability of occurrence. However, this interpretation is lost by averaging across species. In the fictional example, the average of the HSI curves is slightly determined by the rare species at low depositions and by the characteristic displacement species at

high depositions. An alternative normalization is obtained by an equal area under the curve for all species, see Figure 18. The focus is shifted to the rare species that generally occur in a limited, often low, nitrogen range. As a result, rare species determine the shape of the response curve of a habitat type to a much greater extent. These are also often, but not always, the species that suffer negative consequences from nitrogen deposition which is at the core of our project. The disadvantage of the area normalization, just like the HSI normalization, is that the response curve of a habitat type has an unclear interpretation. Note that, especially for strongly decreasing curves, the normalized curve can exceed the value one as in Figure 18. The normalized curve for the Netherlands is more or less independent of the rainfall and temperature entered and also of the precise weighting over the soil types.



**Figure 17** HSI normalized response curves with a maximum response of 1 (HSI) for a fictitious habitat type with two common species, two rare species and two displacement species. The right graph shows the average of the HSI normalized curves for the habitat type.

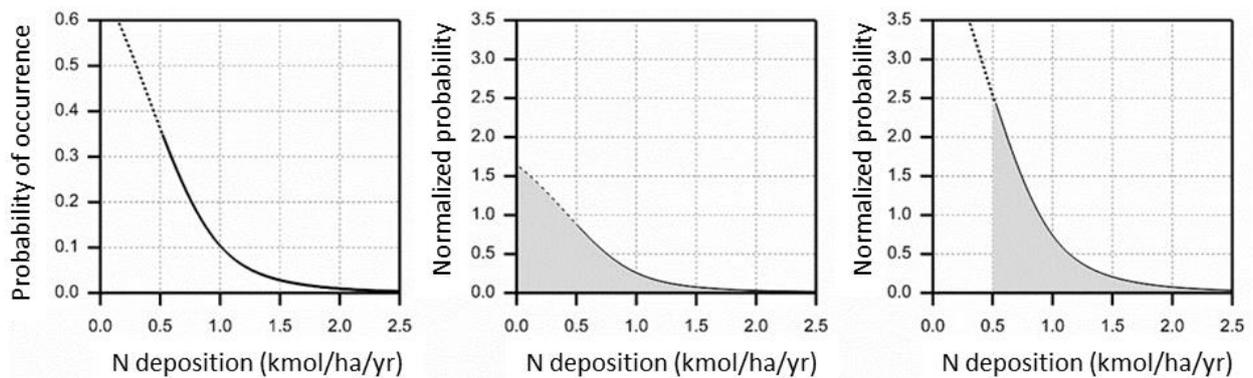


**Figure 18** Normalized response curves with equal area one under each curve for a fictitious habitat type with two common species, two rare species and two displacement species. The right graph shows the average of the normalized curves for the habitat type.

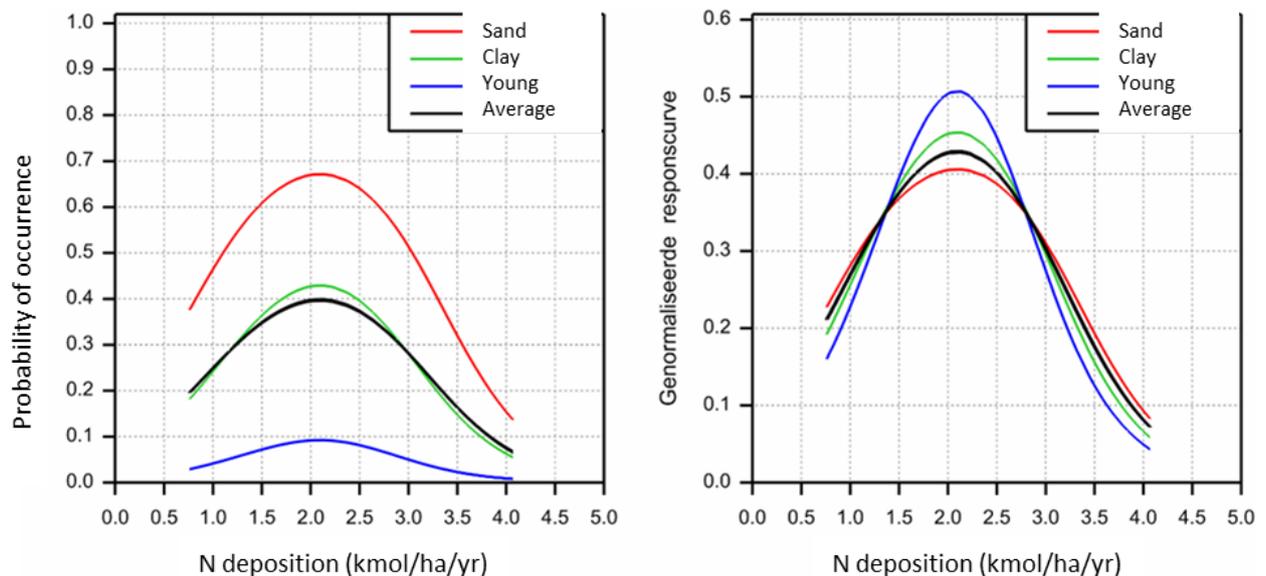
Taking all the pros and cons into consideration we decided to in this project base the response curve for a habitat type on the average of the area normalized response curve of the individual species as shown in Figure 18. However, in this research we further tested this decision and came to another conclusion, namely leaving out the displacement species.

In a more subjective approach, each species could be assigned a weight determined by experts, with rare species receiving a higher weight. This has previously been applied in the "Gelderland" method (Van Dobben et al. 2015).

The response curves for individual species have been fitted to data over a limited range of nitrogen depositions. The response curves can be extrapolated beyond this range, and it is therefore important to carry out the normalization based on the observed range of a species. Figure 19 gives a stylized example where the normalization is based on the range of the extrapolated curve and on the observed range of nitrogen depositions. The ranges shown in Figure 15 have been used for normalization.



**Figure 19** Response curve for a species with an observed range of 0.5 to 2.5 kmol/ha/y with extrapolation to the left (left graph) and the corresponding normalized response curve based on the range (0, 2.5) (middle) and on the range (0.5, 2.5, right, used in this report). The shaded area is equal to one. The curves are identical except for the scale of the y axis.



**Figure 20** Example of estimated response curves for three soil types including the average curve over soil types (left) for a logistic regression model that corrects for soil type. The same curves are given on the right after normalization to area one.

Due to the normalization, the precise method of averaging over soil types, in a regression model with covariates, and the precise values entered for temperature and rainfall were less important. Figure 20 shows

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on the left an example of the estimated response curves for three soil types. These curves run parallel on the logit scale, on the probability scale they have the same shape with different maximum probabilities. After normalization to area one (right) there is much less difference between the curves.

#### 2.1.11 Assessment of response curves for habitat types

The response curves were compared per habitat type with the CL and the empirical CL where available. The response curve may already decrease before the CL, but to be plausible the decrease must mainly take place above the CL or within the range of the empirical CL. In all cases, a curve must show a decline, because all habitat types studied here have a CL and therefore are affected by nitrogen deposition, which should lead to a decline in quality. However, a decline does not always have to be visible in the curve. After all, there may be species that benefit from an increase in nitrogen deposition. Such species show an increase in response, which can affect the response of the associated habitat type. Increasing response curves for habitat types are categorized as not useful for our purpose. All curves were classified as good, fair or poor by five experts. The five judgments have been combined into a final judgment. In various assessments by the experts, the value of Lin's correlation coefficient of concordance ( $\rho$ ) is decisive (Lin et al. 2002). Moderate is used for curves that may be plausible, but that show a somewhat unexpected response, for example a rapid decline or the largest decline before the CL is reached.

#### 2.1.12 Summary of materials and methods

A detailed explanation of the choices made when determining the response curves for habitat types is given in Appendix 6 in Wamelink et al. (2021). A brief step-by-step description of the method is given below. Characteristic plant species for 61 habitat types in the Netherlands was based on "The vegetation of the Netherlands" (Schaminee et al. 1995). Two criteria were used: (1) the presence in the Netherlands and (2) the degree of fidelity of the species. So-called typical species, if not selected, were added (section 2.1.1). The 61 habitat types were classified into 11 so-called structure types (section 2.1.2).

Observed presence and absence of species was based on vegetation plots in the EVA database. Only plots from 1950 onwards in an enlarged Atlantic area were used. Plots above 500 m altitude were not selected (section 2.1.3).

The vegetation plots were assigned to the 11 structure types via the EUNIS type. Plots with an unknown structure type were not used (section 2.1.4).

The nitrogen deposition of a plot was based on the EMEP model, which averages over the deposition of the year of plot and the four preceding years. The nitrogen deposition was corrected for the roughness factor of the plot. Plots with an unknown deposition or a non-positive deposition were not used (section 2.1.5).

Temperature and precipitation from the plots were interpolated using public data sources (section 2.1.6). The soil type of a plot was based on the "World Reference Base for Soil Resources". Plots with soil types that do not occur in the Netherlands were not used. Soil types were combined into five classes: sand, clay, young, peat and water (section 2.1.7).

For each species within a habitat type, a dataset with presence and absence of the species was constructed using a virtual distribution area formed by circles of 25 km around plots where the species occurs. Only plots that corresponded to the structure type of the habitat type were used (section 2.1.8).

The resulting dataset for a species was used to estimate a response curve corrected for temperature, precipitation and soil type. Curves were only estimated for species with at least 100 occurrences. This means that very rare species have been eliminated. To obtain a curve for the Netherlands, only as a function of nitrogen deposition, an average was taken over the soil types and the average temperature and precipitation in the Netherlands during the past 10 years was entered into the estimated curve. To prevent extrapolation of the response curves, a range of observed nitrogen depositions was defined for each habitat type (section 2.1.9).

Response curves for habitat types were obtained by averaging normalized response curves for individual species. Due to the normalization, the species were given equal weight during averaging (section 2.1.10).

The response curves for the 61 habitat types were assessed for reliability by expert judgment (section 2.1.11).

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## 2.2 EVA-database

### 2.2.1 Checking the raw data and the species and habitat types

The EVA database contains over 1,100,000 entries (plots or relevés). The plots were made for many different purposes and not specifically for this project. This means per definition that the database is unbalanced in many ways, it is an assembly of many projects with their own goals and purposes. Their commonality is species composition record within a delineated area (ranging from 1 m<sup>2</sup> to several 100 m<sup>2</sup> in forests), including species occurrence frequency in the plot (often with the Braun-Blanquet scale). The species occurrence-frequency (or coverage) in a plot was not used in Doren-1. We only used absence/presence data. Although that seems quite straightforward, already here the challenges start. The EVA-database already implemented several checks, especially on the nomenclature, still there are differences in names that also in this project lead to problems or even missing data. Examples include spelling mistakes, differences in names in different countries, different notation of subspecies or the absence of subspecies and so on. For this reason, the species list for the habitat types and the sub species lists used for the analyses were re-evaluated. This led to a translation list from EVA-species list to our list (Appendix 3).

### 2.2.2 Check on species-structure type combination.

For 26 species-structure type combinations an extensive check was carried on the underlying data. The goal was to see if data-anomalies could explain some of the unexpected response curves. Within the framework of this project this was carried out for only 26 combinations due time and labour constraints. However, it can be applied to all the species-structure type combinations. We automated the visualisation of the raw data per species-structure combination in several ways to allow easy and quick visual inspection on outliers etc. This includes checks, balances and summarizing data. We made:

1. A map of the geographical distribution of the plots for the Atlantic region. This reveals whether the plots are situated as expected and if coverage over countries is conform expectations from a bio-geographical point of view. Together with the plot, the settings for the selection are given and some figures about the number of plots etc.;
2. Scatterplots of the average annual temperature, average daily precipitation and year of plot-survey plotted against nitrogen deposition. This gives insight in the distribution of the plots over the abiotic variables and if any unexpected temperatures or precipitation amounts are within the dataset;
3. Density charts, with presence absence plots plotted against nitrogen deposition and the number of positive plots and negative plots (species absent) per deposition class and the resulting probability curve;
4. Number of plots per soil type. This reveals if unexpected combinations of soil type and species occur, e.g., heather for structure type dry heath in water. The review was carried out for both the positive (the 1) as well as for the selected negative findings (the 0). This could reveal whether there is a mismatch between positive and negative findings regarding soil type, which may indicate a mismatch in site conditions;
5. Number of plots per EUNIS type. This gives insight in the species structure type combination per EUNIS type. As for soil type the review was carried out for both the positive (the 1) as well as for the selected negative findings (the 0). This could reveal whether there is a mismatch between the positive and negative findings regarding EUNIS type, which may indicate a mismatch for vegetation type.

The combinations of species-structure type were selected to represent as many different combinations as possible, including multiple structure types for a single species, different structure types and species from both wet- and dry conditions. Appendix 4 gives the species-structure type combinations and the assessment of the species. The figures for heather (*Calluna vulgaris*) are given as an example in Figures 21-24 in chapter 3. The species-structure type combinations were selected to investigate if visualising the data could reveal anomalies in the data. The method was not applied yet to all species-structure type combination, reviewing all of them would ask for a much greater effort than feasible within this project.

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## 2.3 Additional empirical relationships between atmospheric nitrogen deposition and plant species richness: a visual inspection

Compared to Doren-1, for this study the visual inspection of gradient categories could be done for six additional habitat types and two habitat types with previously confusing data (Aherne et al. 2020). All the field data were collected in Ireland. Total species richness per relevé and the subset of species identified as positive indicators for that type by the Irish National Parks and Wildlife Service (indicator species number per relevé) were analysed. These data were kindly provided by Julian Aherne and Kayla Wilkins (Trent University). In the analysis the nitrogen deposition gradient was aggregated to equal sized categories (in this case 2.5 kg N ha<sup>-1</sup> yr<sup>-1</sup> deposition ranges) and the average and 95%-confidence interval of the biodiversity measures were calculated for each category using Sigmaplot 14. In this section the results have been presented in figures per habitat type. Dose response curves have been fitted by 2<sup>nd</sup> order polynomials (splines).

## 2.4 Evaluation of the response curves from Doren-1

### 2.4.1 From Genstat to R

In the initial Doren-1 project (Wamelink et al. 2021) the analyses were carried out using GenStat (VSN International, 2021). In the Doren-2 project, the analyses have been reimplemented in R (R Core Team, 2021). The advantage of R lies in it being open source and more widely used than GenStat. In R we used package GAM to fit the spline models. This procedure is the closest analogue to the previously used fitting procedure of GenStat. As a unit check, the analyses of Doren-1 have been repeated with the reimplemented code to verify that the results were unchanged. The evaluations in this chapter were carried out with the new R program.

### 2.4.2 Degrees of freedom for the spline

In Doren-1 the number of degrees of freedom for the spline function was set at 2 for practical reasons. In this research, for both a selection of species and habitat types the number of degrees of freedom was varied in 2, 3 and 4. The fitted curves were plotted together with the number of positive findings per nitrogen deposition interval.

### 2.4.3 Evaluation of the response curves

The responses for the habitat types were derived again, but then based on the new species composition (see chapter 2.5, SI 1), i.e. without taking displacement species into account. The results from Doren-1 project were then compared with the new results (Table 5). The curves of the habitat types were judged again, based on the sometimes-changed response curve.

In 2022 and 2023 new ranges and critical loads became available (Bobbink et al. 2022, Wamelink et al. 2023). For the judgement, the old Dutch Critical Loads (CL) and empirical critical ranges were less important than in the earlier judgement. It was now assumed that they could be wrong, where in Doren-1 it was assumed that the CL and empirical range were the criteria to base the judgement on (and thus just). Still if the descent of the response curve coincided with the empirical CL and/or was in line with the CL, the curve was often assumed to be good. For each curve the judgement was shortly underpinned (see Table 5). For sake of completeness, the response curves from Doren-1 were compared with the new empirical range and CL as well.

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## 2.5 Species composition of habitat types

### 2.5.1 Species list selection

We compiled four species lists per habitat type:

1. The original list from Doren-1, but without any displacement species (also excluding displacement species that are simultaneously characteristic and displacement species for the habitat type; this is a difference with Doren-1). This is species list 1, in short SI 1. This list was also used in chapter 2.4.
2. The species from SI 1 that are also on the 'Red List' (Sparrius et al, 2014) i.e., only the 'Red List' species that are characteristic for a habitat type were included in the list. This is species list 2, in short SI 2.
3. Typical species. Since these are all characteristic species, this is again a sub-set of list 1. This list is a species list that is defined by the Dutch Ministry of Agriculture, Fisheries, Food security and Nature. It contains species that are regarded as typical for a habitat type by experts and includes both rare and common species. The species have their optimum in the habitat they are typical for but can also occur outside the habitat type. This is species list 3, in short SI 3.
4. 'Red List' species of the typical species list under list 3. This is also a sub-selection of list 1 and combines the criteria under sub 2 and sub 3. This is species list 4, in short SI 4.

The composition of the original list including displacement species can be found in 'Digital Appendix 1 specieslist.xlsx' and the evaluated four lists can be found in 'digital Appendix 2 species list per variant.xlsx'. For each species under consideration for lists 1 to 4, we set a minimum of 100 occurrences in the EVA database. Following the species list definitions, we evaluated how many species met the requirements for species lists 1 to 4 for each habitat type. We set a minimum of 10 species for a reliable response curve for a habitat type.

Each species list was evaluated by estimating the corresponding response curve for the habitat type. Note that the underlying species responses did not change. The variation was due to in the selection of individual species responses that together constitute a habitat type response for all four species lists, response curves per habitat type were estimated, including uncertainty, applying the new program written in R.

## 2.6 Confidence interval

We developed a bootstrap procedure to calculate the confidence interval around the fitted curves. The curve fitted is a spline (see Perperoglue et al. 2019 for an extensive explanation about splines in R). The bootstrap procedure is part of the R-program that fits the response curves and makes estimates of the confidence intervals, which will therefore always be given with the response curves from now on. In the first step we applied a non-parametric bootstrap to each species-structure model. This procedure involves subsampling with replacement from the data that is used to fit the model and refit the model to each bootstrap sample. Each species-structure type model was bootstrapped 50 times, i.e. a response curve was estimated 50 times by sampling the (plot)dataset 50 times. Because of the sampling a different curve is estimated each time and based on the 50 samples the confidence interval can be quantified.

In the next step, the species-structure type models were combined to estimate the confidence interval per habitat type response curve. Here we randomly drew from the 50 (species-structure) bootstraps for each of the species that were included in a certain habitat. For example, if a habitat has 5 species, we drew one (of the 50) bootstrap samples for each of the 5 species. Note that in this example this gives a total of 505 combinations that we can draw from. Per habitat we drew 5.000 times. The 95% confidence intervals were then calculated by taking the 0.025, and 0.975 quantiles across the 5.000 draws. The confidence interval includes the effect of the number species per habitat type.

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## 2.7 Reassessment of the response curves from Doren-1 solely based on the empirical range from 2022 and the critical load from 2023

The empirical critical load range (Bobbink et al. 2022) and the critical load (Wamelink et al. 2023) were used to replace the empirical critical load ranges of Bobbink & Hettelingh (2011), as well as the critical load by van Dobben et al (2012). The empirical critical load range is based on European field nitrogen addition experiments and if data are lacking expert knowledge. A range is given because there are differences between the countries (climate, rainfall and soil type) which has influence on the critical load. The critical loads for the Netherlands (as is given in Wamelink et al. 2023) are based on the empirical critical ranges from Europe and model runs for the Netherlands. The response curves are the same as in Doren-1, but they are now compared with the new empirical CL and CL. This was done, as in Doren-1, by the first author. Curves were categorized in three classes, good, fair and poor. In the figures of the response curves the classification was visualized as a dot, green for good, yellow for fair and red for poor. The number of response curves were counted per category and compared with the score from Doren-1.

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## 3 Results

### 3.1 EVA-database

In general, a minimum number of positive findings is required for a reliable response curve. Also important is sufficient variation over the different parameters. Essential as well is the number of negative findings. Once these are too few, it is difficult to estimate a reliable response curve. This is especially true at the higher deposition levels, where a low number of negative findings and a few positive ones may lead to an unrealistic response with an increasing curve at the high end of the range.

It is also important that similar vegetations where the species is present or absent are used. These effects are better visualized due to the confidence interval of the response curve that is given (see Chapter 2.6). In some cases, this could even influence the whole response curve, for instance for *Gentiana pneumonanthe*, with a peak at 5.5 kmol/ha/yr for nitrogen deposition. Based on the figures (see Figure 21-24), it is possible to better understand why some of the responses are unlikely to represent the real response and may more likely be caused by data anomalies. Also, a mismatch between positive and negative findings for soil type and EUNIS class led to problematic response curves in certain cases. Appendix 4 provides a review of all 26 species-structure type combinations. The check on the species names spelling also improved the dataset.

## DOREN 2023

Analyses of EVA data for heather (*Calluna vulgaris*) for dry dwarf shrubs

### Selection process

EVA headers source	w:\PROJECTS\Doren19\brondata\EVA\delivery_20201118\EVA_Doren_header.csv
# headers before filtering	1,197,738
years	1950 - 2020
max elevation [m above MSL]	500
NDep averaging period	5 year
# headers after filtering	449,621
# positive headers	54,428
# positive headers with droog dwergstruweel	7,190
# negative headers	395,193
# negative headers with Dry dwarf shrub	956
# negative headers with droog dwergstruweel and within 25m	686

### Header map and AOI



Locations of 7,190 positive headers for *Calluna vulgaris* - droog dwergstruweel and negative headers within 25 km distance.

**Figure 21** Data summary report for heather (*Calluna vulgaris*) combined with dry dwarf shrub structure type and location map of the positive (orange) and negative plots (blue dots) to estimate the response curve (the positive findings mostly block the view of the negative ones).

Figure 21 gives an overview of the selection criteria from the EVA-database and nitrogen deposition database, in this case for the combination *Calluna vulgaris*-dry dwarf shrubs, they also apply to Figure 22-24. The number of headers indicates the number of plots. In this case it is clear that the number of positive findings in dry dwarf shrubs is high and even higher than the number of negative findings. Although genuine, this may lead to anomalies in the response curve. The map in Figure 21 provides an overview of positive (orange dots) and negative (grey dots) plots. As expected, *Calluna vulgaris* can be found all over the Atlantic region, but in the south only in wetter coastal and lowland areas. Remarkably, findings in Scotland are almost absent, whereas the Netherlands seem overrepresented in the database.

## Scatterplots



**Figure 22** Scatterplots of vegetation plots containing heather (*Calluna vulgaris*) in dry dwarf shrub structure type. N-deposition plotted against average annual temperature (top) average daily precipitation (middle) plot-survey year (bottom). In orange the positive findings, in blue the negative findings (positive findings are plotted over negative findings).

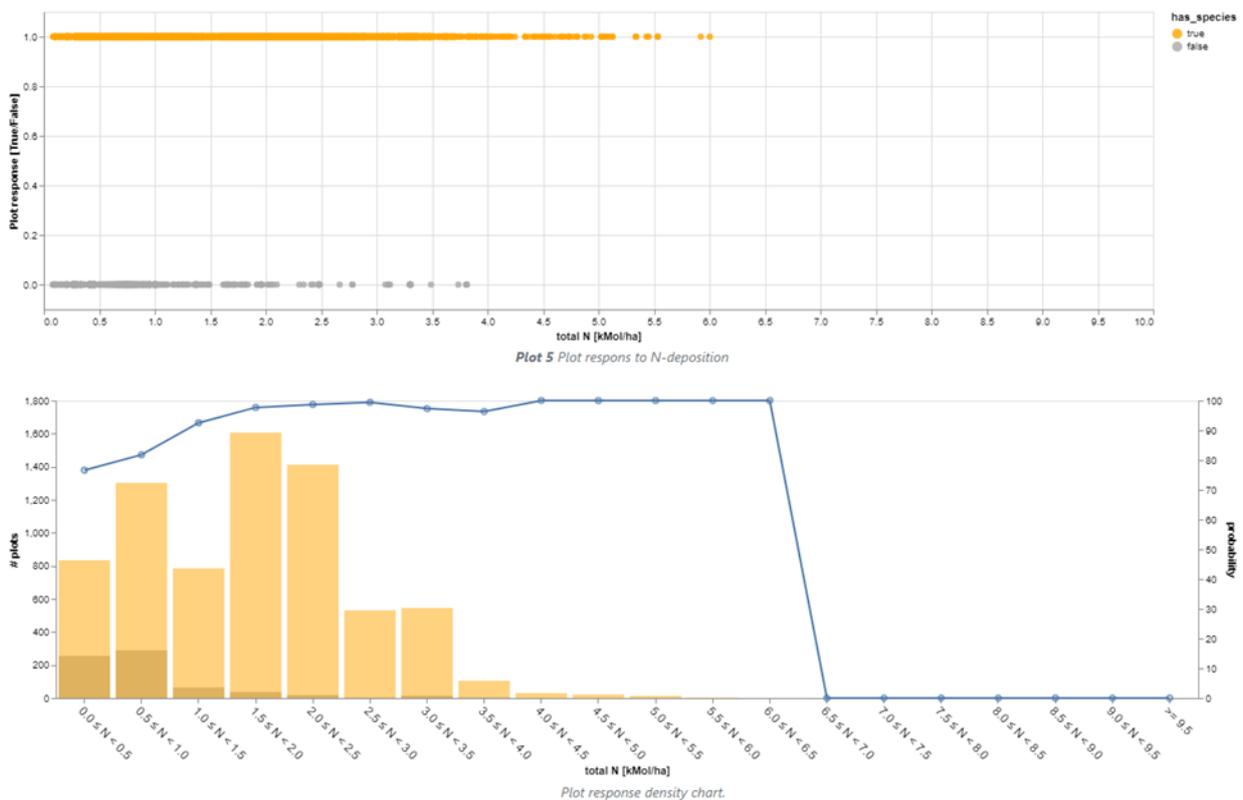
Figure 22 gives information about the distribution of the positive and negative findings of total nitrogen deposition against average annual temperature (top), average daily precipitation (middle) and the year the plot was made (bottom). Here again the positive findings are plotted over the negative findings. Although some negative findings are visible, the plots are dominated by the positive findings. Negative findings are plots that meet the selection criteria, but where the *Calluna vulgaris* is absent. This indicates that for the given combinations, the positive and negative findings are in the same range. If they would greatly deviate from each other, this might be an indication that the response curve is erroneous. On the other hand, it could also be genuine, e.g. the species only occurs at low depositions and thus will not occur in plots with high deposition levels. The latter is clearly not the case for *C. vulgaris*. The temperature plot (top) shows that most findings are between 8 and 11 °C, but that there are quite some findings lower than that range and even below an average annual temperature of 0 °C. The nitrogen deposition is low for the extreme temperatures and high deposition levels mostly occur between the 7 and 11 °C.

For precipitation (middle plot) most findings are below an average daily amount of 3 mm/day, precipitation levels below 1 mm/day are absent, but *C. vulgaris* can occur up till very high precipitation levels. The high deposition levels start at the lowest precipitation levels, but most values are in the range of 1.8 – 2.8 mm/day.

For both temperature and precipitation *C. vulgaris* still occurs at extreme values, but here also the negative findings are scarce. This may lead to relative high chances of occurrence at the higher part of the response curve giving rise to unrealistic effects in the curve.

When looking at the years the plots were made, there is a reasonable distribution over the period of interest, though the oldest period is slightly underrepresented, as could be expected. Nitrogen deposition levels rise after around 1968, with the highest values around 1990. After 1990 measures were implemented to limit nitrogen deposition, which is visible in the plot, though relative high levels occur till the end of the period.

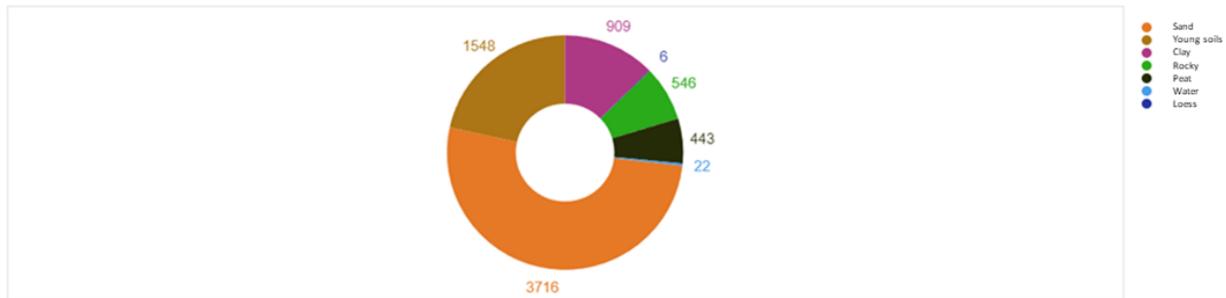
### Response density charts



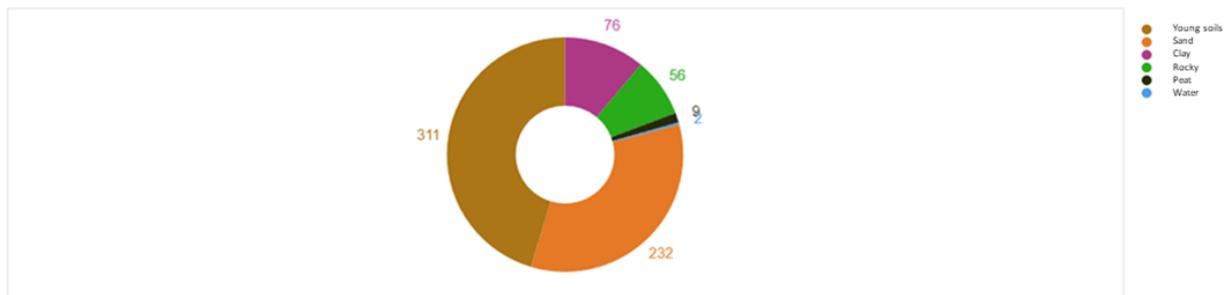
**Figure 23** The top figure gives the positive (orange) and negative (grey) plots for *Calluna vulgaris* combined with dwarf shrub structure type. Below: the number of positive plots (light orange) and negative plots (dark orange) per deposition class and the resulting probability curve (blue).

Figure 23 gives a 0-1 negative/positive plot (top) and a density chart with probability curve (bottom) against nitrogen deposition for *C. vulgaris*. From the former, it is clear that negative findings for *C. vulgaris* are absent for the very high nitrogen deposition values. The lower figure gives the same result. From this figure it also becomes clear that the number of negative plots is low over the whole deposition range. The absence of the negative plots at high deposition levels results in the highest probability per nitrogen class at these levels. This shows that enough negative values are very important and that the lack of these sometimes as shown here for *C. vulgaris* may lead to unrealistic responses, even though it is known that *C. vulgaris* can survive under high deposition rates, at least for some time. It also shows that just calculating the probability as a response curve can lead to misinterpretations as well, using a spline as we did in the Doren-1 project (Wamelink et al. 2021) mitigates this effect.

## Soil types

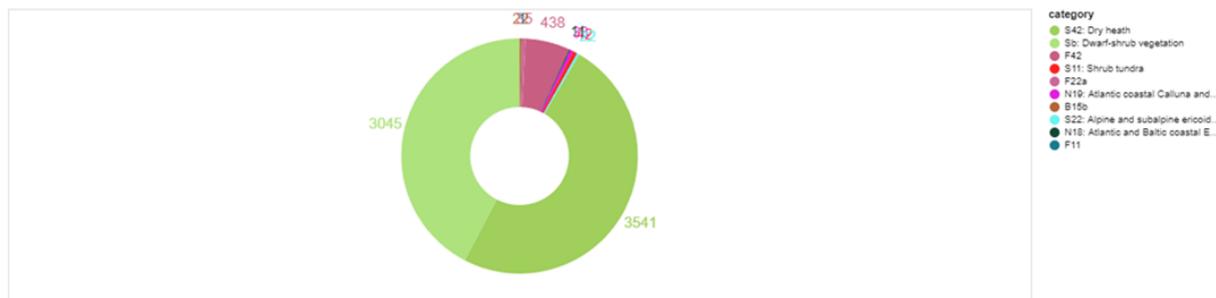


Distribution of 7190 positive findings over soil types

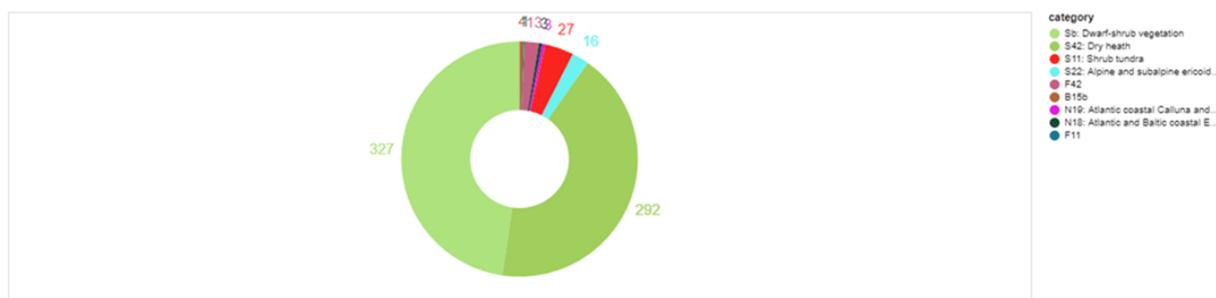


Distribution of 686 negative findings over soil types

## Distribution over the EUNIS classes



Distribution of 7190 positive findings over EUNIS types



Distribution of 686 negative findings over EUNIS types

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**Figure 24** The number of plots (top) and negative plots (lower) for soil type class (top two figures) and EUNIS class (bottom two figures) for *Calluna vulgaris* combined with dry dwarf shrub structure type.

Figure 24 gives the division of the plots over the soil and vegetation types both for the positive and negative plots for *Calluna vulgaris*. A majority of the plots occur on sand and young soils, though the positives are more often on sand compared to negative plots. Clay and rocky soils are represented equally. When looking at EUNIS types the main types are Dry heath and Dwarf-shrub vegetation, both not surprising. We conclude that the overviews for soil type and vegetation type were as expected and did not lead to possible bias in the response curves for *C. vulgaris*.

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### 3.1.1 Discussion

Reviewing data from the EVA-dataset provided insight into mutual correlations between presence/absence and covariables (soil, precipitation and temperature). For the selected species-structure type combinations, anomalies in the data could be identified. These explained, at least partly, the observed response curve increases at high nitrogen deposition levels. Further reviewing the response curves of all unexpected response curves is therefore recommended. Species with clearly problematic data distributions can then be identified and omitted, or their data selection could be adjusted. For the example given here, *C. vulgaris*, the results indicate that there is a biased number of negative findings, with only positive findings at high deposition rates. This leads to an unexpected response curve for *C. vulgaris* with an unlikely optimum at relative high deposition levels. This specific case was already identified by Wamelink et al. (2021). Omitting the former heathlands that turned into grasslands (no dwarf-shrub structure type) in the selection resulted in many missing negative findings. The example of *C. vulgaris* shows that data visualisation revealed patterns that enabled us to gain insight in why the species response is as it is, how likely it is influenced by bias in the dataset and how reluctant the response curve should be interpreted. Completing the dataset could solve this problem, but it may also lead to omitting a species from the species list. This can be done for other species as well, but it may not be as obvious as for *C. vulgaris*, a well-known species. Based on the results a correction for the anomalies could be implemented.

## 3.2 Additional empirical relationships between atmospheric nitrogen deposition and plant species richness: a visual inspection

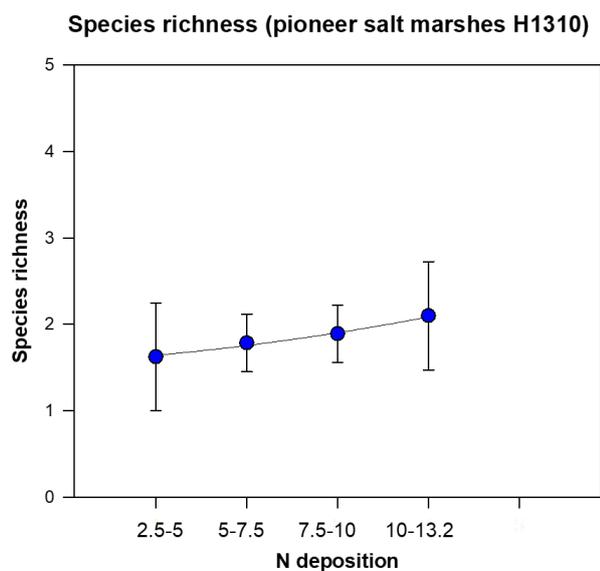
### 3.2.1 Pioneer salt marshes (H1310)



**Figure 25** Pioneer salt marsh in the Netherlands (photo: Bas van de Riet).

This habitat type is present on mud and sand planes in the intertidal zone of (shallow) seas. The vegetation is very species-poor and dominated by annual halophytes such as *Salicornia* (Figure 25). Inundations by sea water occurs daily.

For this habitat type 69 plots were present. The gradient in N-deposition was  $4.06 - 13.17 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ . The species richness of the vegetation was identical to the number of indicator species per plot, thus only one figure can be shown. A slight increase in species richness was found with higher N-deposition over the range (Figure 26).



**Figure 26** Mean species richness of the vegetation of pioneer salt marshes (mean  $\pm$  95%-confidence interval) per nitrogen deposition interval. Note: highest category also incorporates few data between 12.50 and 13.17 kg/ha/yr, hence the larger interval.

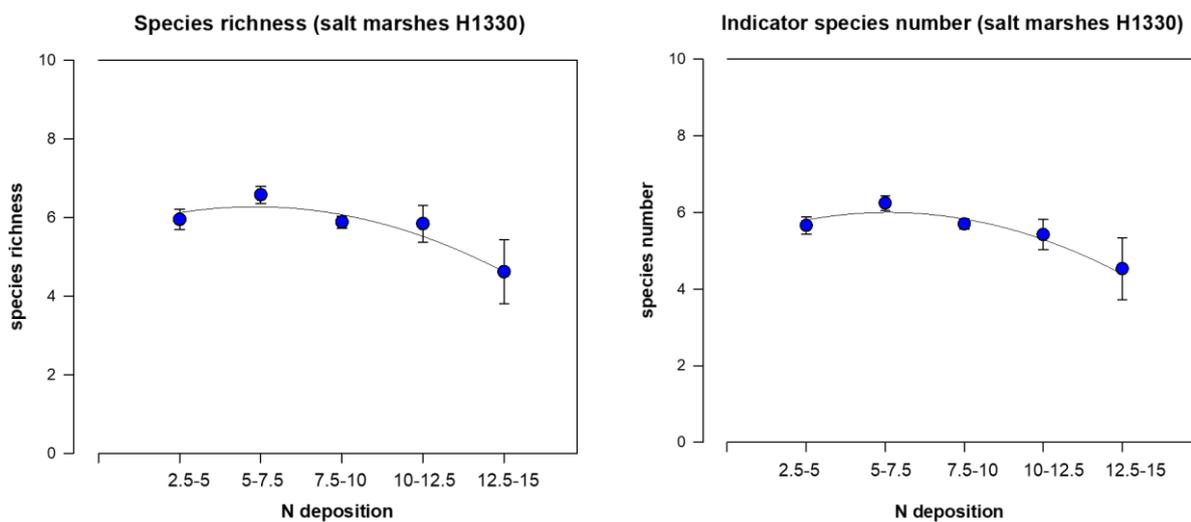
### 3.2.2 Salt marshes (H1330)



**Figure 27** Salt marsh (H1330) at Terschelling, the Netherlands (photo Bas van de Riet).

This habitat is present on the high/mid parts of salt marsh environments in North-West Europe. It also lies in the intertidal zone of shallow seas. Flooding with seawater is less frequent compared with pioneer salt marshes. The vegetation is characterised by halophytic species, and the species richness is rather low (Figure 27). Most of the present plant species (> 90%) are also positive indicator species for this habitat type.

In this salt marsh (H1330) survey, 1,123 plots were analysed across a N-deposition gradient of 3.78 – 13.30 kg N ha<sup>-1</sup> yr<sup>-1</sup>. Total species richness of the vegetation was only a little bit higher than the number of indicator species per plot. Both figures indicated a decrease in species number above 10 kg N ha<sup>-1</sup> yr<sup>-1</sup> (Figure 28).



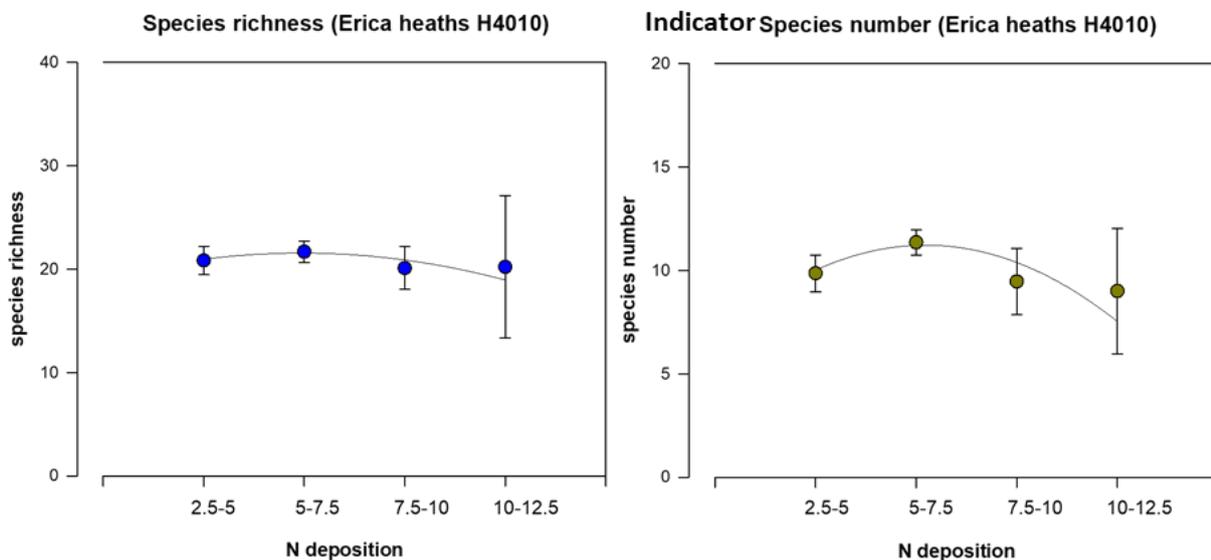
**Figure 28** Species richness (left) and indicator species number (right) of salt marshes (H1330, mean  $\pm$  95%-confidence interval).

### 3.2.3 Erica wet heaths (H4010)



**Figure 29** A wet heath on sandy soils with *Erica tetralix* (photo: Roland Bobbink).

This dwarf shrub community is found on both mineral (sandy) and peaty soils with high water tables in winter. The water table is clearly lower in summer. The full name of this habitat type is Northern Atlantic wet heaths with *Erica tetralix* (H4010). Species number is rather high for a heathland vegetation. A large part of this habitat type is present on the Pleistocene sandy regions in the Netherlands (Figure 29). A total of 231 plots of *Erica* heaths were used for this analysis, all originating from Ireland. The gradient in N-deposition was 3.80 – 11.32 kg N ha<sup>-1</sup> yr<sup>-1</sup>. The number of plots in the highest N-category was (too) low (n=5). Total species richness of the vegetation was double as high as the number of indicator species per plot. Both figures indicated a decrease in species number above 10 kg N ha<sup>-1</sup> yr<sup>-1</sup>. Especially, indicator species number seems to decrease above 7.5 kg N ha<sup>-1</sup> yr<sup>-1</sup> (Figure 30).



**Figure 30** Species richness (blue symbols) and indicator species number (green symbols) of *Erica* heaths (H4010, mean ± 95%-confidence interval).

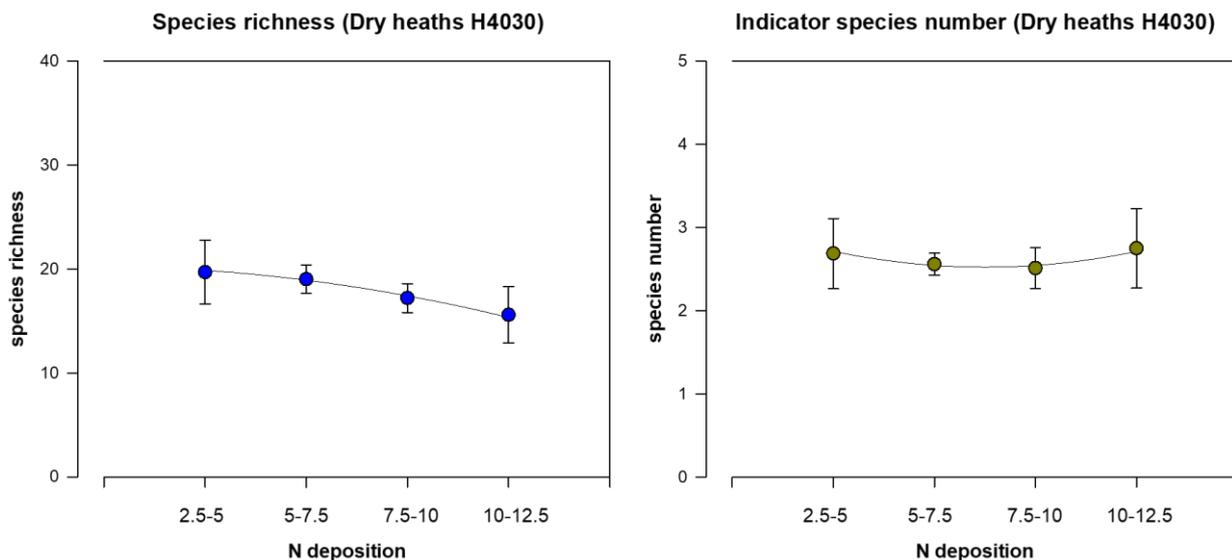
### 3.2.4 European dry heaths (H4030)



**Figure 31** A view of a European lowland dry heath (photo Roland Bobbink).

European dry heaths (H4030), mostly dominated by *Calluna vulgaris* (Figure 31) are widespread in the Atlantic zone of Europe. They are found on dry, acidic nutrient-poor substrates, such as Pleistocene sands of the European sand belt. Several bryophytes and lichens are part of the vegetation. It is a semi-natural habitat requiring management for its persistence.

In this survey 164 plots of Dry heaths (H4030) were available for analysis, with a N-deposition gradient of 3.73 – 17.40 kg N ha<sup>-1</sup> yr<sup>-1</sup>. However, the category with N-deposition beyond 12.5 kg could not be used due to too few plots (n=2). Total species richness of the vegetation was 6-7 times the number of indicator species per plot. Species richness of the dry heaths decreased with N deposition, especially above 7.5 kg N ha<sup>-1</sup> yr<sup>-1</sup>. However, occurrence of indicator species number remained stable across the available N range, probably because of the low number of these species (< 3/plot) (Figure 32).



**Figure 32** Species richness (blue symbols) and indicator species number (green symbols) of Dry heaths (H4030, mean ± 95%-confidence interval).

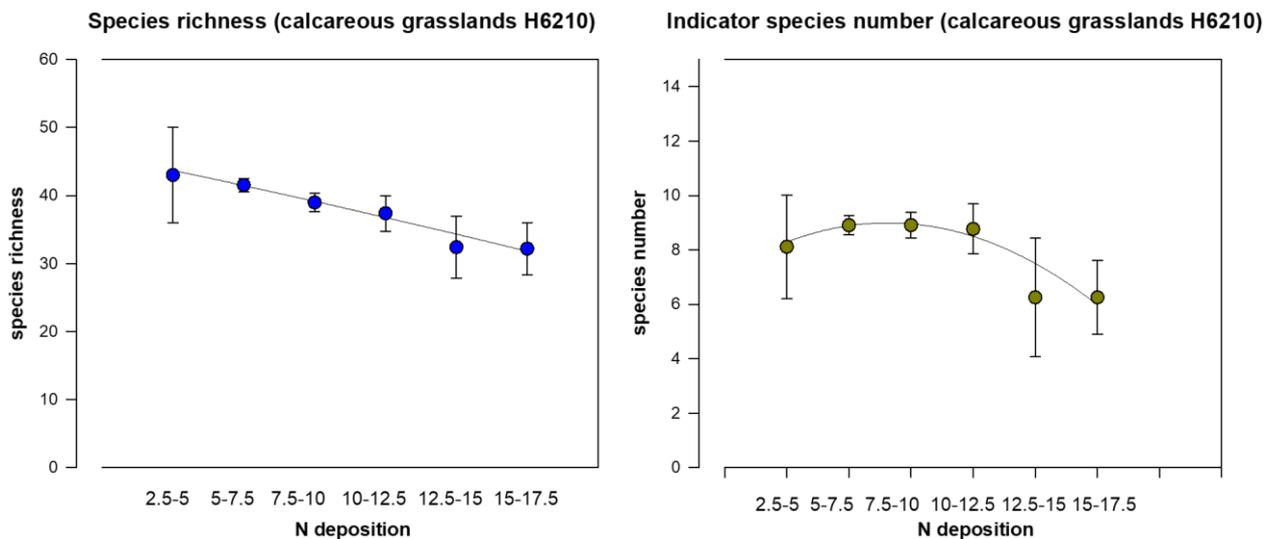
### 3.2.5 Calcareous grasslands (H6210)



**Figure 33** Picture of a calcareous grasslands (photo: Roland Bobbink).

Calcareous grasslands (H6210) are semi-natural vegetations with rendzinas soils formed on different kinds of limestones. The vegetation is species-rich with several orchid species (Figure 33); the faunal diversity is also high. The formal name of this habitat type is Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia* (H6210)).

507 plots of calcareous grasslands could be used for analysis. The gradient in N-deposition was 4.11 – 16.72 kg N ha<sup>-1</sup> yr<sup>-1</sup>. The number of plots in the lowest and the two highest N categories were relatively low (n=8-12). Species richness of the vegetation decreased linearly with N-deposition (clearly > 7.5 kg N ha<sup>-1</sup> yr<sup>-1</sup>), whereas the indicator species number showed a peak and then a decline in number (> 12.5 kg N ha<sup>-1</sup> yr<sup>-1</sup>) (Figure 34).



**Figure 34** Species richness (blue symbols) and indicator species number (green symbols) of calcareous grasslands (H6210, mean  $\pm$  95%-confidence interval).

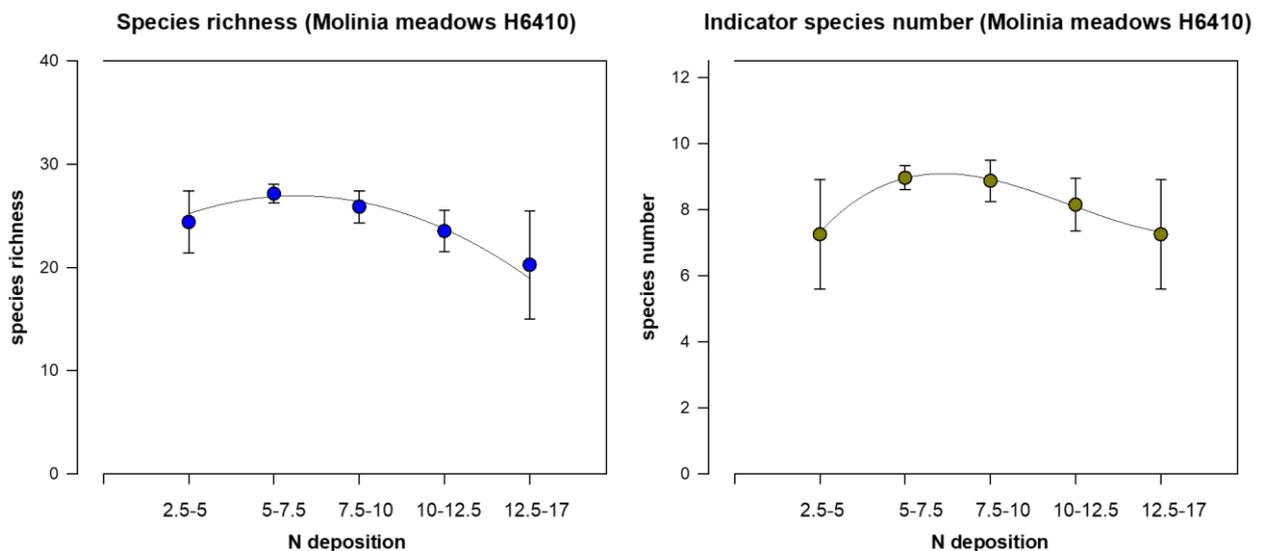
### 3.2.6 *Molinia* meadows (H6410)



**Figure 35** A view of a *Molinia* meadow (in Dutch "blauwgrasland") (photo Roos Loeb).

*Molinia* meadows (H6410) are fen meadows with moist, moderately base-rich peaty or clayey-silt-laden soils, often with fluctuating water tables. This habitat is species-rich, with *Molinia caerulea* accompanied by a wide range of associated species, such as *Cirsium dissectum* (Figure 35) and including rushes, sedges and tall-growing herbs.

In this survey 366 plots of *Molinia* meadows (H6410) were available for analysis with a N-deposition gradient of 3.50 to 16.55 kg N ha<sup>-1</sup> yr<sup>-1</sup>. Above 12.5 kg N ha<sup>-1</sup> yr<sup>-1</sup> only 8 plots were present and put in one category. The fitted curves of the total species richness and the indicator species number were more or less identical, with an optimum and a decrease above 10 kg N ha<sup>-1</sup> yr<sup>-1</sup> (Figure 36).



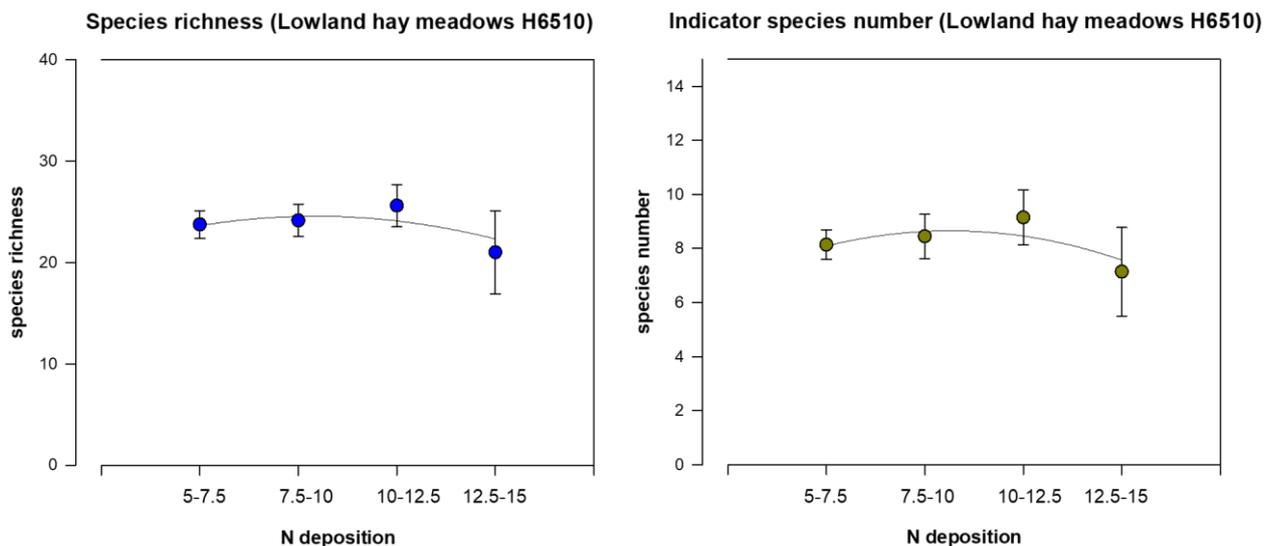
**Figure 36** Species richness (blue symbols) and indicator species number (green symbols) of *Molinia* grasslands (H6410, mean  $\pm$  95%-confidence interval).

### 3.2.7 Lowland hay meadows (H6510)



**Figure 37** Lowland hay meadow near the river Rhine (photo Roland Bobbink).

Lowland hay meadows (*Alopecurus pratensis*, *Sanguisorba officinalis*) (H6510) comprise species-rich hay meadows on moderately fertile soils of river and tributary floodplains. Most examples are cut annually for hay, with light aftermath grazing. Seasonal flooding may maintain an input of nutrients (Figure 37). A total of 125 plots of Lowland hay meadows were used for analysis. The gradient in N deposition was 5.55 – 15.53 kg N ha<sup>-1</sup> yr<sup>-1</sup>. The number of plots in the highest N category (12.5 – 15.5 kg N ha<sup>-1</sup> yr<sup>-1</sup>) was rather low (n=7). The fitted curves of the total species richness and the indicator species number were more or less identical, with a weak decrease at the highest N category (Figure 38).



**Figure 38** Species richness (blue symbols) and indicator species number (green symbols) of Lowland hay meadows (H6510, mean ± 95%-confidence interval). Note: highest category between 12.5 – 15.5.

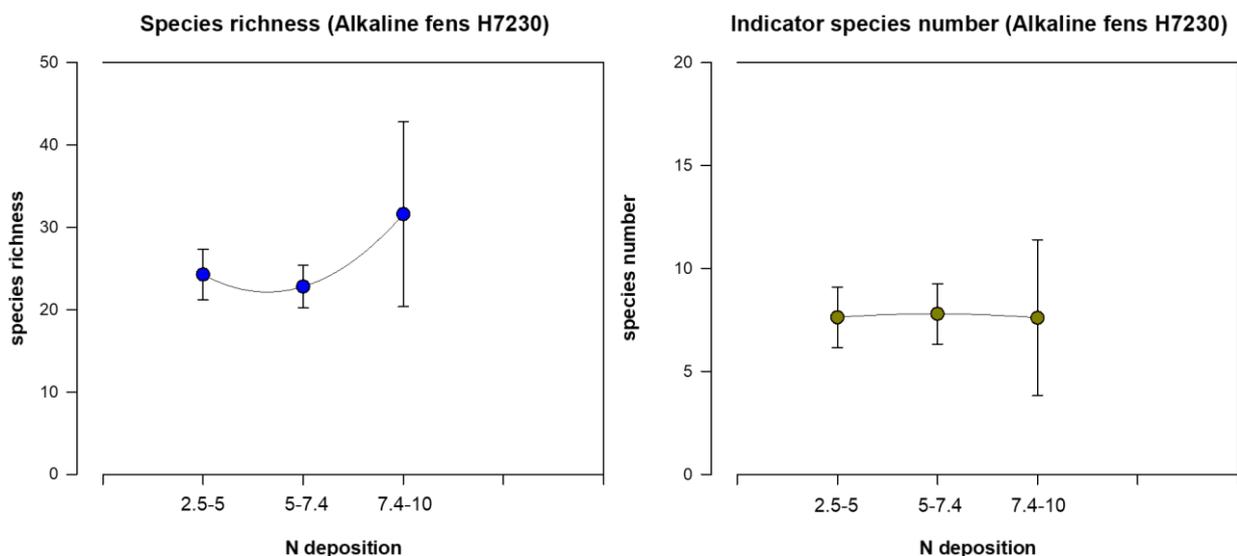
### 3.2.8 Alkaline fens (H7230)



**Figure 39** Overview of an alkaline fen in Belgium (photo: Hein van Kleef).

Alkaline fens (H7230) are peat-forming wetlands with many small sedge species and typical brown mosses (*Caricion davallianae*). The soil is generally wet and influenced by calcareous base-rich ground water (Figure 39). Especially the moss layer is very species-rich and characteristic. Alkaline fens have declined dramatically in the past century.

Only 32 locations of alkaline fens were available in this study. The range of N deposition was restricted to 4.19 – 9.97 kg N ha<sup>-1</sup> yr<sup>-1</sup>. Only 3 categories could be formed, with the highest one (7.4 – 10) with very few samples (n=3). It seems that N-deposition did not influence the species richness of the vegetation (or number of indicator species), however, the studied N-gradient is too restricted to draw conclusions (Figure 40).



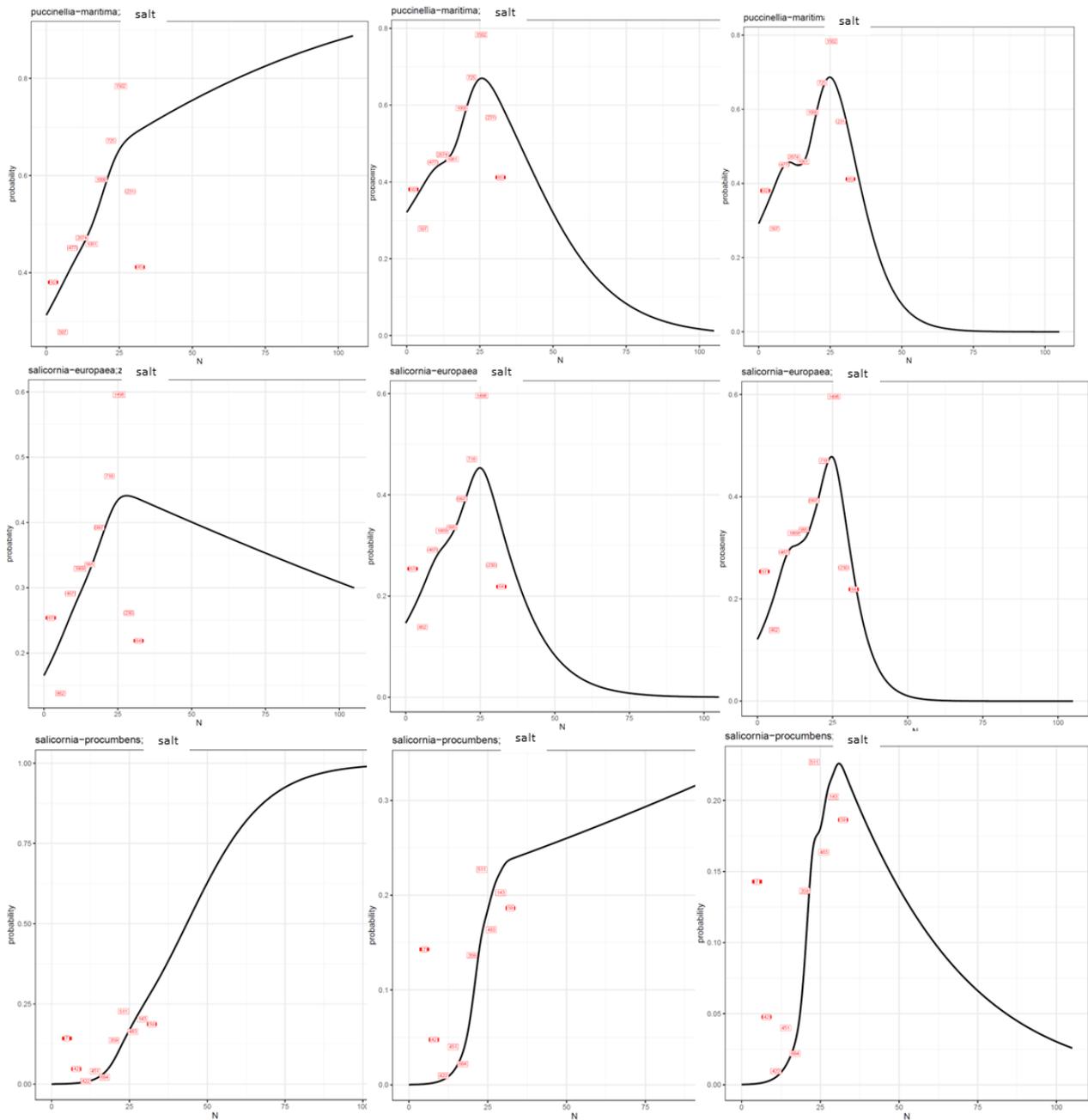
**Figure 40** Species richness (blue symbols) and indicator species number (green symbols) of Alkaline fens (H7230, mean ± 95%-confidence interval).

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## 3.3 Evaluation of the response curves from Doren-1

### 3.3.1 Degrees of freedom for the spline

Especially halophyte species gave unexpected responses in Doren-1, when applying 2 degrees of freedom for the spline function. For this reason, we here present some examples of halophytes and how the number of degrees of freedom (df) influences the response (Figure 41). All responses can be found in three electronic appendices (figs df2.pdf, figs df3.pdf and figs df4.pdf). The curve for *Puccinellia maritima* for df=2 gave a steady increase with nitrogen deposition, even though the data may suggest another curve. This curve was applied in Doren-1 and judged as poor. With 3 or 4 df an optimum curve appears, that better corresponds with the datapoints. Of these, df=4 resembles the data closest and seems the best choice whilst also complying to expectations: a descent at higher nitrogen deposition levels. For *Salicornia europaea*, a descent is present at higher deposition levels, but only limited. For df=3 and df=4 an optimum curve emerges, with here again the curve with df=4 best following the datapoints. For *Salicornia procumbens* df=2 and df=3 gave an ascending response curve, while only for df=4 an optimum was observed. What all three species have in common is lack of datapoints beyond 35 kg/ha/yr nitrogen deposition and that a major part of the curve is an extrapolation, which should be avoided.



**Figure 41** Response curves for *Puccinellia maritima* (top), *Salicornia europaea* (middle) and *Salicornia procumbens* (bottom) for three different degrees of freedom for the spline, 2 (left), 3 (middle) and 4 (right), all for structure type salt. The numbers in red give the number of findings, positive and negative, per nitrogen deposition interval (in kg/ha/yr), the probability of the interval can be read on the y-axis.

### 3.3.2 Evaluation of the response curves

The new judgement of the response curves is given in Table 5, including a short remark. The effect on the final judgement of the response curves for habitat types is large, but also due to the new empirical ranges and Dutch CL. This does not include yet a change in number of degrees of freedom for the spline.

Four habitat types changed in classification from poor to fair: "2170 Dunes with *Salix repens* ssp. *argentea*", "6510-B Lowland hay meadows (*Alopecurus* subtype)", "7140-B *Spagnum* reed land" and "91E0-A Alluvial forest (softwood)".

Eight habitat types changed in classification from fair to good: 2120 Embryonic shifting dunes, 2160 Dunes with *Hippophae rhamnoides*, 2190-C Humid dune slacks (chalk poor), 2320 Dry sand heaths with *Calluna*

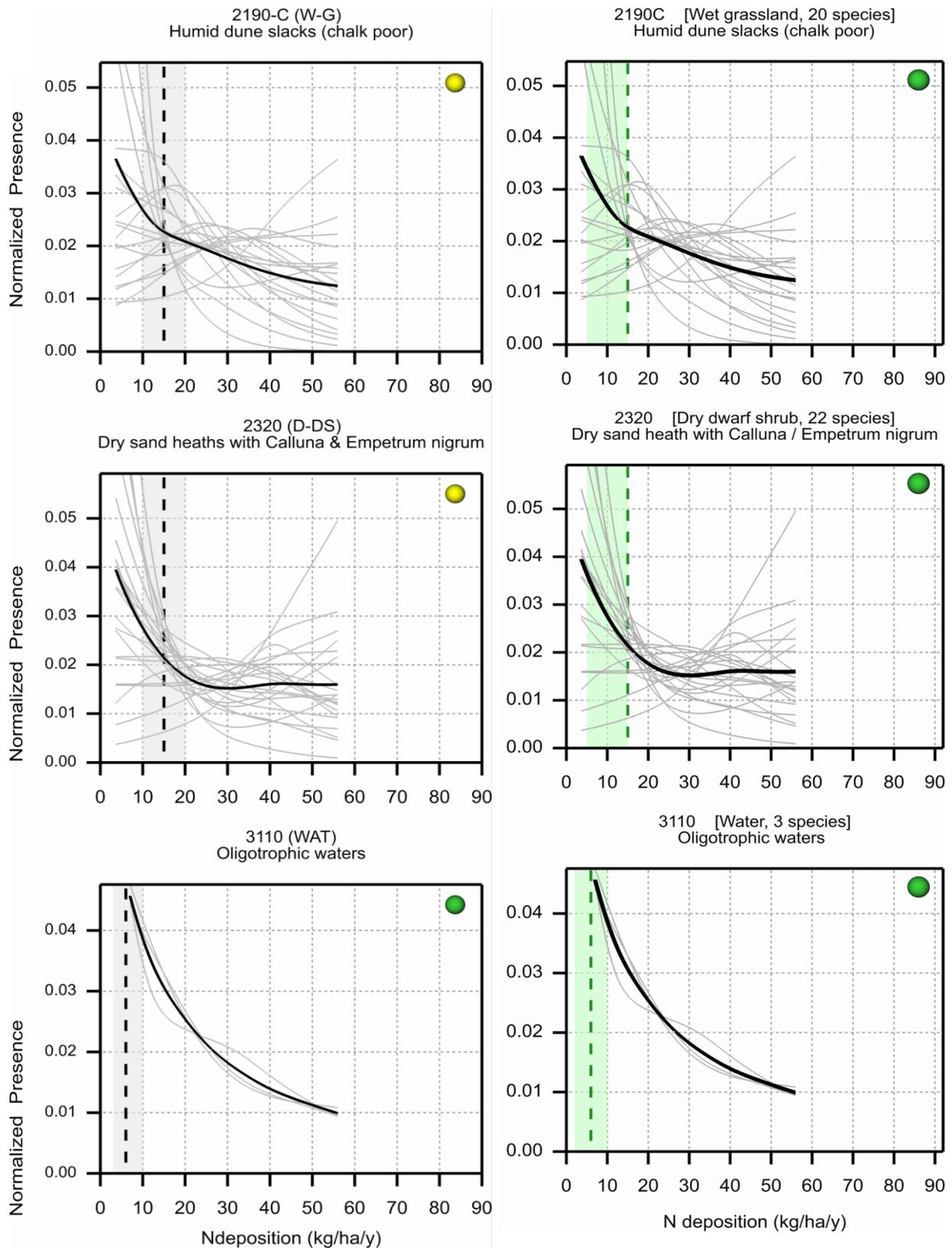
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and *Empetrum nigrum*, 6130 Calaminarian grasslands, 7220 Petrifying springs with tufa formation, 91E0-B Alluvial forest (ash-elm) and 91E0-C Alluvial forest (stream bank).

Five habitat types changed from poor to good: 3150 Natural eutrophic lakes, 6410 *Molinia* meadows, 6510-A Lowland hay meadows (*Arrhenatherum* subtype), 7210 Calcareous fens with *Cladium mariscus* and 9190 Old acidophilous oak woods.

One habitat type changed from good to fair, 1310B, Pioneer salt marshes (*Salicornia maritima* subtype). It is the only habitat type for which the judgement was lower than in Doren-1.

Figure 42 gives an example of the old and new response curves with the old and new empirical range and CL and the new judgement (green dots). For 2190C Humid dune slacks (chalk poor) and 2320 Dry sand heaths with *C. vulgaris* and *Empetrum nigrum*, the empirical range changed. The CL did not change because remained within the empirical range. Where in the old situation a major part of the curve-descent occurred at depositions outside the empirical range, this now occurs within the empirical range. Together with the decision that CL is no longer decisive in the judgement, this causes the judgement to change from fair to good. Thus, both habitat types are now reliable enough to be used for CL estimations. For both types the curves indicate that the current CL in the Netherlands is probably too high to prevent these habitat types from deterioration. Not much changed for the third habitat type in the example (3110 Oligotrophic waters): the empirical range is lower at the lower end. The response curve did not change, neither did the CL or the judgement, it was and remains good. The decrease of the quality starts at the maximum of the curve, which is also at the CL. More field data in areas with low deposition rates could give conclusive evidence if the decrease already starts at the lowest nitrogen deposition rates.



**Figure 42** Response curves for nitrogen deposition for three habitat types. On the left the curves and judgement for Doren-1 and on the right for Doren-2, with fair (yellow dot) and good (green dot) judgement. The Doren-1 responses compared with the old empirical range (grey rectangle) and critical load (black dashed line), the Doren-2 compared with the new empirical range (light green rectangle) and CL (dark green dashed line).

**Table 5** Assessment of the response curves per habitat type based on the old empirical range and CL by the first author. There are three categories, good (green), fair (fair, yellow) and poor (red). In the column judgement, the old judgement from Doren-1 (left) and the new judgement from this report, Doren-2 based on the new empirical CI and CL, are given.

Habitat	Name habitat type	Emp. range	CL	Judgement		Comment
				Doren-1	Doren-2	
1310-A	Pioneer salt marshes ( <i>Salicornia</i> )	20-30	23 23	Poor	Poor	Increasing curve
1310-B	Pioneer salt marshes ( <i>Sagina maritima</i> )	10-20	20 20	Good	Fair	Descent but high deposition (dep) increase, fits better with new empirical (emp) CL
1320	Spartina swards	20-30	23	Poor	-	No species
1330-A	Atlantic salt meadows (outside dyke)	10-20	20 20	Good	Good	But more increasing species
1330-B	Atlantic salt meadows (inside dyke)	10-20	20	Good	Good	But more increasing species
2110	Embryonic shifting dunes	10-20	20	-	-	No species
2120	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> ('white dunes')	10-20	20	Fair	Good	Same as Doren-1, but the CL is no longer regarded as leading, these are very nutrient poor systems
2130-A	Grey dunes, chalk rich	5-15	15	Good	Good	Same curve
2130-B	Grey dunes, chalk poor	5-15	13	Good	Good	Same curve
2130-C	Grey dunes, Nardetea	5-15	11	Good	Good	Same curve
2140-A	Dunes with <i>Empetrum nigrum</i> (moist)	10-15	12	Good	Good	One species with optimum curve missing
2140-B	Dunes with <i>Empetrum nigrum</i> (dry)	10-15	12	Good	Good	One species has a less strong increase
2150	Decalcified fixed dunes	10-15	12	Good	Good	One species has a less strong increase
2160	Dunes with <i>Hippophae rhamnoides</i>		28	Fair	Good	Descent now mainly after CL
2170	Dunes with <i>Salix repens ssp. argentea</i>		32	Poor	Rea	New insight and curve slightly different, more stable at higher depo
2180-A	Wooded dunes (dry)	10-15	15	Fair	Rea	Same response, descending response
2180-B	Wooded dunes (moist)		31	Good	Good	Almost same response, less pronounced optimum curves of some species
2180-C	Wooded dunes (inner dune)		25	Good	Good	Same response curve
2190-A	Humid dune slacks (open water)	10-20	14 30	Good	Good	Same response curve
2190-B	Humid dune slacks (chalk rich)	5-15	20	Good	Good	Slightly different curve
2190-C	Humid dune slacks (chalk poor)	5-15	15	Fair	Good	New insight, fits better with new emp CL
2310	Dry sand heaths with <i>Calluna</i> and <i>Genista</i>	5-15	10	Good	Good	Same curve, fits better with new emp CL
2320	Dry sand heaths with <i>Calluna</i> and <i>Empetrum nigrum</i>	5-15	15	Fair	Good	Response of one species less increasing and new insight, fits better with new emp CL
2330	Inland dunes	5-15	10	Good	Good	Response of one species less increasing
3110	Oligotrophic waters	5-10	6	Good	Good	Almost same curve
3130	Oligotrophic to mesotrophic standing waters	5-10	7	Good	Good	One species less increasing
3140	Hard oligo-mesotrophic waters	5-10	7 >34	Good	Good	One species less increasing
3150	Natural eutrophic lakes		30 >34	Poor	Good	New insight
3160	Natural dystrophic lakes and ponds	5-10	10	Good	Good	Less species
4010-A	Wet heaths with <i>Erica tetralix</i> (inland sandy soils)	5-15	15	Poor	Poor	Species increase less pronounced but still not good
4010-B	Wet heaths with <i>Erica tetralix</i> (lowland fens)	5-15	7	Good	Good	Species increase less pronounced
4030	European dry heaths	5-15	10	Good	Good	Increase species less pronounced
5130	<i>Juniperus communis</i> formations	5-15	15	Good	Good	Less good than before, decrease smaller
6110	Rupicolous calcareous or basophilic grasslands	10-20	20	Good	Good	Increase some species more pronounced
6120	Xeric sand calcareous grasslands	10-20	18	Good	Good	Same response
6130	Calaminarian grasslands	5-15	15	Fair	Good	Fits better with new emp CL
6210	Semi-natural dry grasslands	10-20	20	Good	Good	More species with an increasing response
6230	<i>Nardus</i> grasslands	6-20	10	Good	Good	Less pronounced increase for some species

Habitat	Name habitat type	Emp. range	CL	Judgement		Comment
				Doren-1	Doren-2	
6410	<i>Molinia</i> meadows	10-20	11	Poor	Good	New insight, fits better with new emp CL and less pronounced increase curve some species
6430-C	Hydrophilous tall herb fringe communities (dry woodland edge)		26	Poor	Poor	Increase
6510-A	Lowland hay meadows ( <i>Arrhenatherum</i> subtype)	10-20	19	Poor	Good	New insight, fits better with new emp CL
6510-B	Lowland hay meadows ( <i>Alopecurus</i> subtype)	10-25	22	Poor	Rea	New insight, decrease still minimal, fits better with new emp CL
7110-A	Active raised bogs (active bog landscape)	5-10	7	Good	Good	One increasing species less pronounced
7110-B	Active raised bogs (heath bogs)	5-15	10	Good	Good	One increasing species less pronounced
7120	Degraded raised bogs		7-25	Good	Good	Few species with less pronounced increase
7140-A	Quacking bogs	15-25	17	Good	Good	Curve changed shape and is now a steady decrease
7140-B	<i>Sphagnum</i> reedland	5-15	7	Poor	Rea	No longer optimum curve, but decrease still at high value (25 kg/ha/y)
7150	Depressions on peat substrates	5-15	15	Good	Good	Same curve
7210	Calcareous fens with <i>Cladium mariscus</i>	15-25	20	Poor	Good	New insight, fits better with new emp CL
7220	Petrifying springs with tufa formation	15-20	20	Fair	Good	New insight
7230	Alkaline fens	15-25	16	Good	Good	Same curve
9110	<i>Luzulo-Fagetum</i> beech forests	10-15	15	Good	Good	Same curve
9120	Atlantic acidophilous beech forests	10-15	15	Good	Good	Same curve
9160-A	Oak or oak-hornbeam forests (sandy soils)	15-20	20	Good	Good	Some increasing curves lower
9160-B	Oak or oak-hornbeam forests (hills)	15-20	20	Good	Good	Same curve
9190	Old acidophilous oak woods	10-15	15	Poor	Good	Steady decrease from the beginning
91D0	Bog woodland		25	Good	Good	Same curve
91E0-A	Alluvial forest (softwood)		34	Poor	Rea	New insight, increasing species slightly lower
91E0-B	Alluvial forest (ash-elm)		28	Fair	Good	New insight
91E0-C	Alluvial forest (stream bank)		26	Fair	Good	New insight
91F0	Riparian mixed forests		29	Poor	Poor	Kept it at poor, but distinct decrease around 55 kg/ha/yr, much higher than CL

### 3.4 Species composition of habitat types

The full evaluation of the curves is given in Appendix 5, the number of characteristic species per habitat type and species list is given in Appendix 6.

The number of habitat types with at least ten characteristic species varies per species list (Table 6; total). As expected, the list without displacement species gives the highest number of response curves (59, the maximum) for habitat types. List SI 2-4 are all sub-lists of SI 1 and gives a lower number of response curves. The list with only 'Red List' species (SI 2) gives the second highest number, but only one more than only typical species (SI 3). The combination of 'Red List' species and typical species (SI 4) gave the lowest number of response curves, only 37.

Table 6 gives the judgement of the response curve based on the species lists. In five cases SI 2 gives a better response curve than SI 1. However, also in 5 cases SI 2 gives a worse response curve than SI 1. This implies that, given that SI 2 yields less response curves, overall SI 1 performs better. SI 3 and SI 4 perform worse than SI 2, which leads to the conclusion that SI 1 is the best species list for overall performance. This is partly due to the very limited number of species in SI 2-4 that qualify, indicating that enough species is crucial for a good estimate of the response curve. Note that response curves with less than 10 species can still perform well, but this must be manually checked. Clearly, this leads to more subjective interpretation of the results.

**Table 6** Overall score of the response curves for nitrogen deposition for the habitat types for four different species list for the habitat types. With SI 1: original species list without displacement species, SI 2: 'Red List' species. SI 3: typical species and SI 4: 'Red List' species and typical species. Only habitat types with more than 9 species are used.

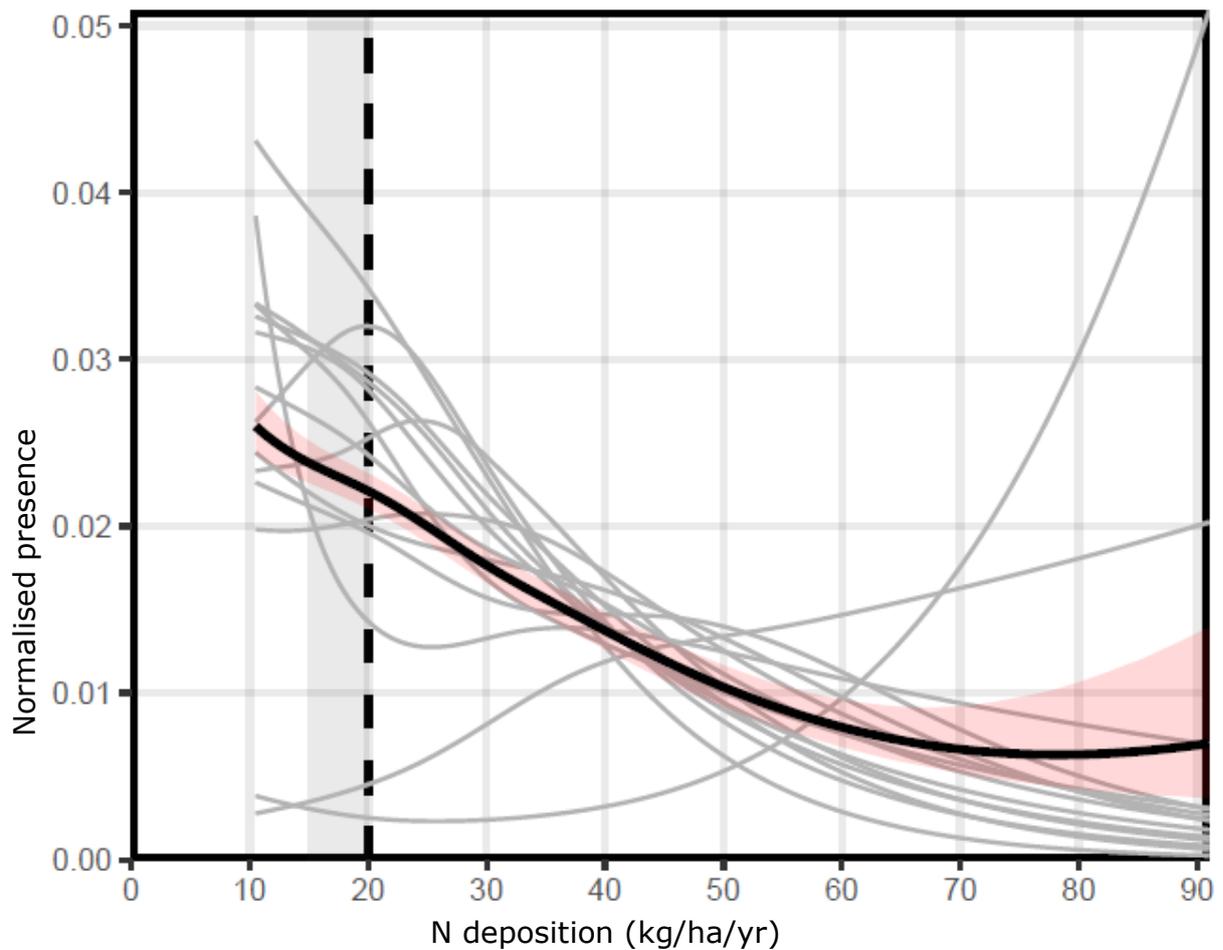
Judgement	SI 1	SI 2	SI 3	SI 4
Good	49	42	41	31
Fair	6	4	2	3
Poor	4	4	6	3
Total	59	50	49	37

### 3.5 Confidence interval

The confidence interval is given in the figures with the response curves for the habitat types and highlighted as a red band around the response curve. The uncertainty does not mirror around the response curve; thus, the quantity of the confidence interval can be different below and above the curve (see Figure 43 for an example; all are given in Appendix 7). For the habitat type Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli* (hills), the confidence interval proved to be largest at the higher end of the nitrogen deposition range. This is due to the bigger variation in the response curves of the underlying species; two of these increase with higher deposition, while all others decrease and have a low normalised presence. They partly reveal a low and decreasing normalised presence, but some species give an increasing or higher normalised presence. For the lower nitrogen deposition levels, the confidence interval is limited, though also here there are different responses. However, there is another factor that influences the confidence interval, being the uncertainty in the species response curves and thus the underlying data from the plots. The number with plots for higher nitrogen deposition levels is limited, giving rise to a higher level of uncertainty.

In general, the uncertainty is low (Appendix 7), especially when there are many characteristic species. At the other end of the range the confidence interval is also low when there is only one characteristic species. When the uncertainty is larger it is often due to one or more species that have a response that deviates from the other species (as for our example in Figure 43). The confidence interval also tends to be larger at the extremes of the response curves, both at high and low deposition rates.

9160-B  
 Sub-Atlantic and medio-European oak or oak-hornbeam forests of  
 the *Carpinion betuli* (hills)



**Figure 43** Response curve for Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli* (hills, 9160B) with the species responses in light grey line, the response curve of the habitat type in black and the uncertainty in light red. Also given are the critical load (dotted line, old version from 2012) and the empirical critical load (grey rectangle, old version from 2011).

### 3.6 Reassessment of the response curves from Doren-1 solely based on the empirical range from 2022 and the critical load from 2023

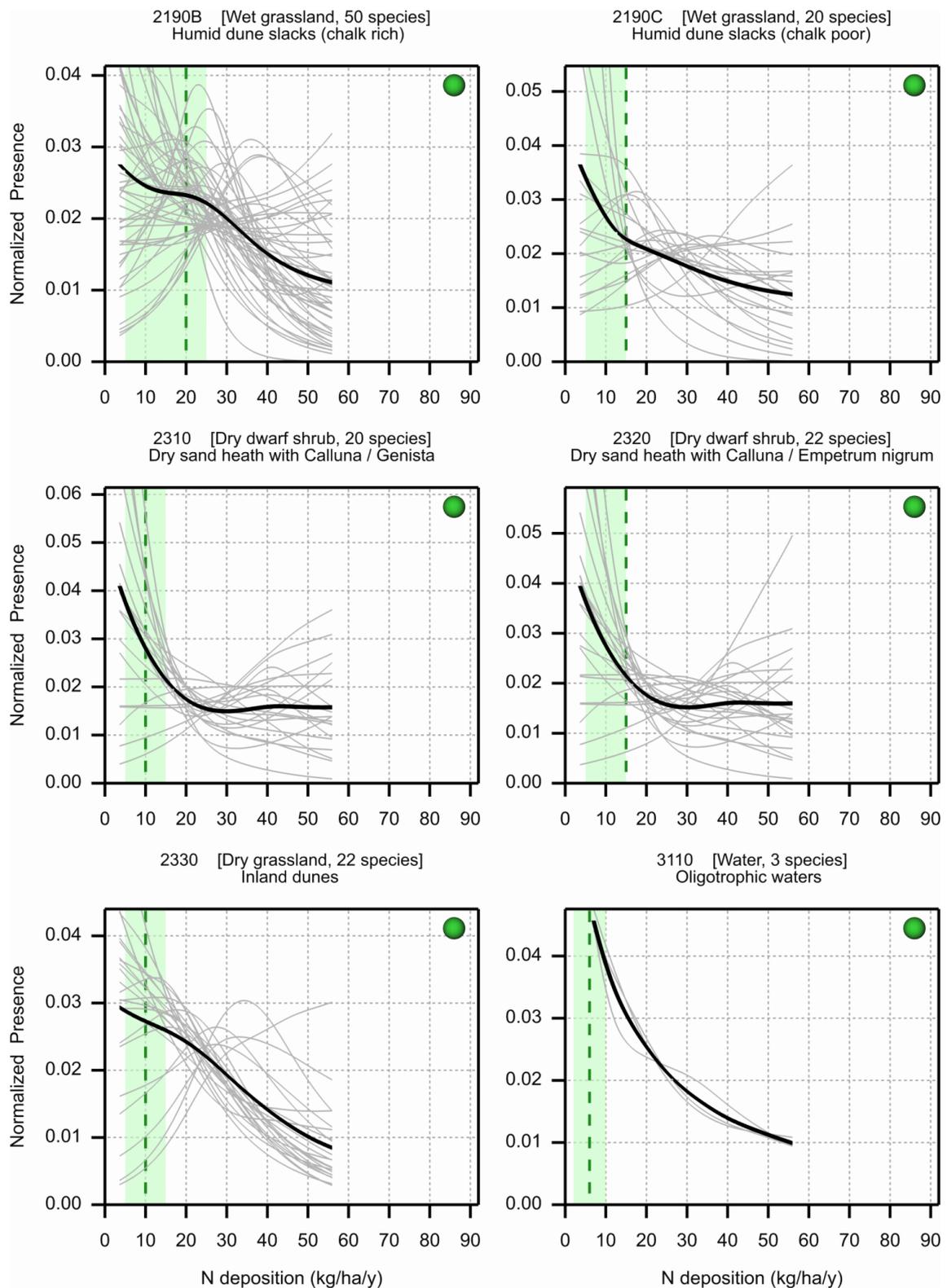
Figure 44 gives an example of the new assessment of the response curves (all can be found in Appendix 8). The description of the curves was adjusted based on the new data and is given in Table 7. Figure 44 provides the results for grassland and heathland types in the dunes and oligotrophic water. For oligotrophic waters a steep decrease from the lowest nitrogen deposition is present. This is in line with the empirical range and the CL given by Bobbink et al. (2022) and Wamelink et al. (2023). The decrease of the curve starts at the CL. For the dune grassland types the decrease of the curves now starts and lies within the empirical ranges and is in line with the CL. Exceptions are 2320 dry sand heath with *Calluna/Empetrum* and 2190C Humid dune slack where the CL is at the maximum of the empirical range. This relative high CL is due to the model outcome that was used to set the CL for this type (see Wamelink et al. 2023). Probably this CL is too high. When looking at the underlying species responses (in light grey) for five examples (3110 excluded) there are also species that show a steady increase or an optimum curve for nitrogen deposition. These species profit

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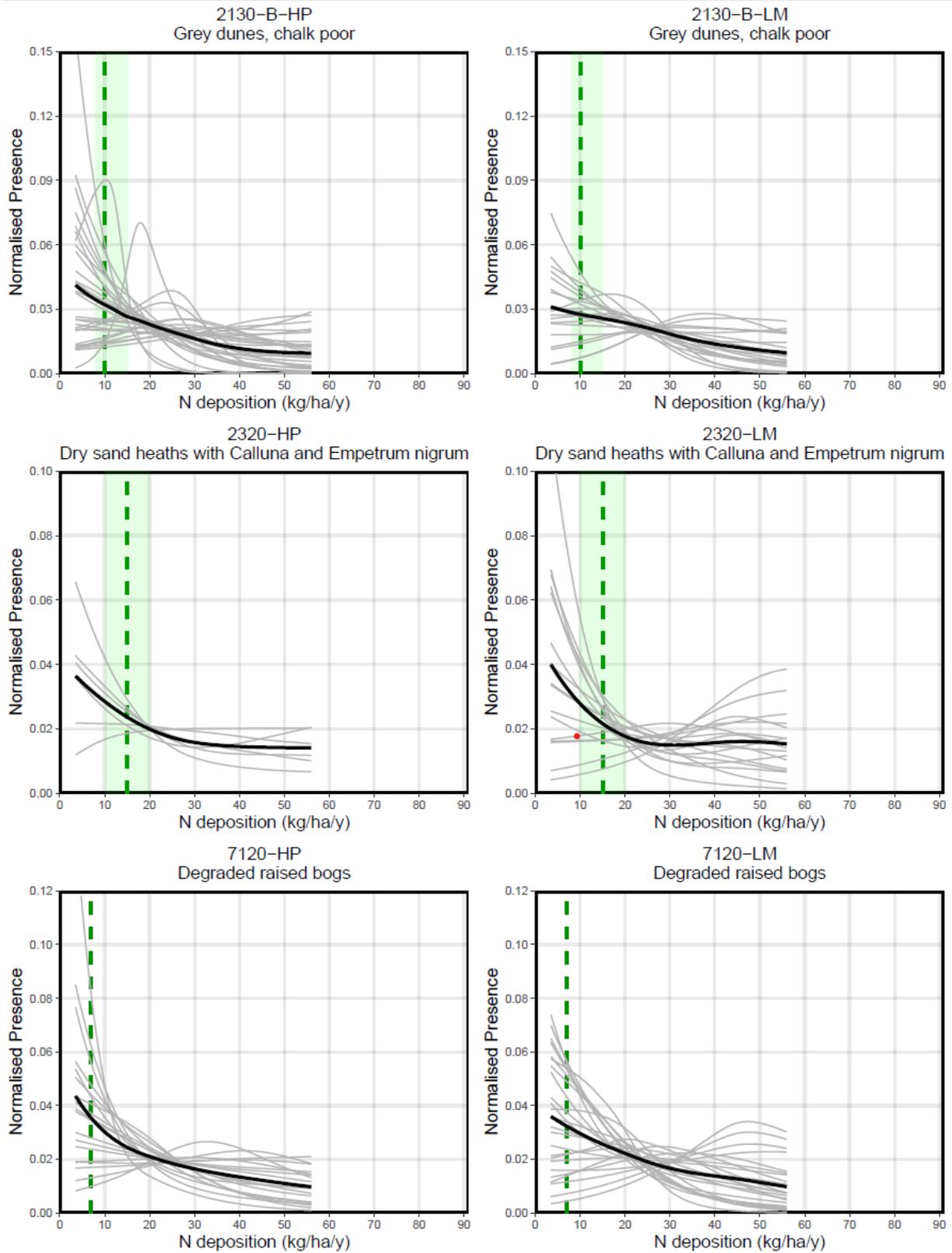
from nitrogen deposition. For all types they form a minority and they do not influence the responses greatly, but there is a minor increase visible for both 2310 and 2320 at high deposition levels.

In general, the response curves for nitrogen deposition of the examined habitat types are more in agreement with the new empirical critical load range (Bobbink et al. 2022) and the Dutch CL (Wamelink et al. 2023) than the old ones (Table 7). For the types that were classified as good already in the earlier assessment, especially the response curves that have a steady descent from the lowest deposition levels agree better, given the lower empirical ranges and CLs. For two habitat types the judgement changed from fair to good and for two other types from poor to fair. This means that there are now 39 response curves judged as good, 9 as fair and 12 as poor. Note that this is excluding the improvements made in Doren-2, for an overall assessment, so including new empirical ranges and CLs and improvements based on Doren-2, see Table 5 (chapter 3.3.2).

To investigate whether there could be a difference between higher plants versus mosses/lichens regarding the responses, we estimated the curves separately for three habitat types: Grey dunes (chalk poor, 2130B), Dry sand heaths with *Calluna* and *Empetrum nigrum* (2320), and Degraded raised bogs (7120). Though there were some minor differences, the response curves were quite similar (Figure 45). The biggest differences were visible at the lower deposition rates for Grey dunes and Degraded raised bogs, where for lichens and mosses the descent was less steep. For Dry sand heath, the opposite is visible with a somewhat stronger descent for the lichens and mosses.



**Figure 44** Response curves of species (light grey lines) and habitat types (black line). The light green bar gives the empirical CL range (Bobbink et al. 2022), the dark green dotted line the modelled Dutch CL (Wamelink et al. 2023) and the green dot the assessment of the response curve by the first author. In the header the habitat number is given, between brackets the structure type and the number of characteristic species. The second line gives the short name of the habitat type.



**Figure 45** Response curves for three habitat types based on only higher plants (left) or only mosses and lichens (right).

**Table 7** Assessment of the habitat types (by the first author) based on the new empirical range (Bobbink et al. 2022) and new critical load (Wamelink et al. 2023). The range of the decrease is the range in kg/ha/yr where the main drop in quality of the response curve appears. Note that this is excluding the improvements made in Doren-2, for an overall assessment, so including new empirical ranges and CLs and improvements based on Doren-2, see Table 5 (chapter 3.3.2).

Code	Name habitat type	Description of the curve	Decrease range (kg/ha/yr)	Assessment
1310A	Pioneer salt marshes ( <i>Salicornia</i> )	Increasing curve, only five species, all species show an increasing response which is unlikely.		Poor
1310B	Pioneer salt marshes ( <i>Sagina maritima</i> )	Steadily decreasing response with an increase in decrease within the empirical critical range (CR) and just below the Critical Load (CL).	30	Good
1320	<i>Spartina</i> swards ( <i>Spartinion maritimae</i> )	Only one characteristic species ( <i>Spartina anglica</i> ), with an inexplicable response (hyperbola).		Poor
1330A	Atlantic salt meadows ( <i>Glauco-Puccinellietalia maritimae</i> , outside the dyke)	Descending curve with an increase in decrease within the empirical CR and with a larger decrease just before the CL.	20	Good
1330B	Atlantic salt meadows ( <i>Glauco-Puccinellietalia maritimae</i> , inside the dyke)	Descending curve with an increase in decrease within the empirical CR and with a larger decrease just before the CL.	20	Good
2110	Embryonic dunes	No characteristic species.		
2120	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> ("white dunes")	From the lowest deposition a sharp descending curve, descent till the highest deposition. Strong descent before the empirical critical load range. Is the descent too strong in the beginning or is this genuine? The strong descent is mainly caused by <i>Eryngium maritimum</i> and <i>Calystegia soldanella</i> . <i>Eryngium maritimum</i> is a 'Red List' species but given its Ellenberg characteristic value for nutrient richness not very sensitive. The same applies for <i>Calystegia soldanella</i> . Maybe vegetation succession interferes with the response here.	15	Fair
2130A	Fixed coastal dunes with herbaceous vegetation ("grey dunes", chalk rich)	Descending curve with a stronger descent from the CL on, descending till the lowest deposition. The new empirical CR from Bobbink et al. (2022) is more in agreement than the old empirical CR (Bobbink & Hetteling 2011).	50	Good
2130B	Fixed coastal dunes with herbaceous vegetation ("grey dunes", chalk poor)	Steadily descending curve that slightly evens out at higher deposition. The new empirical CR from Bobbink et al. (2022) is more in agreement than the old empirical CR (Bobbink & Hetteling 2011).	40	Good
2130C	Fixed coastal dunes with herbaceous vegetation ("grey dunes", <i>Nardetea</i> )	Descending curve with a small bend at deposition above the CL. Descent continues till the maximum deposition. The new empirical CR from Bobbink et al. (2022) is more in agreement than the old empirical CR (Bobbink & Hetteling 2011).	40	Good
2140A	Decalcified fixed dunes with <i>Empetrum nigrum</i> (moist)	Descending curve with a small bend at deposition above the CL. Descent continues till the maximum deposition but differences are relatively small.	40	Good
2140B	Decalcified fixed dunes with <i>Empetrum nigrum</i> (dry)	Strong descent before the CL but mostly within the range of the empirical CL. After the CL there is almost no descent. The sharp drop at the lower end is mostly caused by <i>Cladonia</i> species and <i>Viola canina</i> .	20	Good
2150	Atlantic decalcified fixed dunes ( <i>Calluno-Ulicetea</i> )	Strong descent before the CL but mostly within the range of the empirical CL. After the CL there is almost no descent. The sharp drop at the lower end is mostly caused by <i>Cladonia</i> species.	20	Good
2160	Dunes with <i>Hippophae rhamnoides</i>	Steady descent for the whole range with a sharper decrease after the CL. The CL is relatively high, but not reflected in the curve. Many species of which some very strongly react with a sharp descent from the lowest deposition.	65	Fair

Code	Name habitat type	Description of the curve	Decrease range (kg/ha/yr)	Assessment
2170	Dunes with <i>Salix repens subsp. argentea</i>	Strong descent at low deposition levels then gradually less steep descent. Descent starts already at much lower deposition levels than the relative high CL. There are four characteristic species, <i>Empetrum nigrum</i> and <i>Luzula multiflora</i> react as expected, <i>Schoenus nigricans</i> shows a steep descent, fitting for a species which is showing a steep decline in the Netherlands. Also due to the limited number of species this type is cored as poor.	35	Poor
2180A	Wooded dunes (dry)	Slightly descending curve for the whole deposition range for a type with a low CL. A (stronger) descent was expected. <i>Avenella flexuosa</i> does not react on nitrogen deposition, which we can not explain. Many species of which a part, not unexpected, show a strong increase: <i>Frangula alnus</i> , <i>Holcus mollis</i> and <i>Sorbus aucuparia</i> .	85	Fair
2180B	Wooded dunes (moist)	Strong descent starts already before the CL, but the descent continues after the CL to even out at high deposition rates. Many characteristic species.	55	Good
2180C	Wooded dunes (inner dune)	A slight descent before the CL, after the CL a strong descent to even out at the higher nitrogen levels.	50	Good
2190A	Humid dune slacks (open water)	Strong descending response around the CL evening out at high deposition levels.	30	Good
2190B	Humid dune slacks (chalk rich)	Mild descent evening out around the CL. After the CL descending till the maximum nitrogen deposition. Many characteristic species.	35	Good
2190C	Humid dune slacks (chalk poor)	Strong descent before the CL, before the CL the descent becomes less descending staying the same till the maximum deposition. The curve agrees with the new empirical CR. The strong descent is mostly the result of <i>Empetrum nigrum</i> and <i>Scorpidium scorpioides</i> . Especially the response for the latter, a very rare 'Red List' species, is as could be expected.	50	Good
2310	Dry sand heaths with <i>Calluna</i> and <i>Genista</i>	Strong descent before the CL, stabilising just before the maximum value of the empirical critical range. The curve agrees with the new empirical CR. The strong descent at low deposition rate is mainly the result of a number of <i>Cladonia</i> species.	20	Good
2320	Dry sand heaths with <i>Calluna</i> and <i>Empetrum nigrum</i>	Strong descent before the CL, but in agreement with the empirical CR. The strong descent is the result of a large part of the characteristic species.	20	Good
2330	Inland dunes	Gradually descending response over the whole range with a slightly stronger descent after 20 kg/ha/j.	50	Good
3110	Oligotrophic waters	Descending response for the whole range. The CL is lower than the range the response could be estimated for. Only three characteristic species, all three similar.	40	Good
3130	Oligotrophic to mesotrophic standing waters	Evening out descending response curve. The CL is lower than the range the response could be estimated for.	30	Good
3140	Hard oligo-mesotrophic waters	Descending response curve, slightly increasing at the highest nitrogen depositions. The CL is lower than the range the response could be estimated for. See also H3130. <i>Isolepis fluitans</i> has a S-shaped response curve.	30	Good
3150	Natural eutrophic lakes	Slightly descending curve, evening out at higher deposition. Relative high CL, largest descent below the CL. The overall picture may be genuine, but <i>Stratiotes aloides</i> is showing a steady descending trend, surprising for a species of relative nutrient rich water.	40	Poor
3160	Natural dystrophic lakes and ponds	Strong descent at lower deposition levels, evening out at higher depositions. Four characteristic species with similar curves. Two species show the start of the descending response at the CL.	30	Good

Code	Name habitat type	Description of the curve	Decrease range (kg/ha/yr)	Assessment
4010A	Wet heaths with <i>Erica tetralix</i> (inland sandy soils)	Light descending curve, with already a descent before the CL. Unexpected increasing response curves for species as <i>Drosera intermedia</i> , <i>Erica tetralix</i> , <i>Gentiana pneumonanthe</i> and <i>Sphagnum compactum</i> . The response curve for <i>Molinia caerulea</i> does not show an increase, also unexpected. All the responses of the species are based on vegetation plots of structure type dwarf shrub. Most likely the heathlands overgrown by <i>Molinia</i> are missing, as they are classified as grassland in the EUNIS typology.		Poor
4010B	Wet heaths with <i>Erica tetralix</i> (lowland fens)	Descending curve then evening out and at high deposition levels slightly increasing. Curve fits better with the new empirical CR.	35	Good
4030	European dry heaths	Strong descent at low deposition, already below the CL, then evens out. Curve fits better with new CL and new empirical CR.	20	Good
5130	<i>Juniperus communis</i> formations	Gradely descending curve, the differences are relatively small. The biggest descent is within the empirical CR.	65	Good
6110	Rupicolous calcareous or basophilic grasslands	Descending curve, stabilising around the CL and then decreasing further. Curve fits better with the new empirical CR.	50	Good
6120	Xeric sand calcareous grasslands	Descending trend, at higher deposition the curve evens out. Curve fits better with the new empirical CR.	35	Good
6130	Calaminarian grasslands of the <i>Violetalia calaminariae</i>	Descending curve beyond the CL. The most characteristic zinc tolerant species are missing due to lack of data. The result is determined by common species.	35	Fair
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates ( <i>Festuco-Brometalia</i> )	A slight descent at low deposition levels stabilising around the CL and then a steep descent. The curve fits less well with the new lower empirical CR, though there is already a descent in the curve starting from the lowest deposition.	35	Good
6230	Species-rich <i>Nardus</i> grasslands on siliceous substrates in mountain areas (and submountain areas in Continental Europe)	Descending curve The curve fits the new empirical CR well, with a descent at the lowest deposition.	50	Good
6410	<i>Molinia</i> meadows on calcareous peaty or clayey-silt-laden soils ( <i>Molinion caeruleae</i> )	Limited descent, with a minor increase at high deposition levels, where a strong descent was expected. The new empirical CR is lower than the old one, which fits the curve better. The curve of <i>Rhinanthus angustifolius</i> is unexpectedly increasing with nitrogen deposition levels. <i>Carum verticillatum</i> has a very limited range. Most species seem more or less indifferent for nitrogen deposition. It could be that for this habitat type other processes are more important, such as (quality of) seepage, which is not included as covariable.	35	Fair
6430C	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (dry woodland edge)	Slightly increasing curve. The increase starts at higher deposition level than the CL. This subtype is now linked to structure type forest. This could lead to a to high estimate of the deposition and thus a wrong response curve. Many very common species of nutrient rich circumstances determine the response: <i>Aegopodium podagraria</i> , <i>Anthriscus sylvestris</i> , <i>Galium aparine</i> , <i>Glechoma hederacea</i> , <i>Lamium album</i> , <i>Rumex obtusifolius</i> , <i>Silene dioica</i> and <i>Urtica dioica</i> . However, the most characteristic species of the type are very rare.		Poor
6510A	Lowland hay meadows ( <i>Alopecurus pratensis</i> , <i>Sanguisorba officinalis</i> ; <i>Arrhenatherum</i> subtype)	At lower deposition levels a straight line, with a descent at deposition levels higher than the CL but within the empirical CL. The new empirical CR fits less well with the curve, the descent starts just outside the range.	30	Poor

Code	Name habitat type	Description of the curve	Decrease range (kg/ha/yr)	Assessment
6510B	Lowland hay meadows ( <i>Alopecurus pratensis</i> , <i>Sanguisorba officinalis</i> ; <i>Alopecurus</i> subtype)	Almost no response to deposition, only a slight decrease at the low deposition levels. The new empirical CR borders now the descending part of the curve. The differences are minimal. A part of the species are characteristics of nutrient rich grasslands, which has a major effect on the curve.		Poor
7110A	Active raised bogs (active bog landscape)	A descending curve from the CL onwards, with a stabilisation at high deposition levels.	50	Good
7110B	Active raised bogs (heath bogs)	A descending curve from the CL onwards, with a stabilisation at high deposition levels. The new empirical CR fits better with the curve.	50	Good
7120	Degraded raised bogs still capable of natural regeneration	A descending curve from the CL onwards, with a stabilisation at high deposition levels.	50	Good
7140A	Transition mires and quaking bogs (quacking bogs)	Descending curve evening out at high deposition levels. The decrease is increasing at deposition levels beyond the CL. The new empirical CR fits better with the curve.	50	Good
7140B	Transition mires and quaking bogs ( <i>Sphagnum</i> reedland)	Optimum curve with an increase way beyond the CL. The descent is quite strong, but only starts at very high deposition levels. Many species show a similar optimum curve. We can offer no explanation for this curve.	30	Poor
7150	Depressions on peat substrates of the <i>Rhynchosporion</i>	Descending response curve for the whole deposition range. The new empirical CR and CL fit better with the curve.	50	Good
7210	Calcareous fens with <i>Cladium mariscus</i> and species of the <i>Caricion davallianae</i>	Strong descending curve below and above the CL. The new empirical CR and CL fit better with the curve. There are only three characteristic species of which two <i>Cladium mariscus</i> and <i>Myrica gale</i> show a strong descent. <i>Thelypteris palustris</i> shows a response fitting with the CL. For <i>C. mariscus</i> , a species of more nutrient rich waters, a less steep response was expected. The CL is based on species for Calcareous fens, for which we could not estimate a response curve.	50	Fair
7220	Petrifying springs with tufa formation ( <i>Cratoneurion</i> )	Descending curve. The descent already starts at lower levels than the CL. It is possible that the CL is too high and should be reviewed, especially compared to H7210. There are only five characteristic species.	70	Fair
7230	Alkaline fens	Descending curve evening out around the CL. The descent is small but based on many species. Also, here the unexpected increase of <i>Rhinanthus angustifolius</i> at higher nitrogen deposition levels. Also, many species that show an increase at higher deposition levels fitting for species adjusted to nutrient rich circumstances. The effect of these species is masked by the many species that show a descent for nitrogen deposition.	50	Good
9110	<i>Luzulo-Fagetum</i> beech forests	Descending curve for the whole range, evening out at high deposition levels. The new empirical CR and CL fit better with the curve.	70	Good
9120	Atlantic acidophilous beech forests with <i>Ilex</i> and sometimes also <i>Taxus</i> in the shrub layer ( <i>Quercion robori-petraeae</i> or <i>Illici-Fagenion</i> )	Slightly descending curve for the whole range. The lower value of the empirical CL is just below the start of the response curve. The new empirical CR and CL fit better with the curve.	75	Good
9160A	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the <i>Carpinion betuli</i> (sandy soils)	Slightly descending response curve, evening out at high deposition rates.	70	Good
9160B	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the <i>Carpinion betuli</i> (hills)	Descending curve for the whole range. The new empirical CR fits better with the curve, both start at 10 kg/ha/y.	75	Good

Code	Name habitat type	Description of the curve	Decrease range (kg/ha/yr)	Assessment
9190	Old acidophilous oak woods with <i>Quercus robur</i> on sandy plains	Slightly descending response curve, dropping greater at higher deposition rates (after 60 kg/ha/y). The descent is limited and therefore the response was judged as poor. The shape of the curve could be right though. Most species do not show a response for deposition with the exception of <i>Melampyrum pratense</i> and <i>Polytrichum formosum</i> , both showing a decrease. <i>Avenella flexuosa</i> does not show much of a reaction to nitrogen deposition, which is unexpected, since it is known to profit from nitrogen deposition.	40	Poor
91D0	Bog woodland	Descending curve, evening out at higher deposition rates. The descent starts well below the CL. The steep descent is due to <i>Eriophorum vaginatum</i> , <i>Vaccinium oxycoccos</i> and <i>Vaccinium vitis-idaea</i> . The descent of some species may also be related to the ageing and thus darkening of the forest, which in turn is accelerated by nitrogen deposition.	70	Good
91E0A	Alluvial forest with black alder <i>Alnus glutinosa</i> and common ash <i>Fraxinus excelsior</i> ( <i>Alno-Padion</i> , <i>Alnion incanae</i> , <i>Salicion albae</i> ), softwood subtype	Descent already before the CL, at depositions above the CL no effect. The effects are small. The small effect is caused by species that increase at higher deposition rates, <i>Galeopsis tetrahit</i> , <i>Galium palustre</i> , <i>Iris pseudocorus</i> , <i>Salix alba</i> , and <i>Urtica dioica</i> , all species of nutrient rich circumstances. According to van Wamelink et al. (2023) this habitat type is less/not sensitive for nitrogen deposition; hence the descent is unexpected. However, this conclusion can be questioned, but there are no data yet available to back the found response. Therefore, for now, the curve is judged as poor.	30	Poor
91E0B	Alluvial forest with black alder <i>Alnus glutinosa</i> and common ash <i>Fraxinus excelsior</i> ( <i>Alno-Padion</i> , <i>Alnion incanae</i> , <i>Salicion albae</i> ), ash-elm subtype	Descending curve for the whole range, also at lower levels than the CL. A part of the species shows a response that fits well with the CL. The descent is mainly caused by <i>Eurhynchium striatum</i> and to a lesser extent <i>Fissidens taxifolius</i> , <i>Geum urbanum</i> and <i>Rumex sanguineus</i> .	85	Fair
91E0C	Alluvial forest with black alder <i>Alnus glutinosa</i> and common ash <i>Fraxinus excelsior</i> ( <i>Alno-Padion</i> , <i>Alnion incanae</i> , <i>Salicion albae</i> ), stream bank subtype	Descending curve, evening out at higher deposition rates.	65	Fair
91F0	Riparian mixed forests of <i>Quercus robur</i> , <i>Ulmus laevis</i> and <i>Ulmus minor</i> , <i>Fraxinus excelsior</i> or <i>Fraxinus angustifolia</i> along the great rivers ( <i>Ulmenion minoris</i> )	The response shows an optimum curve with a descent at rates above 50 kg/ha/y. The CL is much lower. There are seven characteristic species, of which five show an optimum curve. Two species, <i>Poa nemoralis</i> and <i>Viola odorata</i> , show a descending curve from the beginning.	40	Poor

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## 4 Discussion

### 4.1 EVA-database

Reviewing data from the EVA-dataset provided insight into mutual correlations between presence/absence and covariables (soil, precipitation and temperature). For the selected species-structure type combinations, anomalies in the data could be identified. These explained, at least partly, the observed response curve increases at high nitrogen deposition levels. Further review of all unexpected response curves is therefore recommended. Species with clearly problematic data distributions can then be identified and omitted, or their data selection could be adjusted. For the example given here, *Calluna vulgaris*, the results indicate that there is a biased number of negative findings, with only positive findings at high deposition rates. This leads to an unexpected response curve for *C. vulgaris* with an unlikely optimum at relative high deposition levels. This specific case was already identified by Wamelink et al. (2021). Omitting the former heathlands that turned into grasslands (no dwarf-shrub structure type) in the selection resulted in many missing negative findings. The example of *C. vulgaris* shows that data visualisation revealed patterns that enabled us to gain insight in why the species response is as it is, how likely it is influenced by bias in the dataset and how reluctant the response curve should be interpreted. Completing the dataset could solve this problem, but it may also lead to omitting a species from the species list. This can be done for other species as well, but it may not be as obvious as for *C. vulgaris*, a well-known species. Based on the results a correction for the anomalies could be implemented.

### 4.2 Additional empirical relationships between atmospheric nitrogen deposition and plant species richness: a visual inspection

The new data review yielded species richness and indicator species richness data for eight vegetation types. They can be used for independent validation of the response curves for the vegetation types for nitrogen deposition. They can also be used for other purposes, e.g. for the estimation of or validation of (empirical) critical loads. These eight additional habitat types will help to increase the options for validation of the response curves. However, including the new validation data, we can still only validate a quarter of the habitat types. More validation data is needed including validation data for higher deposition levels.

### 4.3 Evaluation of the response curves from Doren-1

#### 4.3.1 Degrees of freedom

The impact of the number of degrees of freedom on the spline and thus the response curve was considerable, as demonstrated by the three examples for salty soils. The more degrees of freedom that are allowed, the better the curve fits with the data. The resulting response curve with a higher number of degrees of freedom was more in line with expectations, agreeing with data points better when more degrees of freedom were allowed for all three species. The results were in line with earlier research on this topic (Wamelink et al. 2005), who found that sometimes 2 degrees of freedom were sufficient to estimate a good response curve with a spline function, but in other cases additional degrees of freedom were needed. These authors also developed an automated procedure to optimize the degrees of freedom for the spline. This could be applied here as well. This could lead to more reliable curves fitting the data better. It is therefore recommended to implement this in the next version of Doren.

The results clearly show what the effect of extrapolation is on the species response. The unrealistic responses are not cut off when no more data are available. Since for the habitat types they belong data of higher depositions are available the extrapolation is taken into account for the habitats response. This may lead to unwanted effects for the habitat type, as in the case of 1310-A Pioneer salt marshes (*Salicornia*) where an increasing response curve is visible. To prevent these unwanted effects also the species response curves should be cut off to prevent extrapolation for the species response and thus unwanted effects on the response curve of the habitat type. However, this is quite complicated to implement. The first step preventing extrapolation for the species is laborious but doable. The second step estimating the response curve for the habitat type based on species with all different cut-off points is much more complicated and therefore not implemented (yet).

Also, when implementing more degrees of freedom to the spline an optimum curve for the salt tolerant species is visible. This may seem strange, however, the *Salicornia* species all live on the seaside as pioneers under very nitrogen poor circumstances. Some extra nitrogen can therefore be beneficial for these species. The extra nitrogen and litter can also form a phase in the succession towards a more nutrient rich salt marsh.

#### 4.3.2 Evaluation

Many habitat types received a better judgement due to the small change in species composition (leaving out the displacement species) and comparison with the new empirical ranges (Bobbink et al. 2022) and new CL (Wamelink et al. 2023). Only one type had a lower appreciation in the new judgement. This shows that the new values for empirical range and CL are much closer to the results from the Doren-1 project than originally thought at the time that the Doren-1 report was published. Presently 49 types were judged as good, 6 as fair and 4 as poor against 37, 9 and 14 in Doren-1 (Table 8). One habitat type lost its characteristic species after the new selection of species. Moreover, the responses assessed before as good gave a better agreement with the CL and empirical range. It can be concluded that part of the uncertainty in the response curves can be solved by leaving out the displacement species. However, the change in empirical ranges and CLs had a much bigger effect, implying that the response curves of Doren-1 were better than initially expected.

**Table 8** Comparison expert judgement of the first author of the response curves for the Doren-1 and Doren-2 projects. Doren-2 has one habitat type less than Doren-1.

Judgement	Doren-1	Doren-2
Good	37	49
Fair	9	6
Poor	14	4

## 4.4 Species composition of habitat types

Results show that a limited number of characteristic species leads to fewer habitat types that have sufficient species to properly estimate a response curve. The list with all characteristic species, except the displacement species performed overall best mainly based on the number of curves that could be estimated, although the list with only 'Red List' species has some response curves that were judged better. This brings us to conclude that whatever species list is used, or may be newly created, a sufficient number of species is essential, though some response curves were judged better on the basis of 'Red List' species only (SI 2). This was also supported by the results of the uncertainty analyses. The species lists tested here did not perform better than the original list (without displacement species). Consequently, we recommend (and use, see e.g. chapter 4.3) to maintain the original list from Doren-1, but without displacement species (SI 1). We also recommend that a review of the displacement species list is needed; it can have a substantial effect on the response curve.

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## 4.5 Confidence interval

By applying a bootstrap method, we are now able to give an indication of the confidence interval in the response curves. Intervals are highest at the extremes of the response curves and when a limited number of characteristic species is present. This supports the decision not to extrapolate the response curves as these would even have a higher uncertainty. Based on the uncertainty, more data for estimating the curves of the species at especially very high deposition rates is needed, but it is questionable if they are available. Also, at the very low deposition rates more data could make the uncertainty lower and shift the lower limit of the curves closer to 0 kg/ha/yr deposition. Based on the intervals it is possible to identify the most uncertain parts of the curves and look for solutions to lower the uncertainty. To identify the uncertainty caused by all the parameters making up the response curve a full uncertainty analyses must be performed by identifying the uncertainty in all the model parameters.

## 4.6 Reassessment of the response curves from Doren-1 solely based on the empirical range from 2022 and the critical load from 2023

For completeness we also investigated how the judgement of the response curves would change due to the new empirical ranges (Bobbink et al. 2022) and new CL (Wamelink et al. 2023). This deviates from chapter 4.3.2, where also the species list (no displacement species) was adjusted. The changes in judgement are smaller than in 4.3.2, four types received an improved judgement, none became worse. The agreement with the response curves that were previously already assessed to be good also improved.

For completeness the response curves for the evaluation with field data are also given now with the new empirical CL and CL in them. The evaluation was based on field data and not on the CL so the evaluation did not change (see Appendix 9).

## 4.7 General discussion

The results show that the response curves could be improved and also can be improved further, especially when more degrees of freedom will be introduced for the spline that is used to estimate the curves. This supports the validity of the method. However, some steps still have to be made:

1. Further data inspection is needed and can be done with the method developed;
2. Validation with the independent species richness data for nitrogen deposition including the data collected in this research;
3. Adjustment of the method to prevent unwanted effects based on a limited number of data, e.g. the increase of some responses at high deposition levels due to a few positive findings and insufficient negatives;
4. Re-evaluation of the species responses and the species list of the habitat types;
5. A method to come from a response curve towards an estimated CL;
6. A final evaluation of the curves and derived CL by experts.

This method could then, together with the other methods available, empirical data, field data and modelled CL, be used to estimate the final CL.

It was possible to identify issues in the base data and data selection leading to sometimes strange response curves for species and hence habitat types. A simple check on differences in names and solving spelling mistakes already improved the results. For the reviewed species it became clear that at high deposition levels sometimes only a few positive findings were available and insufficient negative findings giving rise to unrealistic curves. These effects may be prevented by allowing more degrees of freedom for the spline. Earlier research (Wamelink et al. 2005) showed that an automated procedure determining the optimal degrees of freedom can improve the response curve.

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An attempt to improve the response per species-soil type combination was unsuccessful. Using the clay percentage instead of the soil type was for now not an option. However, there is more research needed to come to a definitive conclusion.

Adding the bootstrap method to estimate the confidence intervals in the response curves for both species and habitat types gave insight in the variation of the habitat response curve reflecting the variation in the species. It also revealed that especially the response at very high deposition rates is uncertain, especially where the response increases at high deposition rates. This raises the question if responses at very high deposition rates should be given.

The results show that the response curves can be improved by reviewing the data, the uncertainty gives now insight in the more and less reliable parts of the curves. A major change in the review of the curves is caused by the new empirical ranges and new CL. Their change brought them more in line with the Doren response curves, revealing that the method used here is quite reliable and could be used as an extra independent method to estimate CLs.

Up till present day CLs are related to an (average) deposition per year as we did in this research. However, it was hypothesized that the effect nitrogen deposition is more related to the sum of the input of nitrogen. This means the cumulative input over a longer time period would be more indicative than the average over a period of years. This because nitrogen accumulates in the system and is not readily lost from the nitrogen cycle except at high deposition rates when nitrogen may leach to the groundwater. Therefore, we estimated the sum of the deposition received by the vegetation from 1880 onwards. Response curves were not estimated yet, but the data are ready to be used to estimate the curves and compare the results with the response curves based on the five-year average deposition. To be complete, we propose a comparison with 5-year, 10-year, 20-year, 30-year and 50-year average. This could also be a further test of the proposal of Rowe et al. (2017) to use the 30-year average. Working with the sum of the deposition could be tricky, since it is not what the plant in the end experiences, which is the net result of ecological processes. This includes mineralisation nitrogen fixation and denitrification, leaching and nitrogen deposition. According to H. Kros (pers. comm.), the nitrification and denitrification are more or less in an equilibrium, with a small net increase in nitrogen nitrification. Leaching plays a major role only at high deposition levels. All these processes will vary per site and thus give rise to uncertainty in the actual available nitrogen for plants compared with the deposition. Also, over time some of the nitrogen may be immobilized in e.g. litter or stored in wood of trees and thus leaving (temporarily) the nitrogen cycle. However, these processes also may play a role when applying long term averages of nitrogen deposition. This influence could be smaller for the more short-term averages for nitrogen deposition, e.g. 5- or 10-year averages. An important factor in the nitrogen cycle is the impact of management. Nature management in the Netherlands is often, also, dedicated to removal of nitrogen out of the system. Outside the Netherlands this is less common though e.g. mowing always removes nutrients and thus nitrogen from the system. Removing nitrogen from the system has an effect on the availability of nitrogen for plant growth and thus the competitiveness of species. The mitigating effect of management is not included in the response curves yet. Management may cause species that normally can occur under a given nitrogen deposition, still can occur because part of the nitrogen deposition is removed. Obviously, this will influence the sum of nitrogen a vegetation has received since 1880. But it will also influence the average deposition over a certain period of time. Both will lead to an overestimation of the nitrogen amount that enters the nitrogen cycle. It will overestimate the effect nitrogen deposition on the nitrogen cycle and thus may lead to an overestimation of the CL.

Most of the response curves for nitrogen deposition for habitat types, 50 out of 60, show a steadily decreasing trend with increasing deposition and no obvious tipping points could be identified. This makes it questionable whether it is possible to calculate a precise tipping point that could serve as a critical load estimate, which was the original hypothesis for the Doren-project, and sheds doubt as to whether such tipping points truly exist for nitrogen deposition. More research is needed to identify whether such tipping points exist and to what extent such a point could serve as a CL or as one of the methods to derive a CL. The results of the present study indicate that Doren-2 anyhow is a better predictor for CLs than the model employed by Van Dobben et al. (2012), the use of which was continued in the recent report of Wamelink et al. (2023). The model of Van Dobben et al. (2012) predicted for many habitat types a CL above the maximum of the empirical range which indicates that the model predictions are too high.

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Alternatives to estimate a CL based on the here described response curves could be one of the percentiles of the curve (e.g. 1, 5, 25, 50). Given that so many curves have their maximum at the lowest nitrogen deposition, it seems that the present critical loads in the Netherlands are too high. Furthermore, the present findings suggest that for most of the habitat types, the true CL could be 5 kg/ha/yr. As regards the species responses, it seems that every additional deposition to the natural background deposition leads to a decrease in probability of occurrence of habitat-specific species diversity. However, certain of these species still can occur at higher deposition levels. The question is then, what probability is still acceptable? Does it need to be 95% of the maximum or is 50% also sufficient? This could lead to a new method, where the cut-off point is calculated as the 50 percentiles of the five or ten most vulnerable species per habitat type. It should be borne in mind, however, that the current methodology is already a significant improvement compared to the CL modelling as currently employed by Bobbink et al. (2022) and Wamelink et al. (2023), on the basis of Van Dobben et al. (2012). The present results thus reflect the best available scientific state of knowledge for those habitat types for which empirical CLs are lacking, and for which Doren-2 provides a fair or good outcome. A reason for the relative high CL based on the modelling is that the model assumes that all other pressure factors as groundwater table and climate are optimal, which almost always is not the case. Doren incorporated part of these pressures by including these as co-variables. However also in Doren effects of management and loss of connectivity are not included.

In the Doren projects, we assumed that the habitat types that have a CL are vulnerable for nitrogen deposition. We even used this assumption as a starting point for developing our method for the evaluation of the response curves, assuming that there should be a decreasing trend of the response curve. If this trend is not present, we assume that the curve is not reliable. However, this can be disputed. For some habitat types, it could be possible that no CL exists in nature. For now, we assume that the types that have a CL are indeed vulnerable for nitrogen deposition. This is also backed up by field data. It is important to realize that we only estimated response curves for habitat types that have a CL and that we do not assume that all habitat types do have a CL. We advise to include all habitat types in the next project. If the habitat types that have no CL will show to be indifferent to nitrogen deposition, this will become apparent in the curves and will be an extra argument for the credibility of our approach.

Little attention is paid in the present study to the displacement species. They were for a part left out, compared to Doren-1. However, the list of displacement species should be reviewed. Subsequently, it must be decided whether to include these species as part of a habitat type and thus influencing the response curve (or not). For a part of the habitat types, the effect of the displacement species is limited, since their effect is mitigated by the majority of species that is decreasing due to nitrogen deposition. But for a part of the habitat types, especially some grassland and forest types, the influence on the curve of the habitat type is significant and leads to an 'unexpected' response curve, with no effect of nitrogen deposition or even an increase with increasing deposition.

To conclude, given the results and the discussion, we believe that both the species and habitat type response curves, although at present already useful for assessing nitrogen deposition levels above which habitat deterioration takes place, can nevertheless be further improved. Major effects can be expected from allowing more degrees of freedom to the spline and by reviewing the all the unexpected responses on data anomalies and missing data. The first is relatively easy, it just requires a minor change of the program that estimates the responses. The second is quite laborious and may yield less gains in reliability for the habitat curves but is important for further corroborating confidence in the results. Especially compared to the modelling (Van Dobben et al., 2012) that is still used in the Netherlands to estimate the CLs, Doren-2 provides a more reliable alternative to base the CLs on, with the vast majority of the curves judged as good or fair and most of the curves that are now in line with the empirical ranges by Bobbink et al. (2022). A remaining point of discussion is the species composition of the habitat types, especially to what extent displacement species, even though they may be indicative of the habitat type, should be included in the species list.

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# Appendix 1 Clay content versus soil types

## 1. Introduction

In Doren-1, it was hypothesized that the effect of nitrogen deposition on habitat-type species composition co-depends on soil type. In Doren-1, the soil data were approximated in a relatively rough manner by combining 26 soil types of the European soil map (FAO, 2015) into six aggregated classes (sand, clay, young soils peat and water). Soil type was then used as a covariate in estimating the response curve.

A quantitative alternative is a correction based on soil lutum content. "Lutum" is the Dutch term for soil fraction below 2 µm diameter. When lutum content of the soil exceeds 8% the soil is called 'zavel' and beyond 25% it is considered 'clay'. This deviates from the international definition of clay in the used soil map from ISRIC. However, we will use in the remainder of this chapter clay as term, so including the Lutum and Silt fractions.

Quantitative soil related covariates such as % clay or sand could be used directly from the soil map. A qualitative soil type has the disadvantage that the final response curve must be weighted over all soil types. With quantitative soil variables only one value (per habitat type) must be used when estimating the response curves for nitrogen deposition for the Netherlands. The hypothesis was that the use of the lutum content in the soil would improve estimate of the effect of soil type on the effect of deposition compared to using the rather coarse classification of soil type.

## 2. Material and methods

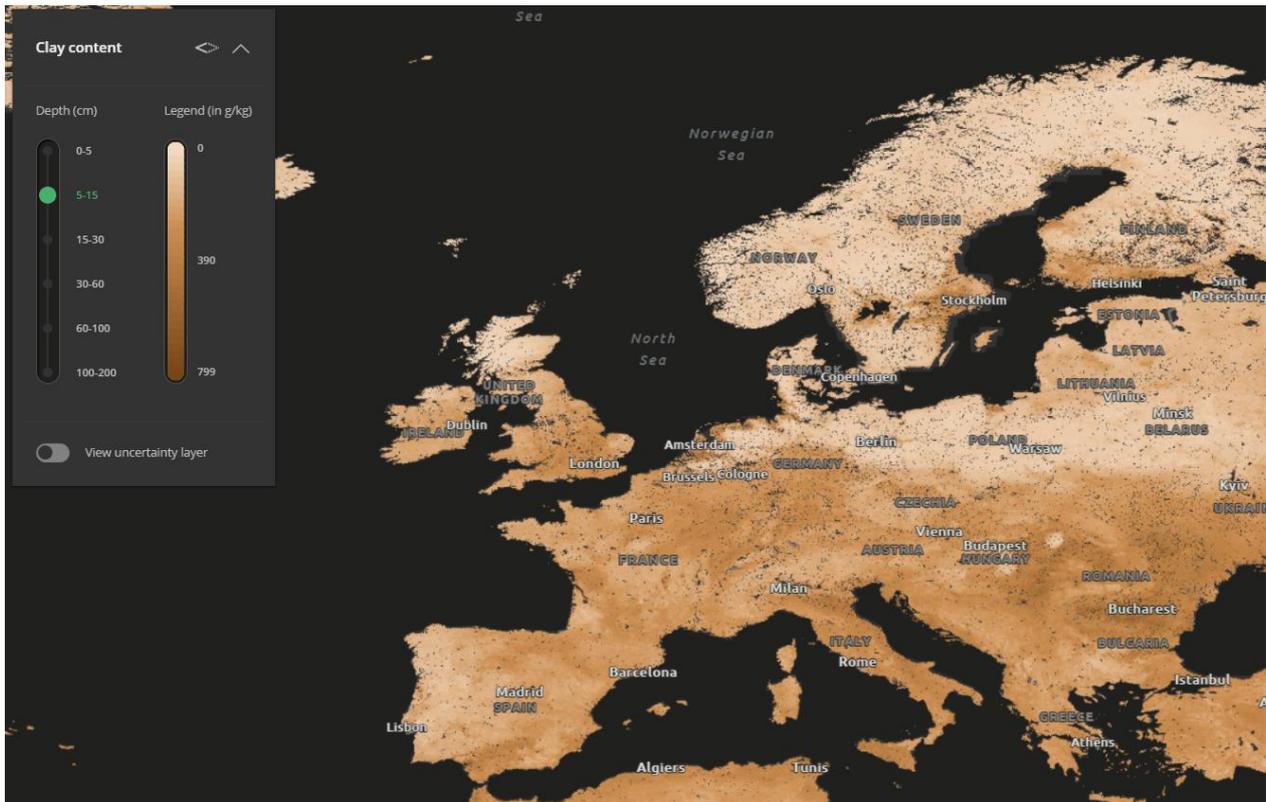
To investigate whether clay content could be a better estimate of the effect of soil type on the effect of deposition rather than the used classification of soil types, clay maps were obtained from ISRIC – world soil information (International Soil Reference and Information Centre, ISRIC – Index of /soilgrids/latest/data/clay/). Each map contains a master VRT file, OVR file (for visualization) and a folder with GeoTIFF tiles. The clay content was modelled for different soil depths e.g. 0-5 cm and 5-15 cm in a resolution of 250m (grid cell size 250x250m, Figure 1). Clay content is defined as the proportion of clay particles (fractions <0.002 mm) in the fine earth fraction. The clay maps are modelled and as such have an uncertainty quantified by probability distributions. For each soil depth four parameters are given: the 5% quantile, the median of the distribution, the mean of the distribution and the 95% quantile. We used the median of the distribution as a covariate.

## 3. Results and discussion

A disadvantage of the ISRIC maps is that the overall clay content is not indicated per grid. Each polygon of the soil map contains several soil types, each with its own texture and the percentage of the polygon that this type occupies spatially. This means that there is a gradient of clay content within a grid cell, which makes it difficult to integrate it as a covariate in the response curves for nitrogen deposition. This is also the case for the soil types, but since they are combined giving a limited amount of soil types, often there is just one soil type. And even if there is more than one soil type, using clay content does not solve this problem. Moreover, the optimal soil depth for our purposes would be 0 to 10 cm which means that two maps need to be combined. This will add another layer and will give raise to a larger uncertainty. The grid cell size of 250x250m was also considered too large to obtain data more reliable than the lumped soil types used in in Doren-1. Therefore, it was decided not to use to clay content as a covariable at the moment. However, further investigation or updates of the clay map may lead to the conclusion that it is possible to use clay content as a variable in the estimation of the response curves for habitat types for nitrogen deposition.

Instead, for now, we recommend constructing a logistic regression model per soil-type/habitat-type/structure-type combination. This could lead to less available data per soil type to estimate the response curves, but most habitat types are limited to one or two aggregated soil types. In this way, the need for a correction of soil type in the logistic regression model is eliminated. However, grouping of the soil type according to Doren-1 should be reviewed before this can be implemented. This newly proposed method is relatively easy

to implement. All required data are already available in the database used for estimating the response curves for nitrogen deposition. An option to still incorporate the clay content in development of the response curves, data may be obtained from SoilGrids 2.0 (ISRIC, not dated).



**Figure 46** Map of Europe showing the clay content (<0.002 mm in g/kg, 0-5 cm depth). Obtained from SoilGrids250m 2.0.

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# Appendix 2 Sum of nitrogen deposition

## 1. Introduction

Doren-1 employed five-year averages of the yearly nitrogen deposition data. An alternative is to calculate the deposition sum until the date the plot was sampled from in our case 1880. The hypothesis behind this is that an ecosystem is not influenced by the annual amount of nitrogen deposition, but by the accumulated dose (e.g Payne et al. 2019). As more nitrogen accumulates in the ecosystem, the influence will be greater and at a certain sum the consequences will become visible through the disappearance of species. The advantage of this method is that it no longer matters whether you get a lot of deposition for a short time or a little bit over a long time. It also allows us to explore for a tipping point in the amount of deposition received.

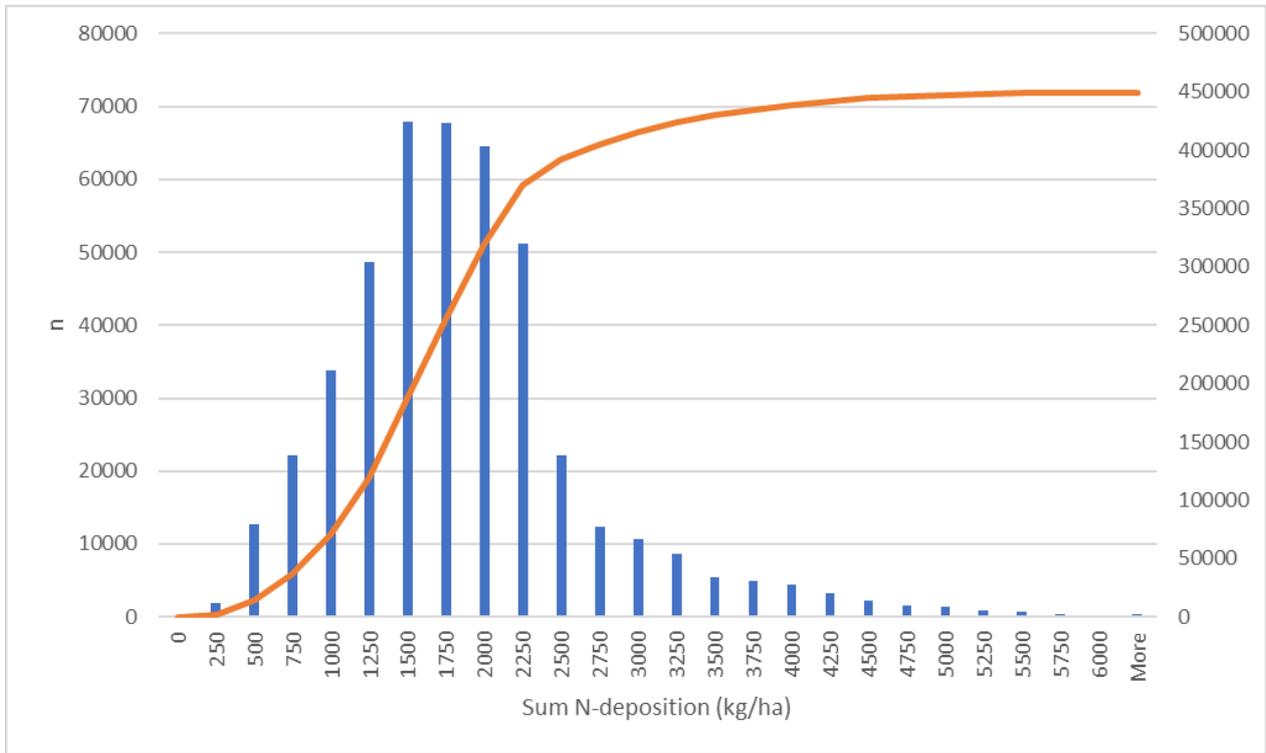
## 2. Method

As starting point we selected the year 1880. This means that a cumulative deposition for e.g. 1950 is provided as the sum of the depositions from 1880 up to and including 1950. For plots sampled in later years, the sum is given as the sum over the years starting in 1880 including the year the plot was sampled. The year 1880 was chosen as starting year because it is the earliest year for which deposition data is available and because it precedes the start of the agricultural and partly the industrial revolution in the Netherlands. In countries such as Belgium and the United Kingdom the revolution started earlier, but information to reconstruct deposition earlier than 1880 is scarce. Deposition calculations were made with the EMEP model (Tsyro et al., 2018, 2019) and follows the method from Doren-1 as also described in chapter 2.

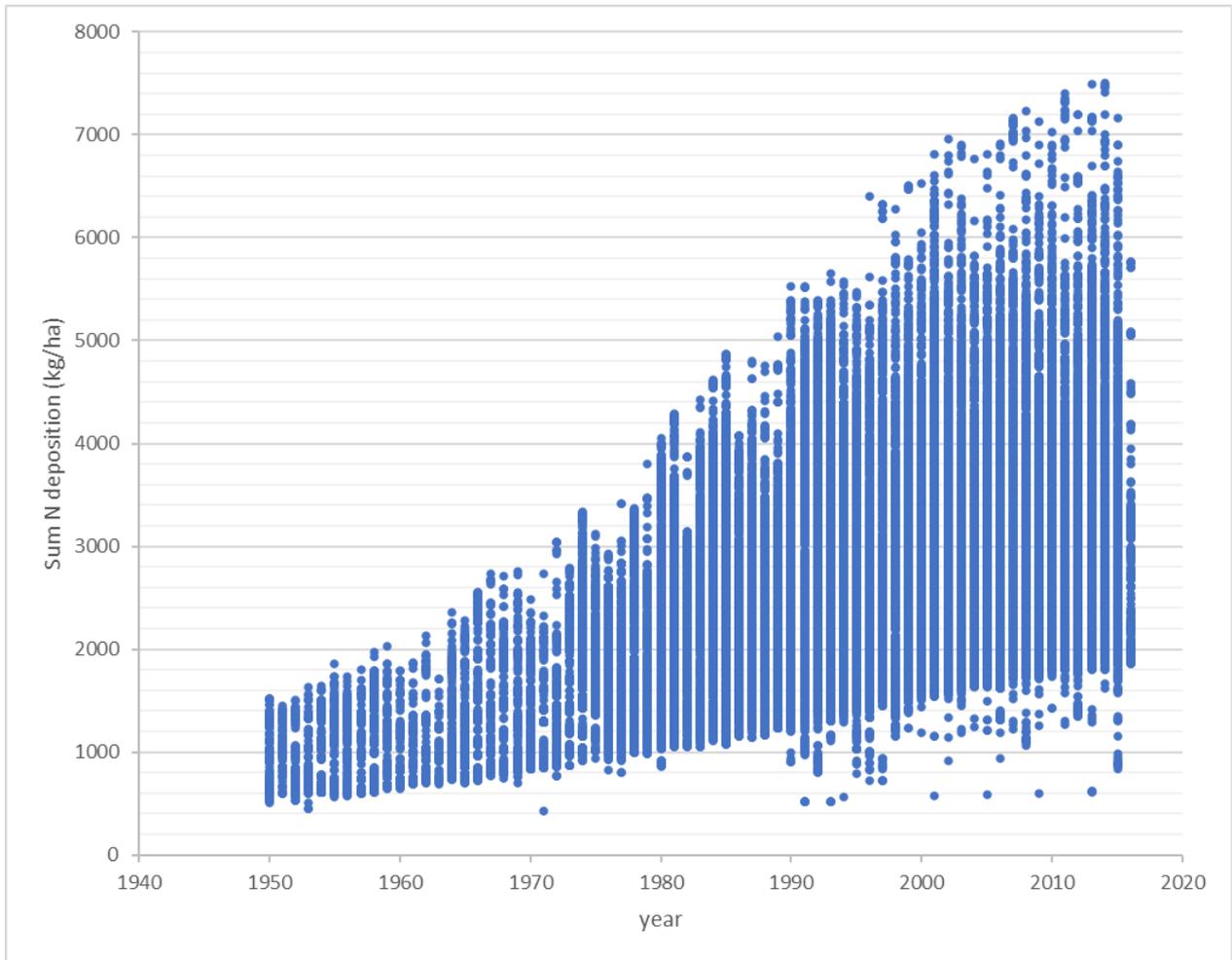
## 3. Results

The sum of nitrogen deposition from 1880 till the date the plot was made ranges from less than 100 kg/ha up to just over 7,000 kg/ha per plot, with a majority of plots receiving nitrogen deposition between 1,000 and 2,500 kg/ha (Figure 47). As expected, the sum, in general, increases with time passed since 1880, for the whole data set and more pronounced for the Netherlands (Figure 48 and 49). The dataset contains plots that even till present day received only a very limited amount of nitrogen deposition. The results at low deposition rates are not only based on plots from the past, but also from present day. Remarkably, this indicates that also at present day there are areas with almost natural background values regarding nitrogen deposition in the selected Atlantic region.

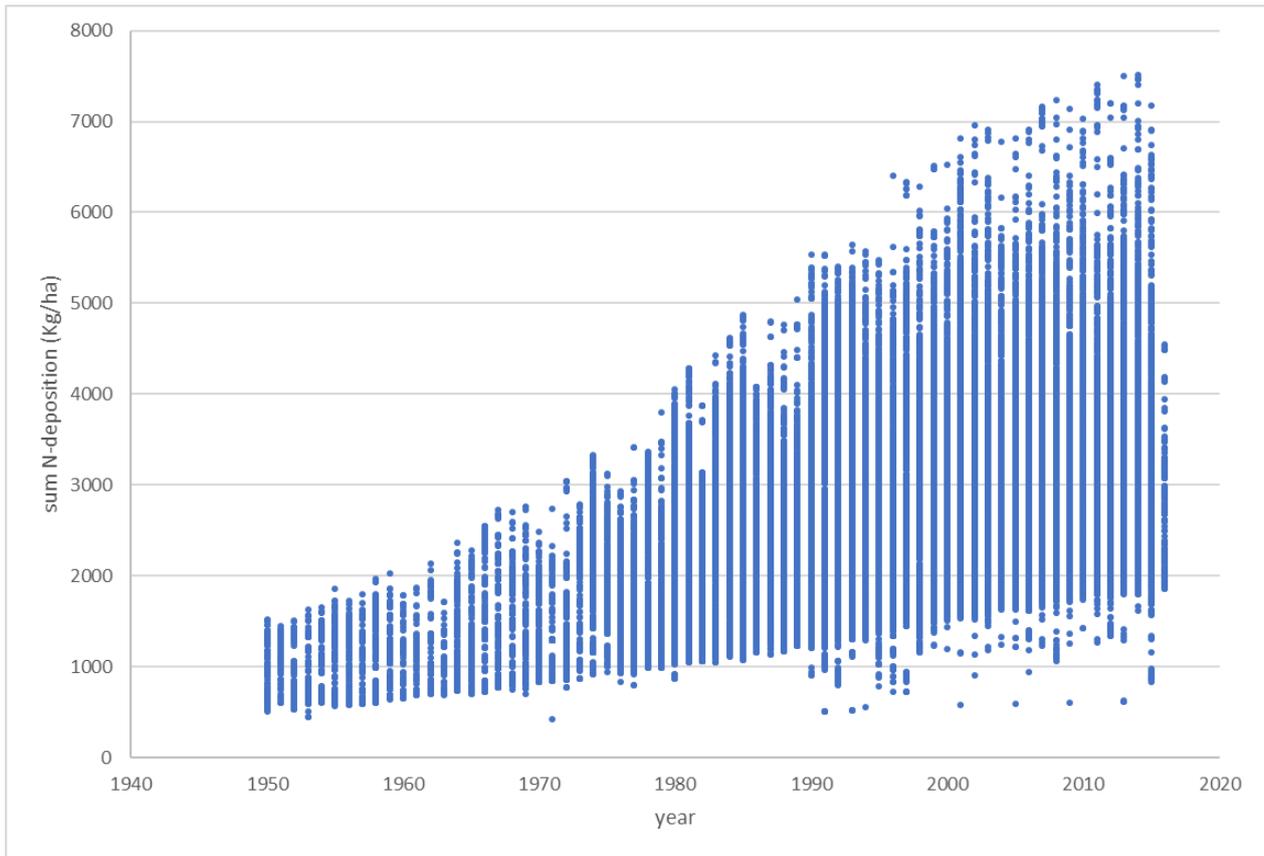
The deposition data are provided in the database are per year, starting in 1880. A programme was written to calculate the sum of the deposition from any given year till the year the plot was made. These adjustments make it possible to calculate the average deposition over any given period before the plot was made. This opens the way to test the effect of the period over which the average deposition is calculated on the response curves.



**Figure 47** Total nitrogen deposition received by the plots from 1880 onwards (left y-axis) and the cumulative frequency (right Y-axis) till the year the plots were sampled. Given is the number of plots per total deposition interval for in total 449621 plots.



**Figure 48** Sum of the deposition from 1880 onward till the date the plot was studied, per plot of the used plots of the Atlantic region. Note that the earliest pots were sampled in 1950.



**Figure 49** Sum of the deposition per plot from 1880 onwards up to the date that the plots were made, for the datapoints in the Netherlands.

#### 4. Discussion

The new deposition calculations from 1880 onward allow calculation of the summed deposition for a plot up to the moment the plot was made. This opens a different way of reviewing the effect of nitrogen deposition compared to Doren-1. Using the sum could e.g. reveal whether there is a maximum amount of cumulative nitrogen deposition that a vegetation can tolerate before species start disappearing. However, nitrogen input is not only dependent on nitrogen deposition, but nitrogen accumulation can also be due to *Rhizobium* bacteria and free-living nitrogen fixing bacteria. Furthermore, nitrogen may also exit the system by denitrification, leaching, immobilisation and removal of biomass. Normally denitrification and immobilisation, are more or less in an equilibrium in most vegetations. Input comes from deposition which may partly leach. Management can remove nitrogen from the system. Especially in non or extensive managed systems the deposition is accumulated in the vegetation. Using the sum of nitrogen deposition therefore could possibly reveal tipping points for vegetation types.

In Doren-1 we used the average deposition over a period of five years. Rowe et al. (2017) suggest that a longer period of 20-30 years gives more reliable results. On the other hand, the effect of accumulated deposition could also wear off after a longer period, resulting in a lower decrease of the number of species. As stated, data about nitrogen deposition prior to 1945 are scarce. Therefore, uncertainty of nitrogen deposition data before 1945 is larger. However, deposition was low especially before 1900, thus the uncertain values constitute only a relatively small part of the cumulative deposition up to e.g. 1980.

The responses per species-structure type were not yet estimated. This can be done in future explorations. In principle the response curves can be estimated with the same programme as used for the response curves for the average yearly nitrogen deposition. This opens interesting avenues for further exploration.

One of these explorations may be the use of average versus cumulative nitrogen deposition, including the investigation of the use of short-term average (5 year as used here) versus long term average (30 years as suggested by Rowe et al. (2017) or even 50 years).

## Appendix 3 Species translation list

The first Table provides the translation from the EVA database to the species list used in the Doren project. The second table gives the same but was added later to the project for generating more species data for the four tested species compositions lists for the habitats.

Species nr	EVA name	Doren name	Dutch name
6	<i>Aconitum lycoctonum subsp. vulparia</i>	<i>Aconitum vulparia</i>	Gele monnikskap
40	<i>Alopecurus geniculatus</i>	<i>Alopecurus geniculatus</i>	Geknikte vossenstaart
77	<i>Helosciadium inundatum</i>	<i>Apium inundatum</i>	Ondergedoken moerasscherm
1965	<i>Aronia floribunda</i>	<i>Aronia x prunifolia</i>	(Zwarte) appelbes
117	<i>Tripolium pannonicum</i>	<i>Aster tripolium</i>	Zulte
596	<i>Halimione pedunculata</i>	<i>Atriplex portulacoides</i>	Gewone zoutmelde
143	<i>Bidens frondosus</i>	<i>Bidens frondosa</i>	Zwart tandzaad
2458	<i>Bidens radiatus</i>	<i>Bidens radiata</i>	Riviertandzaad
144	<i>Bidens tripartitus</i>	<i>Bidens tripartita</i>	Veerdelig tandzaad
2607	<i>Bryum rubens</i>	<i>Bryum rubens/microerythrocarpum/bornholmense</i>	Roodknolknikmos
175	<i>Calamagrostis neglecta</i>	<i>Calamagrostis stricta</i>	Stijf struisriet
49	<i>Calamagrostis x calammophila</i>	<i>Calammophila baltica (x)</i>	Noordse helm
180	<i>Callitriche brutia</i>	<i>Callitriche brutia s.l.</i>	Haaksterrenkroos
2635	<i>Campylopus fragilis</i>	<i>Campylopus fragilis s.str.</i>	Bossig kronkelsteeltje
219	<i>Carex canescens</i>	<i>Carex curta</i>	Zompzegge
215	<i>Carex colchica</i>	<i>Carex ligerica</i>	Zandzegge
261	<i>Carex viridula</i>	<i>Carex oederi s. oederi</i>	Dwergzegge
220	<i>Carex viridula</i>	<i>Carex oederi s. oedocarpa</i>	Geelgroene zegge
2213	<i>Carex viridula</i>	<i>Carex oederi s.l.</i>	Geelgroene/Dwergzegge
245	<i>Carex cuprina</i>	<i>Carex otrubae</i>	Valse voszegge
288	<i>Anagallis minima</i>	<i>Centunculus minimus</i>	Dwergbloem
450	<i>Epilobium angustifolium</i>	<i>Chamerion angustifolium</i>	Wilgenroosje
2152	<i>Chara vulgaris</i>	<i>Chara vulgaris v. longibracteata</i>	
2151	<i>Chara vulgaris</i>	<i>Chara vulgaris v. papillata</i>	
312	<i>Oxybasis glauca</i>	<i>Chenopodium glaucum</i>	Zeegroene ganzenvoet
315	<i>Lipandra polysperma</i>	<i>Chenopodium polyspermum</i>	Korrelganzenvoet
316	<i>Oxybasis rubra</i>	<i>Chenopodium rubrum</i>	Rode ganzenvoet
330	<i>Cirsium acaulon</i>	<i>Cirsium acaule</i>	Aarddistel
4187	<i>Cladonia verticillata</i>	<i>Cladonia pulvinata</i>	Slank stapelbekertje
4184	<i>Cladonia verticillata</i>	<i>Cladonia pyxidata/monomorpha/pocillum</i>	
188	<i>Calystegia sepium</i>	<i>Convolvulus sepium</i>	Haagwinde
189	<i>Calystegia soldanella</i>	<i>Convolvulus soldanella</i>	Zeewinde
398	<i>Avenella flexuosa</i>	<i>Deschampsia flexuosa</i>	Bochtige smele
399	<i>Aristavena setacea</i>	<i>Deschampsia setacea</i>	Moerassmele
2556	<i>Barbula vinealis</i>	<i>Didymodon vinealis</i>	Muurdubbeltandmos
416	<i>Drosera longifolia</i>	<i>Drosera anglica</i>	Lange zonnedaauw
437	<i>Eleocharis palustris</i>	<i>Eleocharis palustris s.str.</i>	Gewone waterbies
1154	<i>Isolepis fluitans</i>	<i>Eleogiton fluitans</i>	Vlottende bies
445	<i>Elytrigia atherica</i>	<i>Elytrigia atherica/maritima</i>	Zeekweek / Strandkweek
2420	<i>Equisetum hyemale</i>	<i>Equisetum hyemale s.str.</i>	Schaafstro
474	<i>Erigeron acris</i>	<i>Erigeron acer</i>	Scherpe fijnstraal
483	<i>Draba verna</i>	<i>Erophila verna</i>	Vroegeling
4242	<i>Evernia prunastra</i>	<i>Evernia prunastri</i>	Eikenmos

Species nr	EVA name	Doren name	Dutch name
1472	<i>Festuca brevipila</i>	<i>Festuca brevipila/lemanii</i>	Hard zwenkgras/Groot schapengras
515	<i>Schedonorus giganteus</i>	<i>Festuca gigantea</i>	Reuzenzwenkgras
519	<i>Schedonorus pratensis</i>	<i>Festuca pratensis</i>	Beemdlangbloem
565	<i>Gentianella ciliata</i>	<i>Gentianopsis ciliata</i>	Franjegentiaan
587	<i>Laphangium luteoalbum</i>	<i>Gnaphalium luteo-album</i>	Bleekgele droogbloem
603	<i>Helictotrichon pratensis</i>	<i>Helictotrichon pratense</i>	Beemd haver
604	<i>Avenula pubescens</i>	<i>Helictotrichon pubescens</i>	Zachte haver
1407	<i>Pilosella peleteriana</i>	<i>Hieracium peleterianum</i>	Vals muizenoor
621	<i>Pilosella officinarum</i>	<i>Hieracium pilosella</i>	Muizenoor
2417	<i>Hieracium murorum</i>	<i>Hieracium sect. Hieracium</i>	
2793	<i>Hypnum cupressiforme</i>	<i>Hypnum cupressiforme v. lacunosum</i>	Groot klauwtjesmos
2788	<i>Hypnum cupressiforme</i>	<i>Hypnum cupressiforme/andoi</i>	Gewoon klauwtjesmos
683	<i>Juncus gerardi</i>	<i>Juncus gerardii</i>	Zilte rus
702	<i>Lamium galeobdolon</i>	<i>Lamiastrum galeobdolon s. gal./montanum</i>	Grote/Kleine gele dovenetel
725	<i>Scorzoneroïdes autumnalis</i>	<i>Leontodon autumnalis</i>	Vertakte leeuwentand
755	<i>Lolium multiflorum</i>	<i>loliummultiflorum</i>	Italiaans raaigras
761	<i>Lotus corniculatus</i>	<i>Lotus corniculatus s.str.</i>	Gewone rolklaver
762	<i>Lotus tenuis</i>	<i>Lotus glaber</i>	Smalle rolklaver
824	<i>Crataegus germanica</i>	<i>Mespilus germanica</i>	Mispel
834	<i>Hypopitys monotropa</i>	<i>Monotropa hypopitys</i>	Stofzaad
876	<i>Ononis spinosa</i>	<i>Ononis repens s. repens</i>	Kruipend stalkruid
877	<i>Ononis spinosa</i>	<i>Ononis repens s. spinosa</i>	Kattendoorn
2434	<i>Ononis spinosa</i>	<i>Ononis repens/spinosa</i>	Kattendoorn/Kruipend stalkruid
3	<i>Orchis anthropophora</i>	<i>Orchis anthropophorum</i>	Poppenorchis
2728	<i>Eurhynchium hians</i>	<i>Oxyrrhynchium hians</i>	Kleisnavelmos
976	<i>Persicaria dubia</i>	<i>Persicaria mitis</i>	Zachte duizendknoop
928	<i>Dichoropetalum carvifolia</i>	<i>Peucedanum carvifolia</i>	Karwijvarkenskervel
930	<i>Phalaroides arundinacea</i>	<i>Phalaris arundinacea</i>	Rietgras
3257	<i>Plagiothecium laetum</i>	<i>Plagiothecium laetum s.l.</i>	Krom platmos
951	<i>Platanthera chlorantha</i>	<i>Platanthera montana</i>	Bergnachtorchis
5243	<i>Poa bulbosa</i>	<i>Poa bulbosa v. bulbosa</i>	Knolbeemdgras (var. bulbosa)
2924	<i>Polytrichastrum formosum</i>	<i>Polytrichum formosum</i>	Fraai haarmos
2926	<i>Polytrichastrum longisetum</i>	<i>Polytrichum longisetum</i>	Gerand haarmos
992	<i>Potamogeton friesii</i>	<i>Potamogeton mucronatus</i>	Puntig fonteinkruid
998	<i>Stuckenia pectinata</i>	<i>Potamogeton pectinatus</i>	Schedefonteinkruid
1006	<i>Argentina anserina</i>	<i>Potentilla anserina</i>	Zilverschoon
1016	<i>Primula acaulis</i>	<i>Primula vulgaris</i>	Stengelloze sleutelbloem
1024	<i>Puccinellia pseudodistans</i>	<i>Puccinellia fasciculata</i>	Blauw kweldergras
1044	<i>Ranunculus peltatus subsp. baudotii</i>	<i>Ranunculus baudotii</i>	Zilte watterranonkel
2416	<i>Ranunculus peltatus</i>	<i>Ranunculus peltatus v. heterophyllus</i>	Penseelbladige watterranonkel
530	<i>Frangula alnus</i>	<i>Rhamnus frangula</i>	Sporkehout
2900	<i>Platyhypnidium riparioides</i>	<i>Rhynchostegium riparioides</i>	Watervalmos
3455	<i>Riccardia sinuata</i>	<i>Riccardia chamedryfolia</i>	Gewoon moerasvorkje
1120	<i>Salix gmelinii</i>	<i>Salix dasyclados</i>	Duitse dot
1127	<i>Salsola kali</i>	<i>Salsola kali s.str.</i>	Stekend loogkruid
1155	<i>Schoenoplectus lacustris</i>	<i>Schoenoplectus lacustris s.str.</i>	Mattenbies
1598	<i>Scirpus x carinatus</i>	<i>Schoenoplectus lacustris x triquetus</i>	Groene bastaardbies
1161	<i>Scirpus lacustris</i>	<i>Schoenoplectus tabernaemontani</i>	Ruwe bies
1179	<i>Hylotelephium telephium</i>	<i>Sedum telephium s. telephium</i>	Gewone hemelsleutel
2025	<i>Sonchus arvensis</i>	<i>Sonchus arvensis v. maritimus</i>	Zeemelkdistel
1238	<i>Spergularia marina</i>	<i>Spergularia salina</i>	Zilte schijnspurrie
2996	<i>Sphagnum auriculatum</i>	<i>Sphagnum denticulatum</i>	Geoord veenmos
3239	<i>Sphagnum angustifolium</i>	<i>Sphagnum fallax/flexuosum/angustifolium</i>	
3066	<i>Syntrichia ruralis</i>	<i>Syntrichia ruralis v. arenicola</i>	Groot duinstertetje

Species nr	EVA name	Doren name	Dutch name
3191	<i>Syntrichia ruralis</i>	<i>Syntrichia ruralis</i> v. <i>calcicola</i>	Klein duinsterretje
1419	<i>Lotus maritimus</i>	<i>Tetragonolobus maritimus</i>	Hauwklaver
1280	<i>Noccaea caerulescens</i>	<i>Thlaspi caerulescens</i>	Zinkboerenkers
1282	<i>Noccaea perfoliata</i>	<i>Thlaspi perfoliatum</i>	Doorgroeide boerenkers
3041	<i>Abietinella abietina</i>	<i>Thuidium abietinum</i>	Sparrenmos
1381	<i>Viola tricolor</i> subsp. <i>curtisii</i>	<i>Viola curtisii</i>	Duinviooltje
1389	<i>Viola stagnina</i>	<i>Viola persicifolia</i>	Melkviooltje
3082	<i>Astomum crispum</i>	<i>Weissia longifolia</i>	Kogeltjesmos

Second table added in 2023. The first column gives species names as used for the description of the Dutch habitat types, the second column gives the name used in the EVA-database.

Species name habitat type	Species name EVA
<i>Aconitum vulparia</i>	<i>Aconitum lycoctonum</i> subsp. <i>vulparia</i>
<i>Apium inundatum</i>	<i>Helosciadium inundatum</i>
<i>Arabis hirsuta</i> s. <i>hirsuta</i>	<i>Arabis hirsuta</i>
<i>Aronia floribunda</i>	<i>Aronia</i> x <i>prunifolia</i>
<i>Aster tripolium</i>	<i>Tripolium pannonicum</i>
<i>Atriplex pedunculata</i>	<i>Halimione pedunculata</i>
<i>Atriplex portulacoides</i>	<i>Halimione portulacoides</i>
<i>Baldellia ranunculoides</i> s. <i>ranunculoides</i>	<i>Baldellia ranunculoides</i>
<i>Baldellia ranunculoides</i> ssp. <i>ranunculoides</i>	<i>Baldellia ranunculoides</i>
<i>Bidens radiata</i>	<i>Bidens radiatus</i>
<i>Blysmus rufus</i>	<i>Blysmopsis rufa</i>
<i>Brachythecium velutinum</i>	<i>Brachytheciastrum velutinum</i>
<i>Bromopsis inermis</i> s. <i>inermis</i>	<i>Bromopsis inermis</i>
<i>Bromopsis ramosa</i> ssp. <i>benekenii</i>	<i>Bromopsis ramosa</i>
<i>Calamagrostis</i> x <i>calammophila</i>	x- <i>Ammocalamagrostis baltica</i>
<i>Caltha palustris</i> s. <i>palustris</i>	<i>Caltha palustris</i>
<i>Carex ligerica</i>	<i>Carex colchica</i>
<i>Centunculus minimus</i>	<i>Anagallis minima</i>
<i>Cirsium acaule</i>	<i>Cirsium acaulon</i>
<i>Cochlearia officinalis</i> s. <i>anglica</i>	<i>Cochlearia officinalis</i>
<i>Cochlearia officinalis</i> ssp. <i>anglica</i>	<i>Cochlearia officinalis</i>
<i>Dactylorhiza majalis</i> s. <i>praetermissa</i>	<i>Dactylorhiza praetermissa</i>
<i>Deschampsia setacea</i>	<i>Aristavena setacea</i>
<i>Drosera anglica</i>	<i>Drosera longifolia</i>
<i>Eleogiton fluitans</i>	<i>Isolepis fluitans</i>
<i>Erodium cicutarium</i> s. <i>dunense</i>	<i>Erodium cicutarium</i>
<i>Erysimum virgatum</i>	<i>Erysimum hieraciifolium</i> aggr.
<i>Euphrasia officinalis</i>	<i>Euphrasia officinalis</i> aggr.
<i>Eurhynchium hians</i>	<i>Eurhynchium swartzii</i>
<i>Evernia prunastra</i>	<i>Evernia prunastris</i>
<i>Festuca arundinacea</i>	<i>Schedonorus arundinaceus</i>
<i>Festuca brevipila</i>	<i>Festuca cinerea</i>
<i>Festuca ovina</i> ssp. <i>guestphalica</i>	<i>Festuca ovina</i> subsp. <i>guestfalica</i>
<i>Galium palustre</i> ssp.	<i>Galium palustre</i>
<i>Gentianopsis ciliata</i>	<i>Gentianella ciliata</i>
<i>Helictotrichon pratense</i>	<i>Avenula pratensis</i>
<i>Helictotrichon pratensis</i>	<i>Avenula pratensis</i>
<i>Hieracium peleterianum</i>	<i>Pilosella peleteriana</i>
<i>Mespilus germanicus</i>	<i>Crataegus germanica</i>
<i>Myosotis laxa</i> s. <i>caespitosa</i>	<i>Myosotis laxa</i> ssp. <i>caespitosa</i>

<b>Species name habitat type</b>	<b>Species name EVA</b>
<i>Nasturtium microphyllum/officinale</i>	<i>Nasturtium microphyllum</i>
<i>Odontites vernus s. serotinus</i>	<i>Odontites vulgaris</i>
<i>Orchis anthropophorum</i>	<i>Orchis anthropophora</i>
<i>Orobanche picridis</i>	<i>Orobanche artemisiae-campestris</i>
<i>Orobanche purpurea</i>	<i>Phelipanche purpurea</i>
<i>Peucedanum carvifolia</i>	<i>Dichoropetalum carvifolia</i>
<i>Phyteuma spicatum ssp. nigrum</i>	<i>Phyteuma nigrum</i>
<i>Placidium rufescens</i>	<i>Catapyrenium rufescens</i>
<i>Puccinellia distans s. borealis</i>	<i>Puccinellia distans</i>
<i>Puccinellia distans ssp. borealis</i>	<i>Puccinellia distans</i>
<i>Puccinellia pseudodistans</i>	<i>Puccinellia fasciculata</i>
<i>Ranunculus baudotii</i>	<i>Ranunculus peltatus subsp. baudotii</i>
<i>Rosa pimpinellifolia</i>	<i>Rosa spinosissima</i>
<i>Salix fragilis</i>	<i>Salix fragilis aggr.</i>
<i>Sanguisorba officinalis</i>	<i>Sanguisorba officinalis</i>
<i>Scirpus lacustris</i>	<i>Schoenoplectus lacustris</i>
<i>Scleranthus annuus s. polycarpus</i>	<i>Scleranthus polycarpus</i>
<i>Senecio nemorensis s. fuchsii</i>	<i>Senecio ovatus</i>
<i>Silene latifolia s. alba</i>	<i>Silene latifolia</i>
<i>Sonchus arvensis var. Maritimus</i>	<i>Sonchus maritimus</i>
<i>Spergularia salina</i>	<i>Spergularia marina</i>
<i>Tetragonolobus maritimus</i>	<i>Lotus maritimus</i>
<i>Thlaspi caerulescens</i>	<i>Thlaspi caerulescens gr.</i>
<i>Thlaspi perfoliatum</i>	<i>Noccaea perfoliata</i>
<i>Tragopogon pratensis s. pratensis/s. minor</i>	<i>Tragopogon pratensis</i>
<i>Veronica hederifolia s. lucorum</i>	<i>Veronica sublobata</i>
<i>Viola curtisii</i>	<i>Viola tricolor subsp. curtisii</i>
<i>Viola lutea s. calaminaria</i>	<i>Viola calaminaria</i>
<i>Viola lutea ssp. calaminaria</i>	<i>Viola calaminaria</i>
<i>Viola persicifolia</i>	<i>Viola stagnina</i>
<i>x Calammophila baltica</i>	<i>x-Ammocalamagrostis baltica</i>
<i>Zannichellia palustris s. palustris</i>	<i>Zannichellia palustris</i>
<i>Zannichellia palustris s. pedicellata</i>	<i>Zannichellia pedunculata</i>
<i>Zostera noltei</i>	<i>Zostera noltii</i>
<i>Salicornia europaea sensu FvN 23</i>	<i>Salicornia europaea</i>
<i>Salicornia procumbens sensu FvN 23</i>	<i>Salicornia procumbens</i>

# Appendix 4 Evaluation of a selection of species-structure type combinations

Combinations were assessed based on plots as given in Chapter 2.

		Species	Species	Species	Species	Species	Species	Species	Species	Species	Species
<b>Species name (Dutch) and structure type</b>		Heather	Heather	Heather	Heather	Heather	Heather	Heather	Heather	Heather	Heather
<b>Structure type</b>		Dry dwarf shrubs	Dry grassland	Dry deciduous forest	Dry shrubs	Swamp	Wet dwarf shrubs	Wet grassland	Wet deciduous forest	Water	Salt
<b>Scientific name</b>		<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>	<i>Calluna vulgaris</i>
<b>Plot 1: Header map and AOI</b>											
Distributed over Europa?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Which countries are missing?		No Portugal, only cost of Spain.	No Portugal, only cost of Spain	Very few Portugal and Spain	No Portugal and Norway	No Spain and Portugal	Many in Sweden	A lot in Denmark, NL en Ireland	No Spain and Portugal	Only few especially in NL, FR, DN and IER	Only Ireland and Denmark
<b>Scatterplots</b>											
remarks		Many positives compared to negatives			Only a few positives compared to negatives		Positives and negatives app. equal	More negatives with increasing N-deposition			
<b>Plot 2: temperature &amp; N-dep</b>											
Are all temperatures represented?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
remarks					Mostly from 9 degrees onwards. from 0,5-6 degrees all positive (13). remarkable: 1 positive in NL in 1992 at 8 mol N and 10 degrees.	Many negative points, especially around 8.5-11 degrees. A few plots at low temperatures				Only from 8.2 degrees	from 8.8 degrees
<b>Plot 3: precipitation &amp; N-dep</b>											

		Species	Species	Species	Species	Species	Species	Species	Species	Species	Species
Are there data at high precipitation values?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
remarks					At high precipitation less negatives. Highest positives at 5mm rainfall and 1 mol N.	Many negatives between 3-6 mol N. At 8.4mm rainfall a positive in Norway in 2007.				Maximum at 4.4mm rain fall in Ireland 1995	Positive at 3.9mm. cluster around 1.5 mm
<b>Plot 4: N-dep per year</b>											
Even distribution over the years?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
remarks									Many positives from 2004		Only plots from 2004 and 1 in 1972
<b>Response density charts</b>											
Do the charts go from high to low at higher nitrogen levels?	Yes/No	Yes	No	No	No	Yes	Varies	varies	No	Yes	Yes
Note if respons goes up at high levels			Yes, maximum around 5.5-6.0	Varies with Ndep	Yes, maximum at 7 - 8.5. 2 positives in NL		from 4.5-5 mol N increase, then decrease	Small optimum at 4.5-5 mol N	Optimum from 8 and major optimim at 9 mol N.		
<b>Division over soil types</b>											
Are soil types the same for positive and negative findings?	Yes/No	No	No	Yes	Not totally	Yes	Yes	Yes	Yes	Yes	Yes
Remarks positive findings		Sand is dominant then young soils	2/3 on sand, then 1/4 on young soils and 1/4 on clay	Young soils, sand and clay	Young soils and sand also on clay	Sand and clay dominant	Sand and clay dominant	Sand and clay dominant	Sand and clay dominant	sand, young soils and clay	clay dominant
Remarks negative findings		Over half on young soils and sand	Clay and sand dominant, also young soils	Young soil, sand and clay	Young soils and clay dominant, also on sand.	Sand and clay dominant	Sand and clay dominant	Sand and clay dominant	Sand and clay dominant	Sand and clay and young soils dominant	clay dominant
Are rock and water dominant?	Yes/No	No	No	No	No	No	No	No	No	No	No
If water and rock alert. Remarks.						More rocks for positives than negatives.			More rocks at positives		



What sticks out	no portugal, only coast of Spain.	no portugal, only coast of Spain.	Few in portugal and spain	no portugal and norway	No spain and portugal	mani in Sweden	Especially in Denemar k NL and Ireland	no spain and portugal	Only few plots in NL, FR, DN en IER	Only IER en DEN	only NL, DE and FR		only in NL	few in scandinavia and no in spain and portugal	Many in denemark, no in scandinavia and spain portugal	Especially along the coast	x	1 in norway
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**Scatterplots**

	Many positives			Only a few positives			Positives and negeatives about equal	Many negatives especially at high Ndep				Manu negatives	Unequal distributed . One cloud of plots only two positives		Much more negatives		x	x
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**Plot 2: temperature & Ndep**

Distribution ok?	Yes/N	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
remarks				Especially above 9 degrees. Till 6 only positives (13). Remarkable : 1 positive in NL in 1992 at 8 mol N 10 degrees	Many negatives especiall y around 8.5-11.					Only from 8.2 degrees onwards	from 8.8 degrees	between 8-14 degrees	between 7.5 - 14 degrees	from 8.5 degrees			Many positives and only a few negatives at low temperatures		1 positive at 3 degrees

**Plot 3: precipitation & Ndep**

At higher precipitation also data?	Yes/N	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	limited	Yes	Yes	No	Yes	Yes	limited	Yes	Yes
remarks				At higher prec. Less highest positives at 5mm and 1 mol N.	Many negatives between 3-6 mol N. at 8.4mm one					Highest positive at 4.4mm in Ireland 1995	A positive at 3.9mm. a cluster around 1.5mm	from 1.8mm onwards	One positive at 4.6mm	from 1,9mm onwards			at 5mm a in Ireland	positive at 9mm	

positive  
in  
Norway  
in 2007.

<b>Plot 4: Ndep per year</b>																			
Are data well distributed?	Yes/N	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
remarks											Many positives from 2004 onwards		Only data from 2004 onwards except 1 in 1972					Only from 1968 onwards	
<b>Response density charts</b>																			
Expected decrease with increasing Ndep	Yes/N	Yes	No	No	No	Yes	varying	varying	No	Yes	Yes	No	Yes	No	No	No	No	No	No
Increase at very high Ndep levels?		Yes, optimum at 5.5-6.0 kmol/ha/y	Varying with Ndep	Yes, optimum 7 - 8.5. 2 positives in NL		from 4.5-5 increase then again decrease	Small optimum at 4.5-5	Increase from 8 and high optimum at 9 mol N.				Optimum around 4-5 mol N	optimum around 3.5-4 mol N	Optima between 3.5 en 6.0 mol N	Optimum between 3.0 - 5.5 mol N	Optimum from 6.0 - 8.5	Optimum from 6 - 7	Optimum from 3.5 - 6.5	
<b>Distribution for soil types</b>																			
Do positives and negatives occur at the same soil types?	Yes/N	No	No	Yes	Not totally	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Remarks positives		Sand and young soils	Sand and then young soils and clay	Young soils, sand and clay	Young soils, sand and clay	Sand and clay	Sand and clay	Sand and clay	Sand and clay	Sand and clay	Sand and clay	Sand, peat and young soils		sand	Young soils rocks and sand	Clay, young soils and sand	Sand, clay and young soils	Clay, young soils and sand	Clay, young soils and sand
Remarks negatives		Young soils and sand.	Clay, young soils and sand	Young soils, clay and sand	Young soils, clay and sand	Sand and clay	Sand and clay	Sand and clay	Sand and clay	Sand and clay	Sand and clay and young soils	Sand, young soils and peat		Sand and peat	Sand and young soils	Clay, sand and young soils	Clay, young soils and sand	Clay, young soils and sand	Clay, sand and young soils



Part 3 of the table

<b>NL species name</b>		<i>Sphagnum compactum</i>	<i>Dactylorhiza maculata</i>	<i>Dactylorhiza maculata</i>	<i>Dactylorhiza maculata</i>	marsh gentian	marsh gentian	marsh gentian	<i>Ornithopus perpusillus</i>
<b>Structure type</b>		Wet dwarf shrub	Wet dwarf shrub	Dry grassland	wet grassland	dry grassland	Wey dwarf shrub	wet grassland	Dry grassland
<b>Scientific name</b>		<i>Sphagnum compactum</i>	<i>Dactylorhiza maculata</i>	<i>Dactylorhiza maculata</i>	<i>Dactylorhiza maculata</i>	<i>Gentiana pneumonanthe</i>	<i>Gentiana pneumonanthe</i>	<i>Gentiana pneumonanthe</i>	<i>Ornithopus perusilles</i>
<b>Plot 1: Header map and AOI</b>									
Distributed over Europa?	Yes/No	Yes	Yes	Yes	Yes	Matig	Matig	Matig	Yes
What sticks out?			None in spain, portugal and norway			Nonen in spain, portugal uk and Scandinavia	Many in NL, D and DK	Many in NL, D and DK	None in scandinavia and portugal
<b>Scatterplots</b>									
		Many positives and negatives in one cloud	Many isolated points besides a big cloud	Big distribution	Some positives with distance to the cloud	Many negatives	Many in a cloud	Many negatives	
<b>Plot 2: temperature &amp; Ndep</b>									
Distribution ok?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
remarks		Only a few plots at 0 - 6 degrees		A few positives at 1 degree	A few positives at 1 degree		Not to bright, from 7 - 14 all plots, big cloud between 8.5 and 11		Few positives at 13 - 14 degrees, compared to the negatives
<b>Plot 3: precipitation &amp; Ndep</b>									
At higher precipitation also data?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
remarks		Big cloud with plots but also at higher prec.	Many negatives at high prec. Op till 6.2.	Uneven distribution	Uneven distribution	Uneven distribution	Also some positives at 3.8mm		1 positive at 3.5mm. negatives around 3kMol (no positives)
<b>Plot 4: Ndep per year</b>									
Are data wel distributed?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
remarks									
<b>Response density charts</b>									
Expected decrease with increasing Ndep	Yes/No	No	No	No	No	Yes	No	No	No
Increase at very high Ndep levels?		Second optimum at 4.5 - 6.5	Two small optima at 4 and 5. Positives are from NL	Small optimum at 4 - 5	Large optimum at 3 and small optimums at 4-5	Very small optimum 5.5 (one plot NL 1989)	Increase at high Ndep	2 optimums at 3 and 5	Increase from 3 kMol till 5, then decrease

**Distribution for soil types**

Do positives and negatives occur at the same soil types?	Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	somewhat	somewhat
Remarks positives		Sand rock and clay	Sand, young soils and clay	Young soils, clay and sand	Young soils, sand and clay	Young soils and sand	sand	Young soils, sand and clay	Sand, young soils and clay
Remarks negatives		Sand, clay and peat	Sand, peat and clay	Sand, young soils and clay	Clay, sand and young soils	Sand and clay		Sand, clay and young soils	Sand, clay and young soils
Are water/rocks dominant? dominant?	Yes/No	Yes	No	No	No	No	No	No	No
if yes rock and water, flag. remarks									

**Distribution for EUNIS types**

Do EUNIS types agree between positives and negatives	Yes/No	somewhat	Yes	Yes	somewhat	Yes	somewhat	No	somewhat
Remarks, which is dominant			S42 Wet Heath and Qa Mires	R grasslands and R22					
Remarks positives		S41 Wet heath, Qa Mires and Q12 blanket bog			3/4 R37	2/3 grasslands (R)	S41, wet heath, Qa Mires and D	R37 (3/4)	R grasslands, R1p and R22
Remarks negatives		Qa mires, S41 Wet heath, Qb wetlands			R35, R36 and R37	1/3 Grasslands	Qa Mires, Qb Wetlands and S41 Wet Heath	R35 (1/2) and R36	R grasslands (1/2) and R22 en R21

## Appendix 5 Overview of the evaluation of the response curves per habitat type for four scenarios

Evaluation of the response curves for the four species list, the old species list (sl 1, original list without displacement species, sl 2 'Red List' species, sl 3 typical species and sl 4 'Red List' species and typical species). Also included is the judgement of the curves for the old species list for the original 2022 species set and the 2023 species set (without displacement species) and the new empirical CL and new CL.

code	name	Emp. CL		sl 1		comment	sl 2	sl 3	sl 4	comment
		range	2022	2023	2022					
1310A	Pioneer salt marshes (Salicornia)	20-30	23	poor	poor	Increasing curve	poor	poor	poor	all increasing curves, uncertainty smaller!
1310B	Pioneer salt marshes (Sagina maritima)	10-20	20	Good	rea	Descent but high dep increae, fits better with new emp CL	good	poor	-	sl 3 like 1, 2 decrease from lowest Ndep
1320	Spartina swards	20-30	23	Poor	-	No species	-	-	-	
1330A	Atlantic salt meadows (outside dyke)	10-20	20	Good	good	But more increasing species	good	good	good	2-4 sl no increase at high Ndep, so better
1330B	Atlantic salt meadows (inside dyke)	10-20	20	Good	good	But more increasing species	good	good	good	2-4 sl no increase at high Ndep, so better
2110	Embryonic shifting dunes	10-20	20	-	-	No species	-	-	-	
2120	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> ('white dunes')	10-20	20	Fair	good	Same as Doren-1, but change of insight	good	good	good	2 and 4 only one species
2130A	Grey dunes, chalk rich	5-15	15	Good	good	Same curve	good	good	good	4 slight increase at high Ndep due to one species
2130B	Grey dunes, chalk poor	5-15	13	Good	good	Same curve	good	good	rea	2 best scenario, bigger range of probability of occurrence
2130C	Grey dunes, Nardetea	5-15	11	Good	good	Same curve	good	good	good	2 best, slightly better than 4
2140A	Dunes with <i>Empetrum nigrum</i> (moist)	10-15	12	Good	good	One species with optimum curve missing	poor	-	-	2 only one species
2140B	Dunes with <i>Empetrum nigrum</i> (dry)	10-15	12	Good	good	One species has a less strong increase	good	-	-	
2150	Decalcified fixed dunes	10-15	12	Good	good	One species has a less strong increase	-	-	-	
2160	Dunes with <i>Hippophae rhamnoides</i>		28	fair	good	Descent now mainly after CL	fair	poor	-	2 and 3 only one species, 3 increase

code	name	Emp. range	CL	sl 1		comment	sl 2	SI 3	sl 4	comment	
2170	Dunes with <i>Salix repens</i> ssp. <i>argentea</i>			32	poor	rea	New insight and curve slightly different, more stable at higher deposition	fair	-	-	2 only two species
2180A	Wooded dunes (dry)	10-15		15	fair	rea	Same response, descending response	-	-	-	
2180B	Wooded dunes (moist)			31	Good	good	Almost same response, less pronounced optimum curves of some species	good	-	-	2 only one species
2180C	Wooded dunes (inner dune)			25	Good	good	Same response curve	good	good	-	2 only two species, 3 only one species with optimum curve at the CL
2190A	Humid dune slacks (open water)	10-20	14	30	Good	good	Same response curve	good	good	good	2 based on four species, 3 and 4 only on three
2190B	Humid dune slacks (chalk rich)	5-15		20	Good	Good	Slightly different curve	good	good	good	2, major descent starts at CL, 3 and 4 less good
2190C	Humid dune slacks (chalk poor)	5-15		15	fair	good	New insight, fits better with new emp CL	poor	good	-	2 two species, 3 only one species, but descent starts within emp. CL
2310	Dry sand heaths with <i>Calluna</i> and <i>Genista</i>	5-15		10	Good	good	Same curve, fits better with new emp CL	good	good	good	all three same response curve, better than original, with a stronger response, but uncertainty is bigger
2320	Dry sand heaths with <i>Calluna</i> and <i>Empetrum nigrum</i>	5-15		15	fair	good	Response of one species less increasing and new insight, fits better with new emp CL	good	-	-	2 only three species, bigger uncertainty
2330	Inland dunes	5-15		10	Good	good	Response of one species less increasing	-	poor	-	3 only two species, descent starts after 20 kg/ha/y, to high
3110	Oligotrophic waters	5-10		6	Good	good	Almost same curve	good	good	good	all three same response curve, sl 4 only two species, large uncertainty (sl 1,2 and 3 have three species!)
3130	Oligotrophic to mesotrophic standing waters	5-10		7	Good	good	One species less increasing	good	good	good	sl 2 and 3 same curve, for 2,3,4 bigger uncertainty
3140	Hard oligo-mesotrophic waters	5-10	7	>34	Good	good	One species less increasing	good	-	-	sl 2 only two species, bigger uncertainty
3150	Natural eutrophic lakes		30	>34	Poor	good	New insight	good	good	good	sl 2 and 4 only one species and big uncertainty
3160	Natural dystrophic lakes and ponds	5-10		10	Good	good	Less species!	good	-	-	sl 2 only one species, big uncertainty
3260A	Water courses of plain to montane levels with the <i>Ranunculus fluitantis</i> and <i>Callitriche-Batrachion</i> vegetation ( <i>Ranunculus fluitantis</i> )			>34	-	-		-	poor	poor	sl 3,4 only one species, u shape and high uncertainty
3260B	Water courses of plain to montane levels with the <i>Ranunculus fluitantis</i> and <i>Callitriche-Batrachion</i> vegetation ( <i>Callitriche-Batrachion</i> )			>34	-	-		-	poor	-	sl 3 only one species, optimum curve, much lower than the CL, large uncertainty
3270	Rivers with muddy banks with <i>Chenopodium rubri</i> pp and <i>Bidens</i> pp vegetation			>34	-	-		-	good	-	sl 3 six species, steep descent from lowest Ndep, different from CL at >34/34!

code	name	Emp. range	CL	sl 1		comment	sl 2	SI 3	sl 4	comment
4010A	Wet heaths with <i>Erica tetralix</i> (inland sandy soils)	5-15	15	Poor	poor	Species increase less pronounced but still not good	good	good	good	sl 2,3,4 only three species, one species strong increase
4010B	Wet heaths with <i>Erica tetralix</i> (lowland fens)	5-15	7	Good	good	Species increase less pronounced	good	good	good	sl 2,3,4 one species, relative low uncertainty for one species
4030	European dry heaths	5-15	10	Good	good	Increase species less pronounced	good	good	good	sl 2,3,4, same curve, descent much stronger
5130	Juniperus communis formations	5-15	15	Good	good	Less good than earlier, decrease smaller	good	-	-	sl 2 only one species, big uncertainty
6110	Rupicolous calcareous or basophilic grasslands	10-20	20	Good	good	Increase some species more pronounced	good	good	good	sl 2 looks best with smallest uncertainty, at the beginning, 4 also small uncertainty, 3 large uncertainty at higher Ndep and a steeper descent at low Ndep, lower than the emp CL. First with overall for the three many species
6120	Xeric sand calcareous grasslands	10-20	18	Good	good	Same response	good	good	good	sl 2,3,4 same response, many species, rather large uncertainty, stronger response than 1. Better than sl 1
6130	Calaminarian grasslands	5-15	15	Fair	good	Fits better with new emp CL	good	fair	rea	sl 2 only three species, 3,4 only one species, optimum curve with optimum at just higher Ndep than CL
6210	Semi-natural dry grasslands	10-20	20	Good	good	More species with an increasing response	good	good	good	sl 2,3,4 same response, bit more pronounced than 1, still some species with increasing response
6230	Nardus grasslands	6-20	10	Good	good	Less pronounced increase for some species	good	good	good	sl 2 many species, 3and4 less species, but all good. 3 and 4 no increasing species, 2 one increasing species
6410	Molinia meadows	10-20	11	Poor	good	New insight, fits better with new emp CL and less pronounced increase curve some species	good	good	good	sl 2,3,4 no increasing species, better fitting with new CL and emp. CL than sl 1,
6430A	Hydrophilous tall herb fringe communities (dry woodland edge)		>34	-	-		-	? good?	-	sl 3 only two species, descending curve, indicating a CL is needed
6430B	Lowland hay meadows (Arrhenatherum subtype)		>34	-	-		-	? good?	good	sl 3 two species, decreasing response from the lowest Ndep, 4 optimum curve of one species, optimum just lower than the CL
6430C	Lowland hay meadows (Alopecurus subtype)		26	Poor	poor	Increase	-	good	good	sl 3,4 only one species, large uncertainty
6510A		10-20	19	Poor	good	New insight, fits better with new emp CL	good	good	good	sl 2,3,4 stronger decrease and no increasing species, better than sl 1
6510B		10-25	22	Poor	rea	New insight, decrease still minimal, fits better with new emp CL	good	good	good	sl 2,3,4 better than 1, only one slightly increasing species at high dep, strong decrease, good fit with new emp CL and new CL
7110A	Active raised bogs (active bog landscape)	5-10	7	Good	Good	One increasing species less pronounced	good	good	good	sl 2 only two species, sl 3,4 three species
7110B	Active raised bogs (heath bogs)	5-15	10	Good	good	One increasing species less pronounced	good	good	good	sl 2,4 only two species, sl 3 three species

code	name	Emp. range	CL	sl 1		comment	sl 2	sl 3	sl 4	comment
7120	Degraded raised bogs		7-25	Good	good	Few species with less pronounced increase	good	good	good	sl 2,3,4 more pronounced decrease than sl 1
7140A	Quacking bogs	15-25	17	Good	good	Curve changed shape and is now a steady decrease	good	good	good	sl 2 better than sl 1, sl 3,4 only one species
7140B	<i>Sphagnum</i> reedland	5-15	7	Poor	rea	No longer optimum curve, but decrease still at high value (25 kg/ha/y)	fair	good	rea	sc2,4 only one species, same end result as sl 1, sl 3 only two species, but curve as could be expected, better than 1
7150	Depressions on peat substrates	5-15	15	Good	good	Same curve	fair	good	-	sl 2 more like old version CL, sl 3 only two species, similar curve as sl 1
7210	Calcareous fens with <i>Cladium mariscus</i>	15-25	20	Poor	good	New insight, fits better with new emp CL	good	-	-	sl 2 only two species
7220	Petrifying springs with tufa formation	15-20	20	Fair	good	New insight	-	-	-	
7230	Alkaline fens	15-25	16	Good	good	Same curve	good	good	good	sl 2 many species comparable with sl 1, sl 3,4 same curve, more or less straight curve till just above CL, then descent
9110	Luzulo-Fagetum beech forests	10-15	15	Good	good	Same curve	good	fair	poor	sl 2 three species, but good fit with emp CL, better than sl 1, sl 3 limited descent till twice emp CL then strong descent, sl 4 only one species with optimum higher than CL
9120	Atlantic acidophilous beech forests	10-15	15	Good	good	Same curve	-	good	-	stronger descent than sl 1, but still limited
9160A	oak or oak-hornbeam forests (sandy soils)	15-20	20	Good	good	some increasing curves lower	good	good	good	sl 2 three species, sl 3 many species, sl 4 two species, all three good looking curves, more pronounced decrease than sl 1
9160B	oak or oak-hornbeam forests (hils)	15-20	20	Good	good	Same curve	good	good	good	sl 2 best curve, sc4 gives minor increase at max Ndep
9190	Old acidophilous oak woods	10-15	15	Poor	good	Steady decrease from the beginning	-	good	-	sl 3 only one species, but clear descent and fits emp CL
91D0	Bog woodland		25	Good	good	Same curve	good	-	-	sl 2 only two species
91E0A	Alluvial forest (softwood)		34	Poor	rea	New insight, increasing species slightly lower	poor	good	-	sl 2 only one species, big uncertainty and optimum around 80kg/ha/y, sl 3 only two species, but steady decrease from beginning
91E0B	Alluvial forest (ash-elm)		28	Fair	good	New insight	-	good	-	sl 3 only one species, steady decrease
91E0C	Alluvial forest (stream bank)		26	Fair	good	New insight	good	good	good	sl 2 four species, steady decrease, sl 3 many species steady decrease, better than sl 1, sl 4 only 3 species, steady decrease
91F0	Riparian mixed forests		29	Poor	poor	Kept it at poor, but distinct decrease around 55 kg/ha/yr, much higher than CL	-	good	-	sl 3 only one species, big uncertainty, steady decrease, but better than sl 1

# Appendix 6 Number of species in habitat types per species list

In the table the number of species per list are given. Q identifies characteristic species, D displacement species. Subtotals per habitat type per subgroups are given and an overall total.

Code	Habitat(sub)type	'Red List' species (R.L.) Total R.L.		Not on the 'Red List'		Total no R.L.	Characteristic total	Displacement total	Overall total		
		Q	D	Q	D						
H1130	Estuaries					2	0	0	2		
H1140_A	Mudflats and sandflats not covered by seawater at low tide					3	0	0	3		
H1160	Large shallow inlets and bays					2	0	0	2		
H1310_A	Pioneer salt marshes ( <i>Salicornia</i> )			6		9	6	0	9		
H1310_B	Pioneer salt marshes ( <i>Sagina maritima</i> )	4		4	17	4	21	4	36		
H1320	<i>Spartina</i> swards	1		1	1	4	2	1	5		
H1330_A	Atlantic salt meadows (outside dyke)	12		12	31	9	69	43	81		
H1330_B	Atlantic salt meadows (inside dyke)	12	1	13	31	8	66	43	79		
H2110	Embryonic shifting dunes				5		10	5	0	10	
H2120	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> ('white dunes')		1	1	10	1	19	11	1	20	
H2130_A	Grey dunes, chalk rich		17	17	98	8	152	115	8	169	
H2130_B	Grey dunes, chalk poor		7	7	66	12	96	73	12	103	
H2130_C	Grey dunes, <i>Nardetea</i>		11	1	12	10	5	28	21	6	40
H2140_A	Dunes with <i>Empetrum nigrum</i> (moist)		1	1	8	3	18	9	3	19	
H2140_B	Dunes with <i>Empetrum nigrum</i> (dry)		5	5	24	1	32	29	1	37	
H2150	Decalcified fixed dunes				14	4	22	14	4	22	
H2160	Dunes with <i>Hippophae rhamnoides</i>		1	1	25	3	33	26	3	34	
H2170	Dunes with <i>Salix repens ssp. argentea</i>		10	10	8	3	20	18	3	30	
H2180_A	Wooded dunes (dry)				26	4	44	26	4	44	
H2180_B	Wooded dunes (moist)		3	3	55	7	79	58	7	82	
H2180_C	Wooded dunes (inner dune)		2	2	60	1	95	62	1	97	

		'Red List' species (R.L.) Total R.L.		Not on the 'Red List'		Total no R.L.	Characteristic total	Displacement total	Overall total
H2190_A	Humid dune slacks (open water)	12	12	56	7	83	68	7	95
H2190_B	Humid dune slacks (chalk rich)	26	1 27	63	6	103	89	7	130
H2190_C	Humid dune slacks (chalk poor)	8	8	22	7	52	30	7	60
H2190_D	Humid dune slacks (tall ferbs)	1	1	30	3	46	31	3	47
H2310	Dry sand heaths with <i>Calluna</i> and <i>Genista</i>	4	4	20	3	35	24	3	39
H2320	Dry sand heaths with <i>Calluna</i> and <i>Empetrum nigrum</i>	3	3	23	1	26	26	1	29
H2330	Inland dunes			26	10	45	26	10	45
H3110	Oligotrophic waters	3	3	5	3	14	8	3	17
H3130	Oligotrophic to mesotrophic standing waters	14	2 16	19	3	45	33	5	61
H3140	Hard oligo-mesotrophic waters	5	5	20	5	27	25	5	32
H3150	Natural eutrophic lakes	1	1	10	1	20	11	1	21
H3160	Natural dystrophic lakes and ponds	11	11	14	3	26	25	3	37
H3260_A	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation (Ranunculion fluitantis)	3	3	12	8	30	15	8	33
H3260_B	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation (Callitricho-Batrachion)			4	8	14	4	8	14
H3270	Rivers with muddy banks with <i>Chenopodium rubri</i> pp and <i>Bidention</i> pp vegetation	2	2	45		60	47	0	62
H4010_A	Wet heaths with <i>Erica tetralix</i> (inland sandy soils)	3	3	10	4	29	13	4	32
H4010_B	Wet heaths with <i>Erica tetralix</i> (lowland fens)	2	2	18	6	34	20	6	36
H4030	European dry heaths	5	5	25	4	41	30	4	46
H5130	<i>Juniperus communis</i> formations	3	1 4	71	5	78	74	6	82
H6110	Rupicolous calcareous or basophilic grasslands	21	21	40	2	56	61	2	77
H6120	Xeric sand calcareous grasslands	22	1 23	65	10	126	87	11	149
H6130	Calaminarian grasslands	5	1 6	8	2	16	13	3	22
H6210	Semi-natural dry grasslands	40	1 41	34	7	83	74	8	124
H6230	<i>Nardus</i> grasslands	36	2 38	38	13	94	74	15	132
H6410	<i>Molinia</i> meadows	11	1 12	28	13	70	39	14	82
H6430_A	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (meadowsweet)	1	1	31	4	49	32	4	50
H6430_B	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels (hairy willowherb)	5	5	18	4	34	23	4	39
H6430_C	Hydrophilous tall herb fringe communities (dry woodland edge)	4	1 5	18	1	40	22	2	45

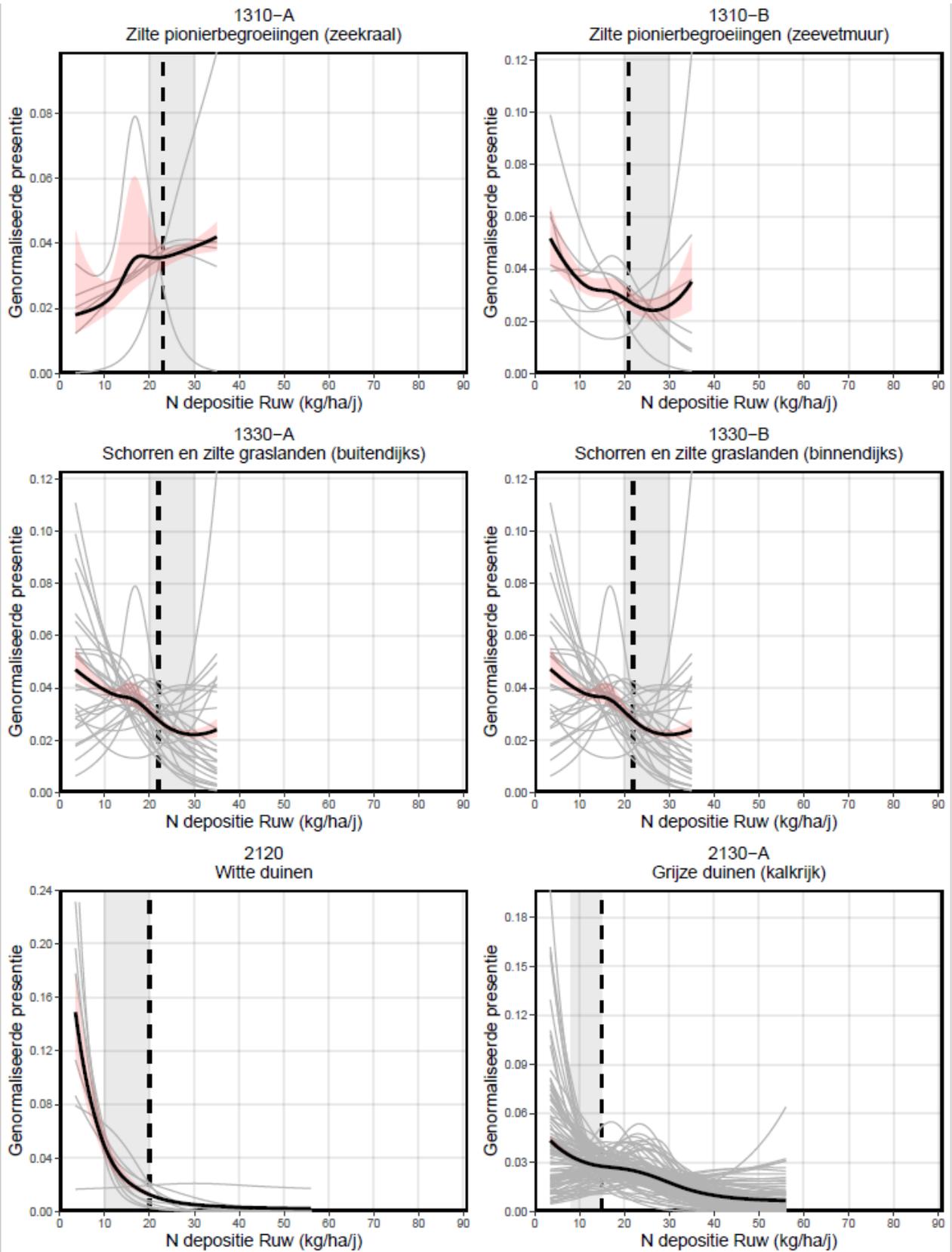
		'Red List' species (R.L.) Total R.L.		Not on the 'Red List'		Total no R.L.	Characteristic total	Displacement total	Overall total	
H6510_A	Lowland hay meadows ( <i>Arrhenatherum</i> subtype)	9	9	30	3	63	39	3	72	
H6510_B	Lowland hay meadows ( <i>Alopecurus</i> subtype)	5	5	31	1	43	36	1	48	
H7110_A	Active raised bogs (active bog landscape)	7	2	9	13	6	27	20	8	36
H7110_B	Active raised bogs (heath bogs)	8	2	10	13	4	30	21	6	40
H7120	Degraded raised bogs	15	2	17	40	6	57	55	8	74
H7140_A	Quacking bogs	18	1	19	37	11	65	55	12	84
H7140_B	<i>Spagnum</i> reedland	1	1	1	20	6	37	21	6	38
H7150	Depressions on peat substrates	6	6	6	6	1	15	12	1	21
H7210	Calcareous fens with <i>Cladium mariscus</i>	2	2	2	1	4	6	3	4	8
H7220	Petrifying springs with tufa formation				8		9	8	0	9
H7230	Alkaline fens	49	4	53	104	16	142	153	20	195
H9110	Luzulo-Fagetum beech forests	3	3	3	29	1	51	32	1	54
H9120	Atlantic acidophilous beech forests				23	2	54	23	2	54
H9160_A	oak or oak-hornbeam forests (sandy soils)	9	9	9	32		68	41	0	77
H9160_B	oak or oak-hornbeam forests (hils)	26	26	26	73	2	126	99	2	152
H9190	Old acidophilous oak woods				9	1	12	9	1	12
H91D0	Bog woodland	4	4	4	20	1	29	24	1	33
H91E0_A	Alluvial forest (softwood)				39	5	57	39	5	57
H91E0_B	Alluvial forest (ash-elm)				21	6	46	21	6	46
H91E0_C	Alluvial forest (beech-shore)	11	1	12	70	1	115	81	2	127
H91F0	Riparian mixed forests				7	6	32	7	6	32
<b>Total</b>		<b>511</b>	<b>25</b>	<b>536</b>	<b>1894</b>	<b>300</b>	<b>3295</b>	<b>2405</b>	<b>325</b>	<b>3831</b>

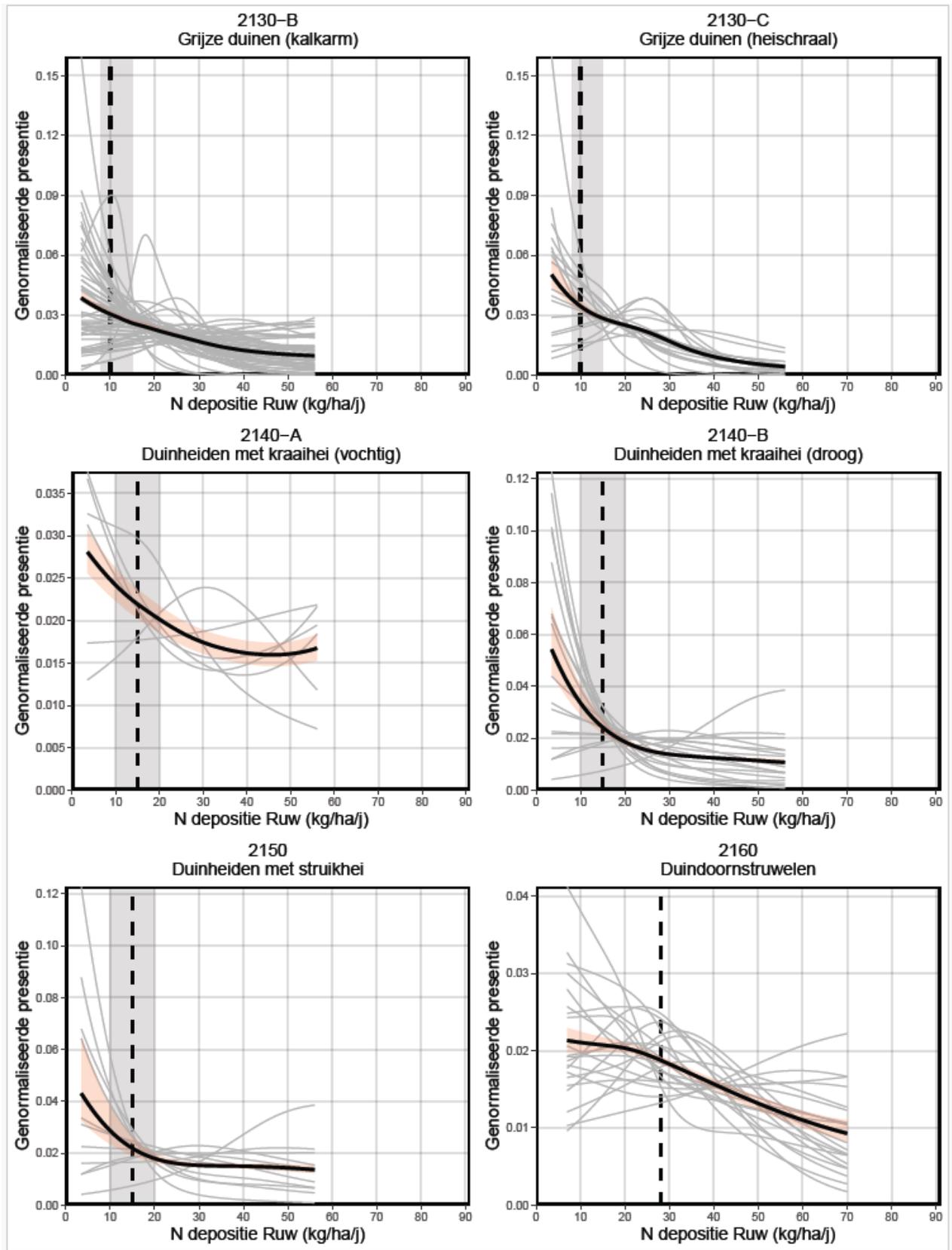
Characteristic species per habitat type are given in digital Appendix 1. Species with a 1 are indicator species, with a 2 are displacement species and with a 3 are both.

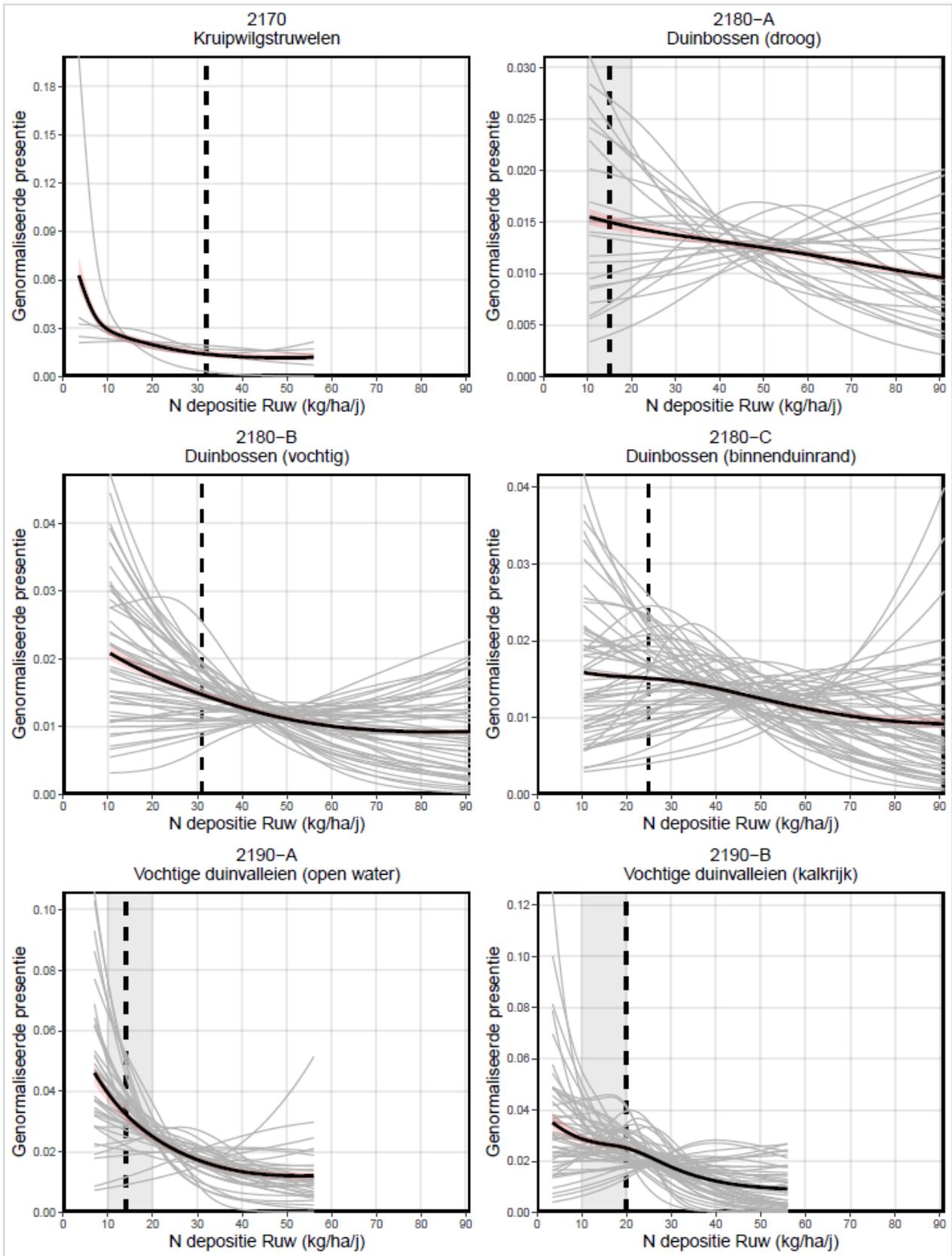
## Appendix 7 Confidence interval of the response curves for nitrogen deposition for habitat types

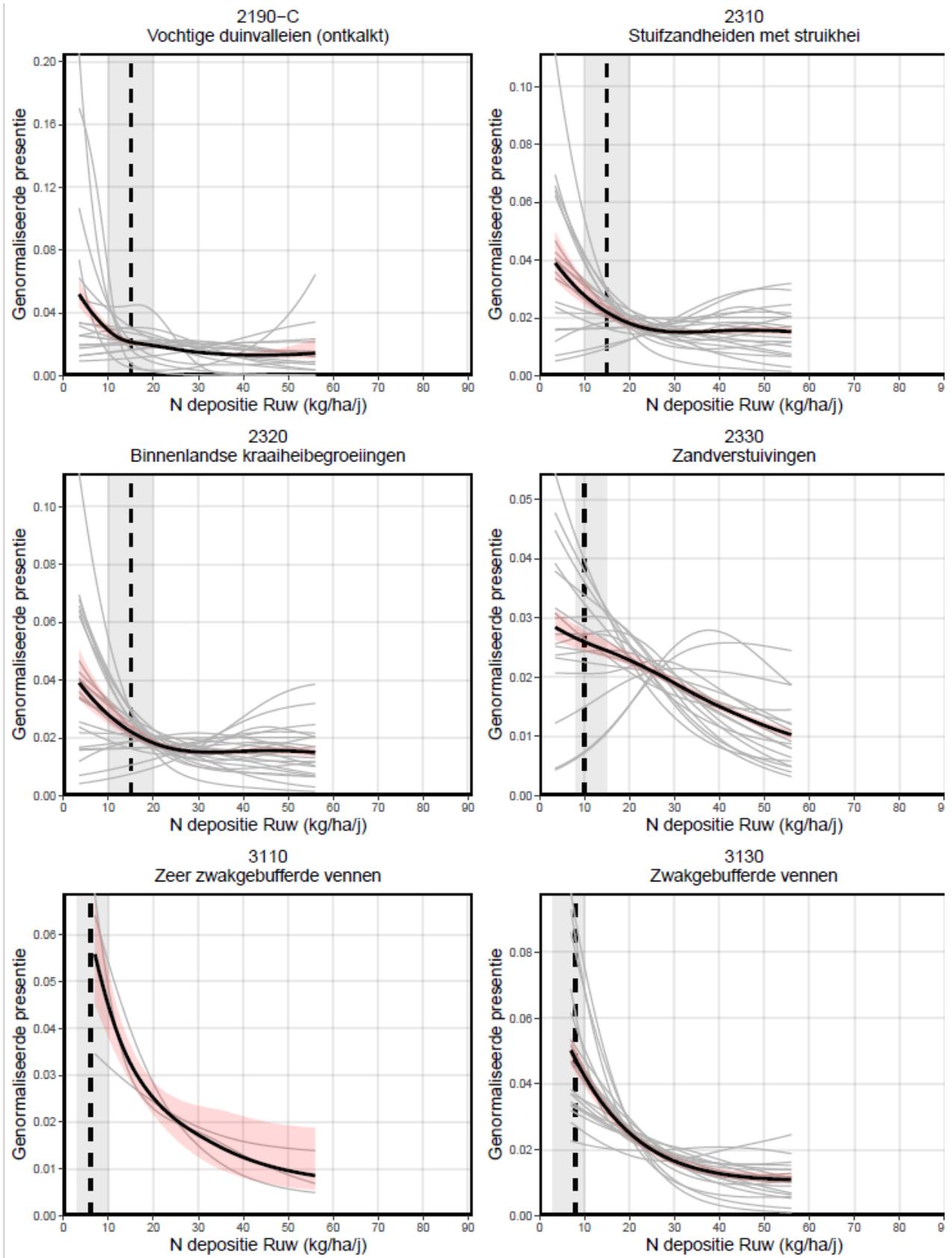
Given are the confidence intervals per habitat type (light red surface, response curve self as a black line), based on a bootstrap procedure, applied to the underlying species response curves for nitrogen deposition (light grey) and the habitat type itself. Note that the old empirical CL (light grey surface) and CL (black dotted line) are displayed in the figures. The figures have Dutch text, the setup of the figures is roughly the same as the other figures in the report. Here below we give first the number and name of the habitat type for clarification. Figure \* gives an example of the figure but then with English text.

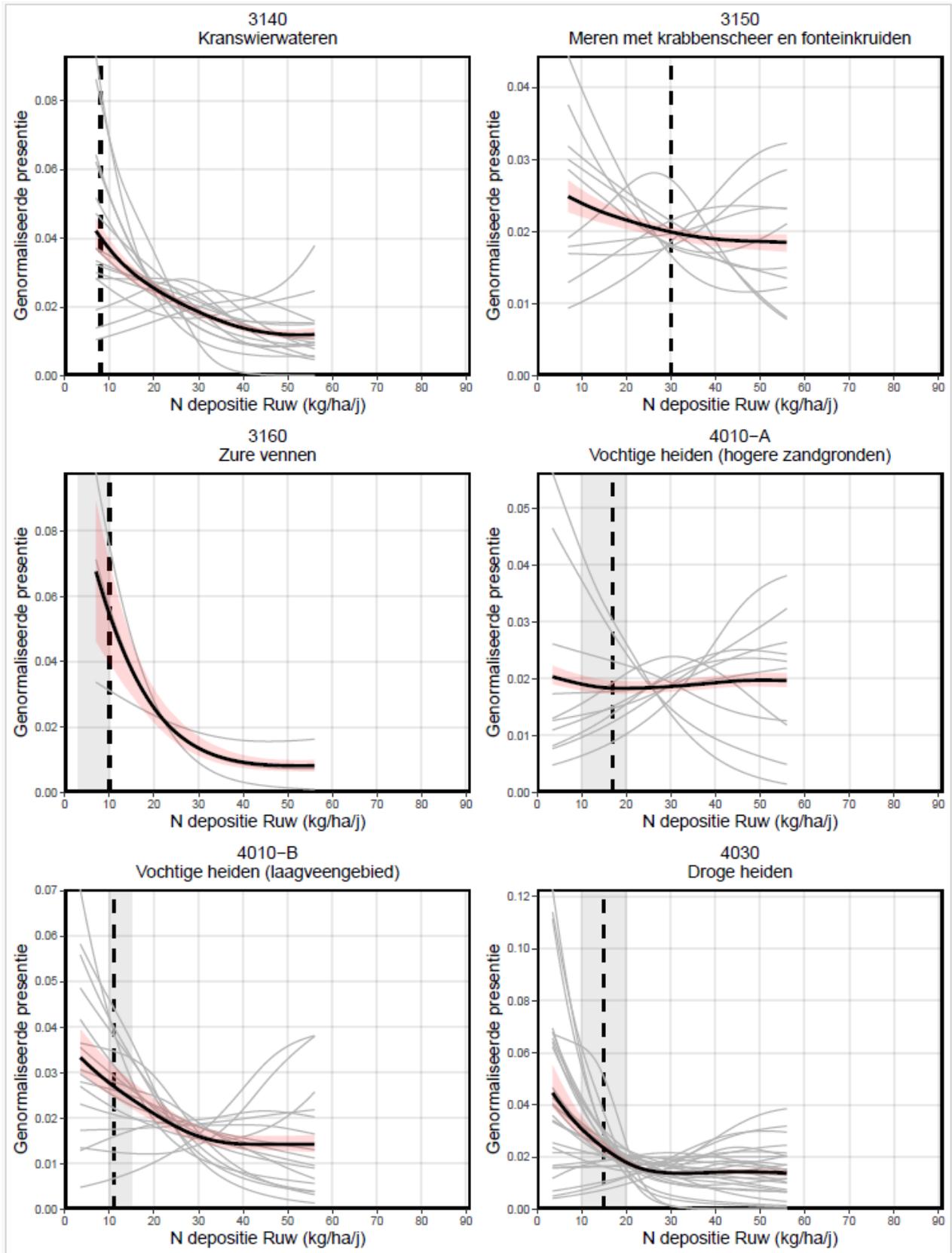
Habitat	Name habitat type	Habitat	Name habitat type
1310-A	Pioneer salt marshes ( <i>Salicornia</i> )	4030	European dry heaths
1310-B	Pioneer salt marshes ( <i>Sagina maritima</i> )	5130	<i>Juniperus communis</i> formations
1320	Spartina swards	6110	Rupicolous calcareous or basophilic grasslands
1330-A	Atlantic salt meadows (outside dyke)	6120	Xeric sand calcareous grasslands
1330-B	Atlantic salt meadows (inside dyke)	6130	Calaminarian grasslands
2110	Embryonic shifting dunes	6210	Semi-natural dry grasslands
2120	Shifting dunes along the shoreline with <i>Ammophila arenaria</i> ('white dunes')	6230	<i>Nardus</i> grasslands
2130-A	Grey dunes, chalk rich	6410	<i>Molinia</i> meadows
2130-B	Grey dunes, chalk poor	6430-C	Hydrophilous tall herb fringe communities (dry woodland edge)
2130-C	Grey dunes, Nardetea	6510-A	Lowland hay meadows ( <i>Arrhenatherum</i> subtype)
2140-A	Dunes with <i>Empetrum nigrum</i> (moist)	6510-B	Lowland hay meadows ( <i>Alopecurus</i> subtype)
2140-B	Dunes with <i>Empetrum nigrum</i> (dry)	7110-A	Active raised bogs (active bog landscape)
2150	Decalcified fixed dunes	7110-B	Active raised bogs (heath bogs)
2160	Dunes with <i>Hippophae rhamnoides</i>	7120	Degraded raised bogs
2170	Dunes with <i>Salix repens ssp. argentea</i>	7140-A	Quacking bogs
2180-A	Wooded dunes (dry)	7140-B	<i>Spaghnum</i> reedland
2180-B	Wooded dunes (moist)	7150	Depressions on peat substrates
2180-C	Wooded dunes (inner dune)	7210	Calcareous fens with <i>Cladium mariscus</i>
2190-A	Humid dune slacks (open water)	7220	Petrifying springs with tufa formation
2190-B	Humid dune slacks (chalk rich)	7230	Alkaline fens
2190-C	Humid dune slacks (chalk poor)	9110	<i>Luzulo-Fagetum</i> beech forests
2310	Dry sand heaths with <i>Calluna</i> and <i>Genista</i>	9120	Atlantic acidophilous beech forests
2320	Dry sand heaths with <i>Calluna</i> and <i>Empetrum nigrum</i>	9160-A	Oak or oak-hornbeam forests (sandy soils)
2330	Inland dunes	9160-B	Oak or oak-hornbeam forests (hills)
3110	Oligotrophic waters	9190	Old acidophilous oak woods
3130	Oligotrophic to mesotrophic standing waters	91D0	Bog woodland
3140	Hard oligo-mesotrophic waters	91E0-A	Alluvial forest (softwood)
3150	Natural eutrophic lakes	91E0-B	Alluvial forest (ash-elm)
3160	Natural dystrophic lakes and ponds	91E0-C	Alluvial forest (stream bank)
4010-A	Wet heaths with <i>Erica tetralix</i> (inland sandy soils)	91F0	Riparian mixed forests
4010-B	Wet heaths with <i>Erica tetralix</i> (lowland fens)		

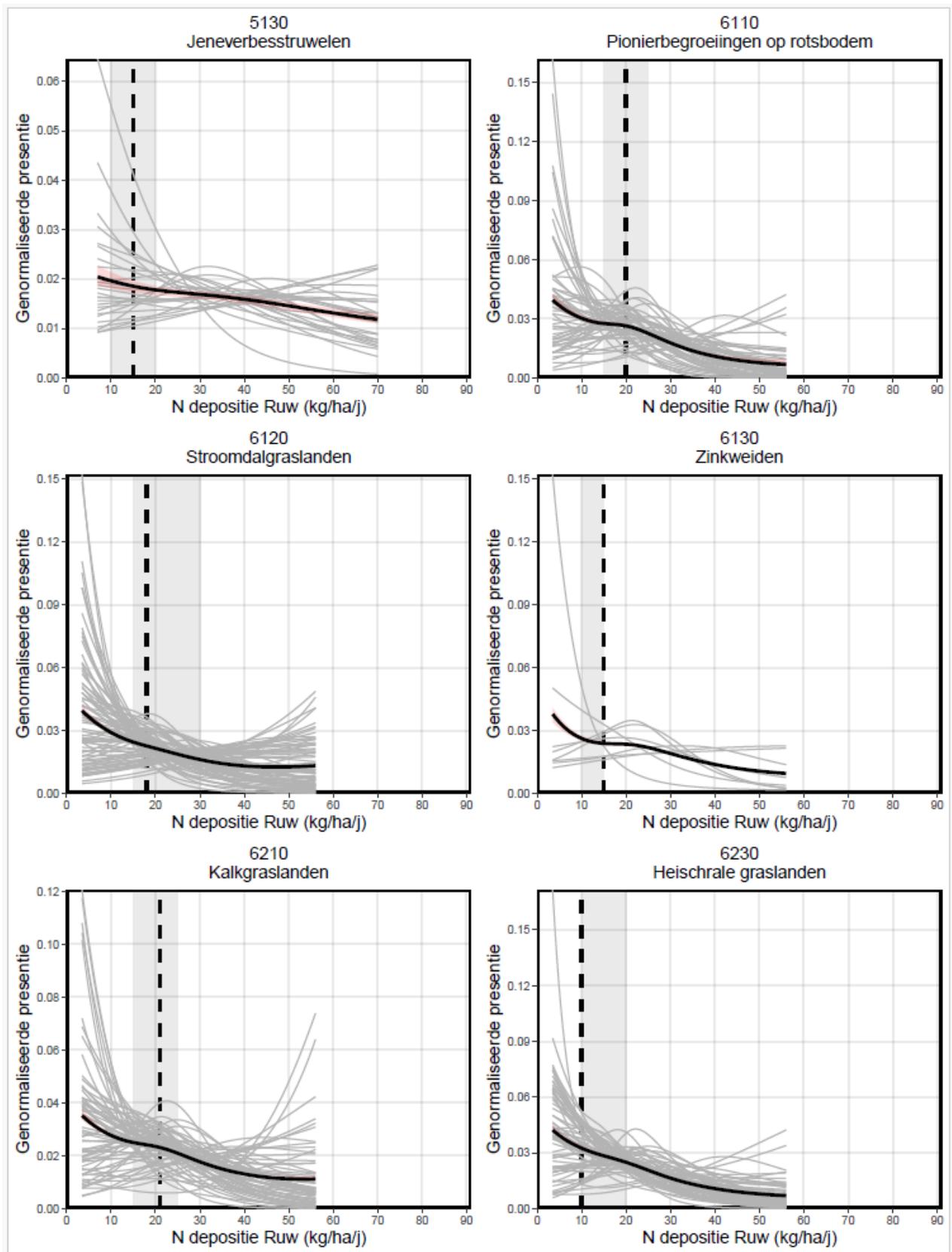


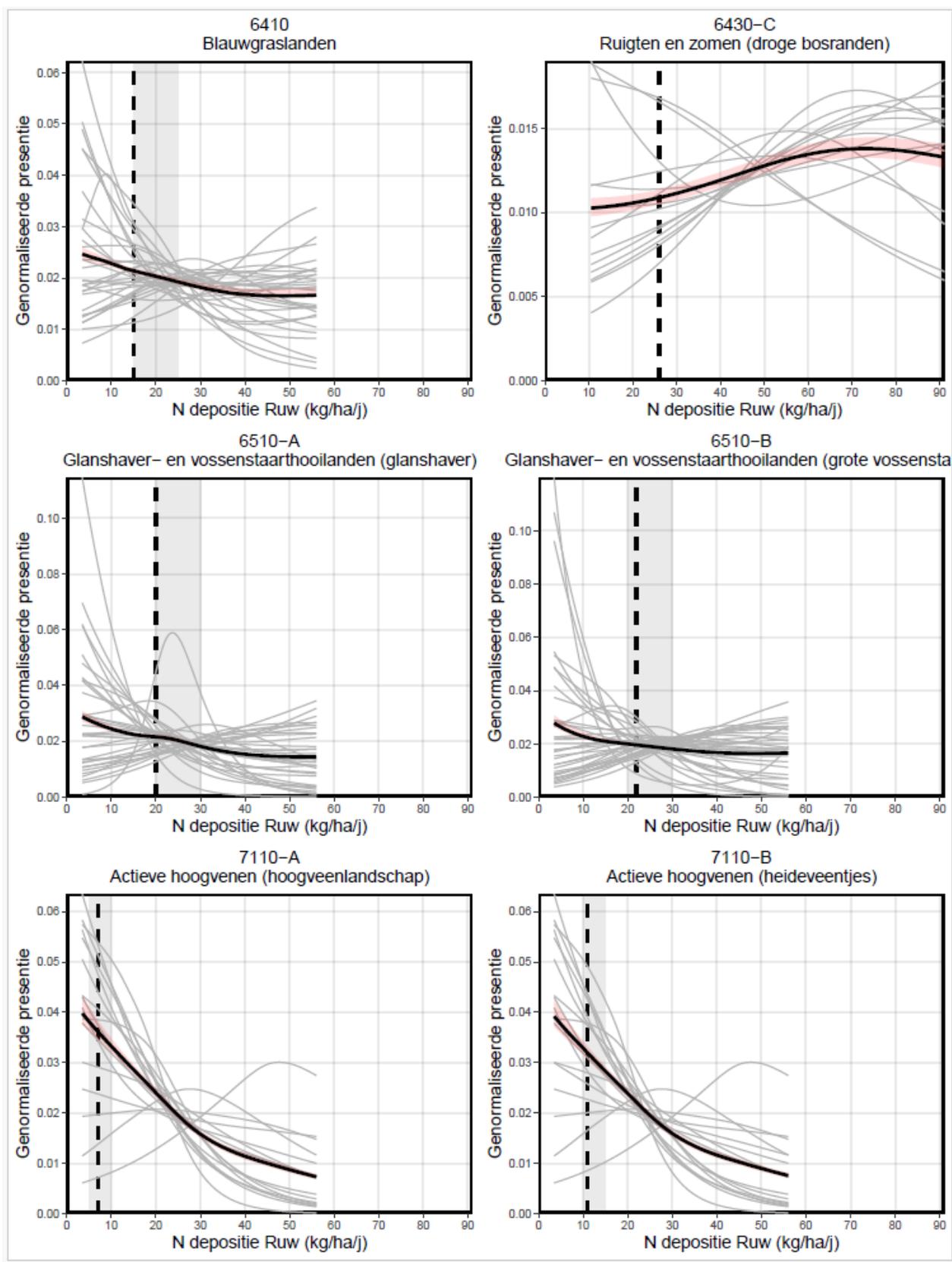


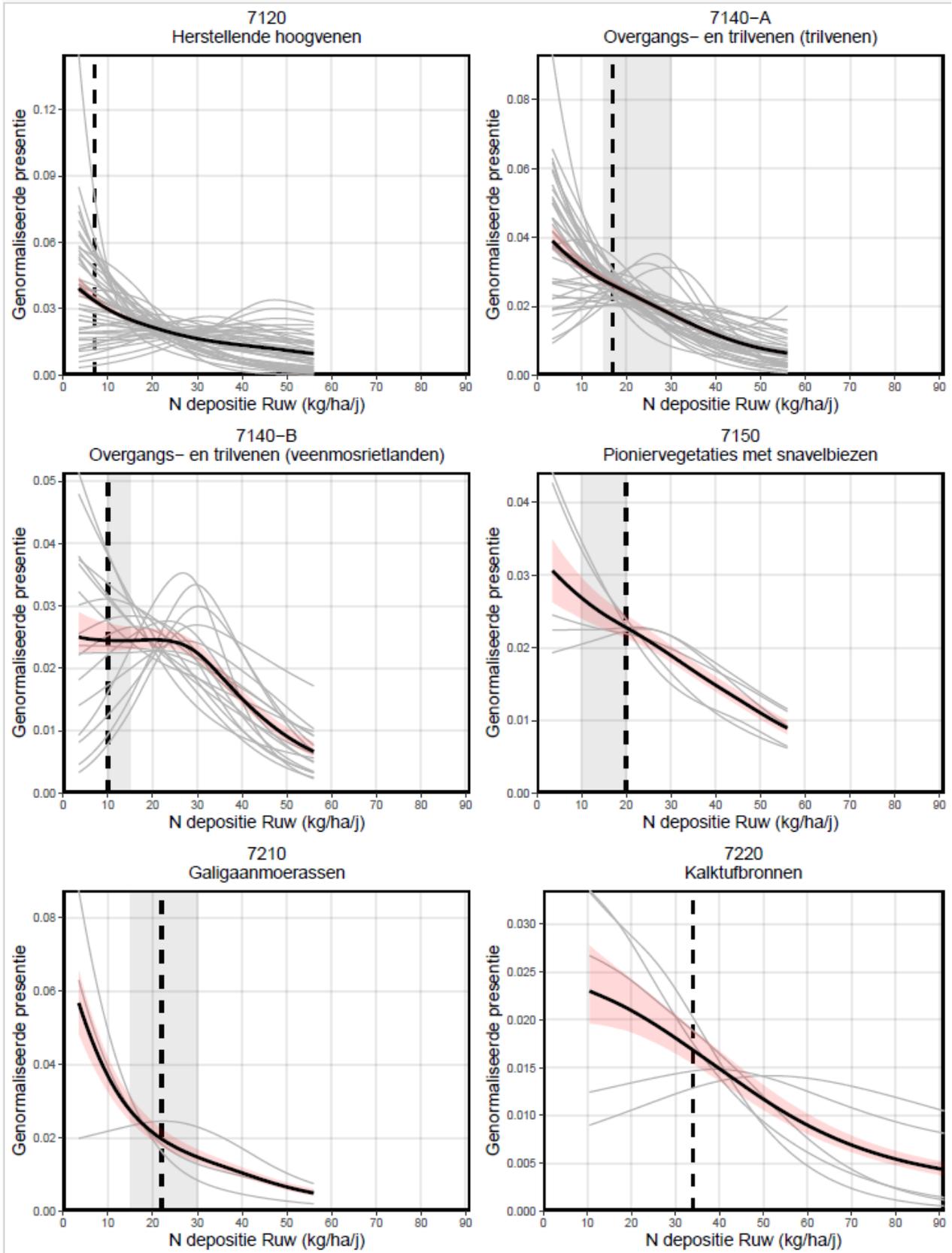


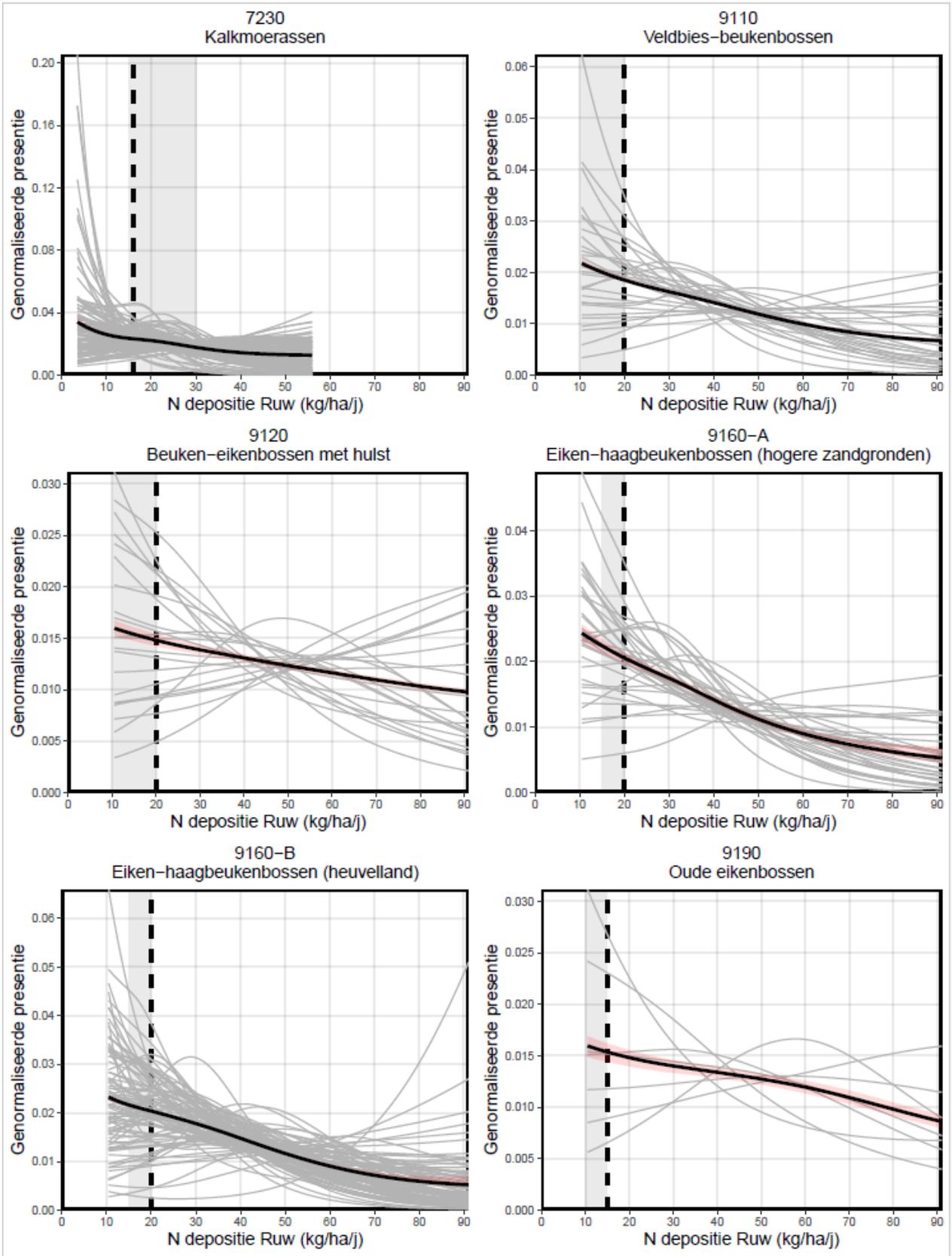


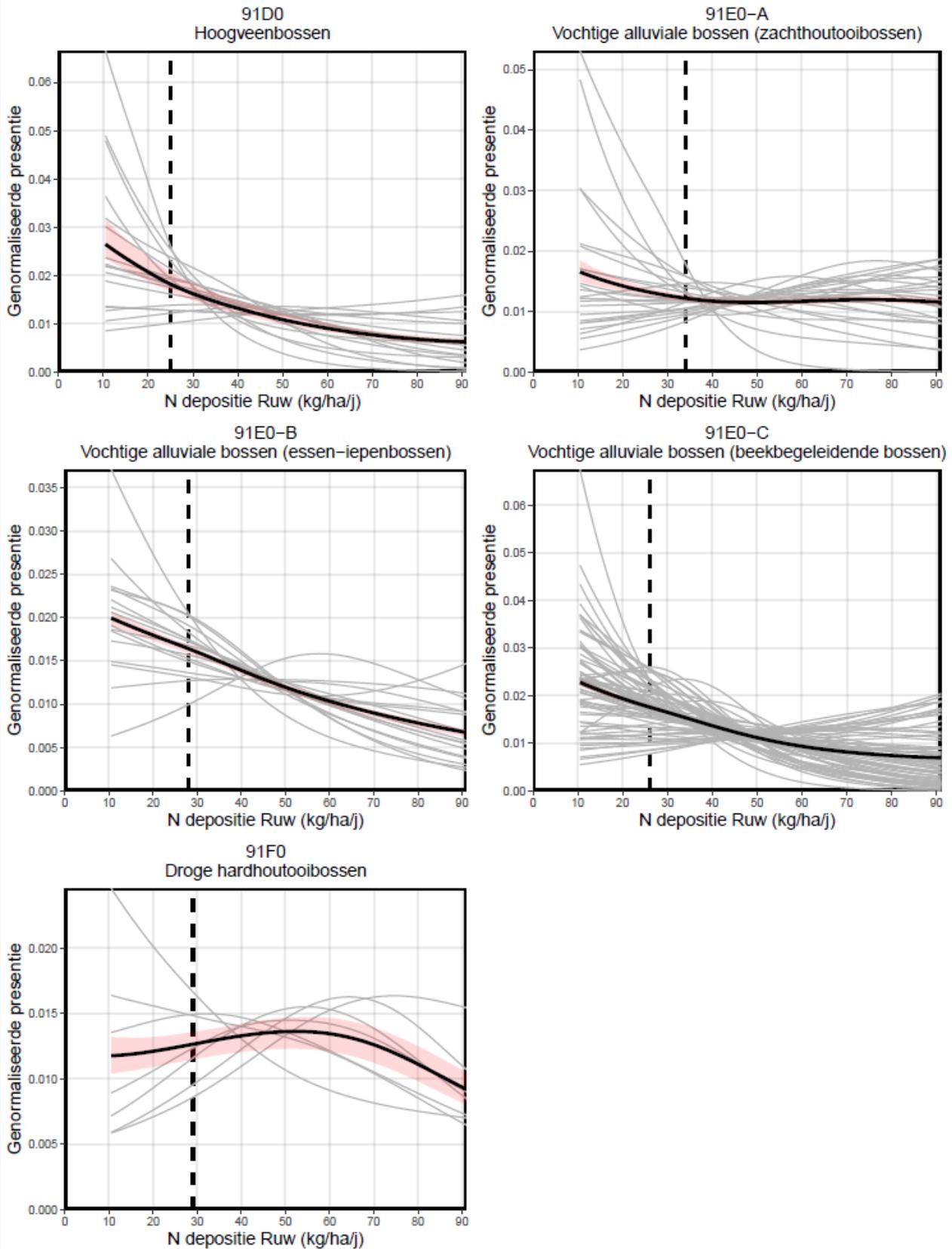








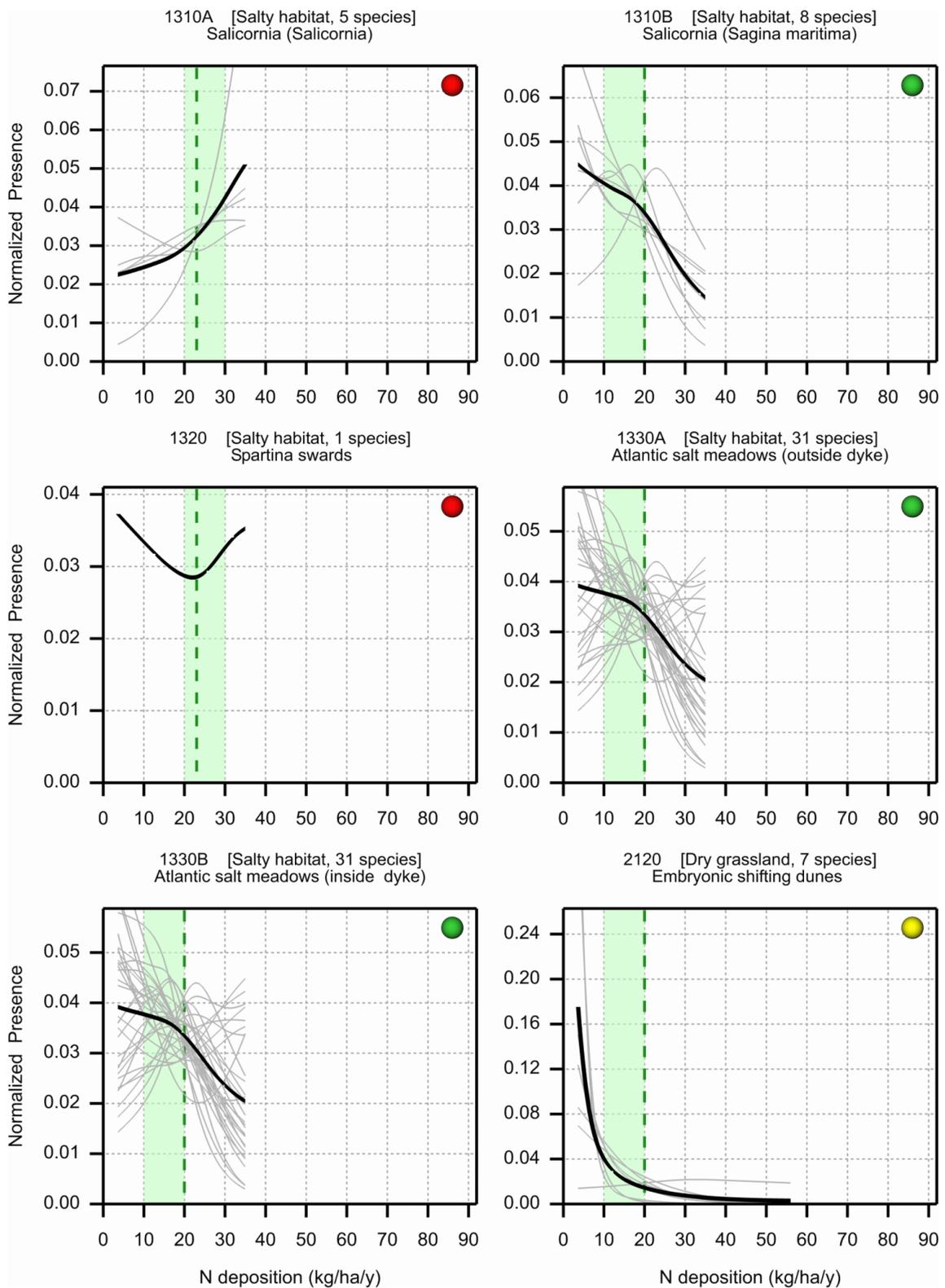


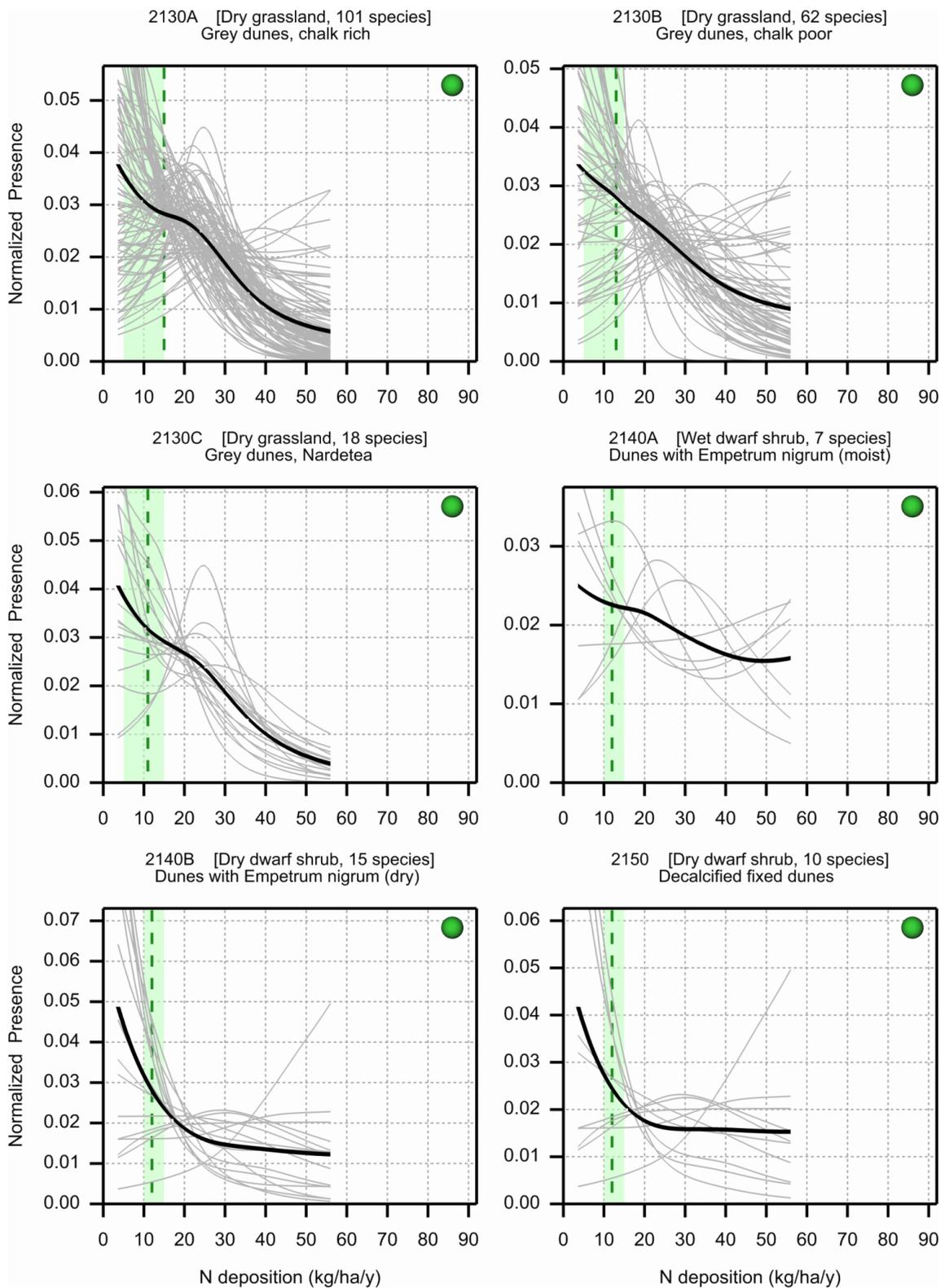


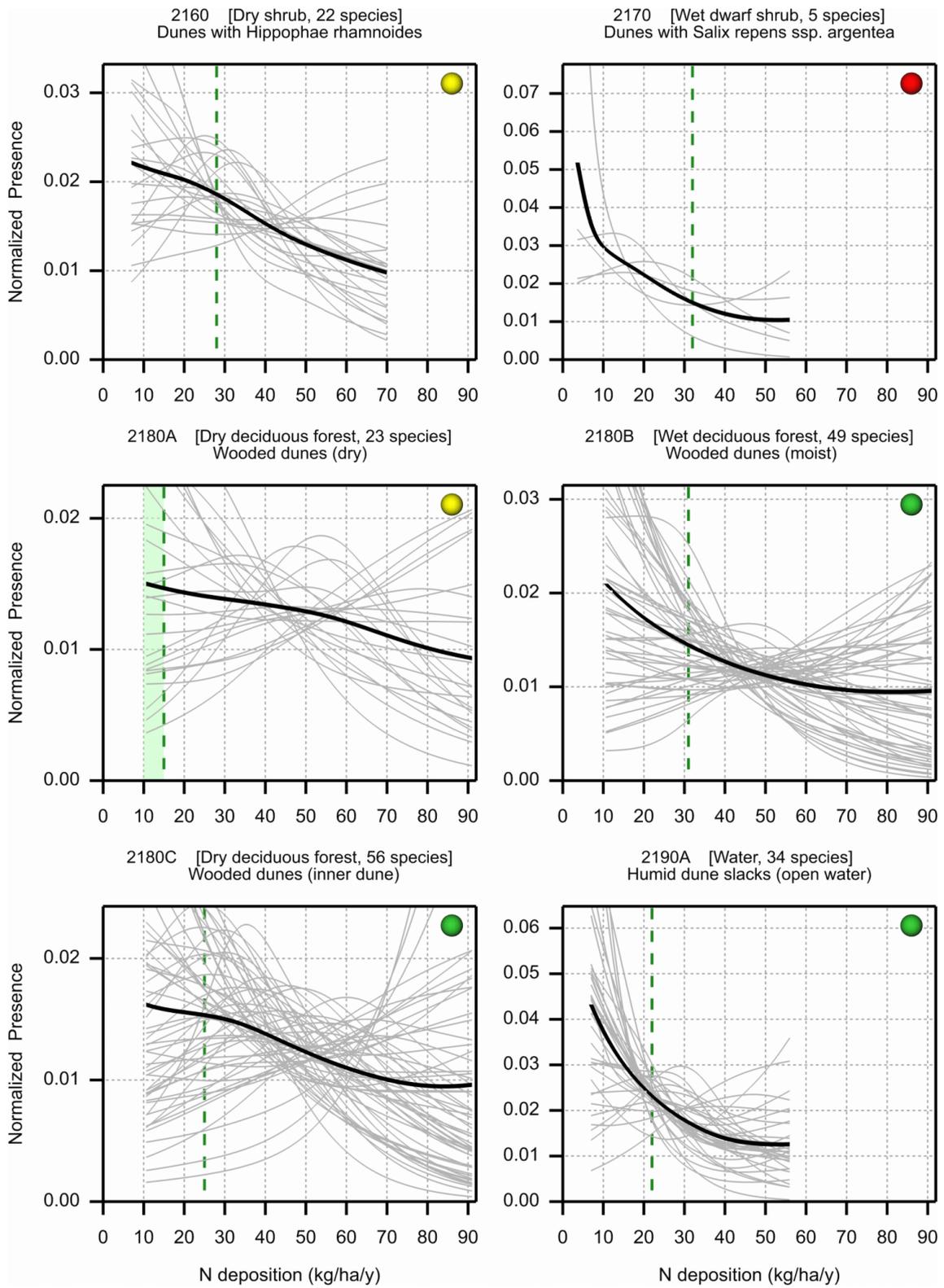
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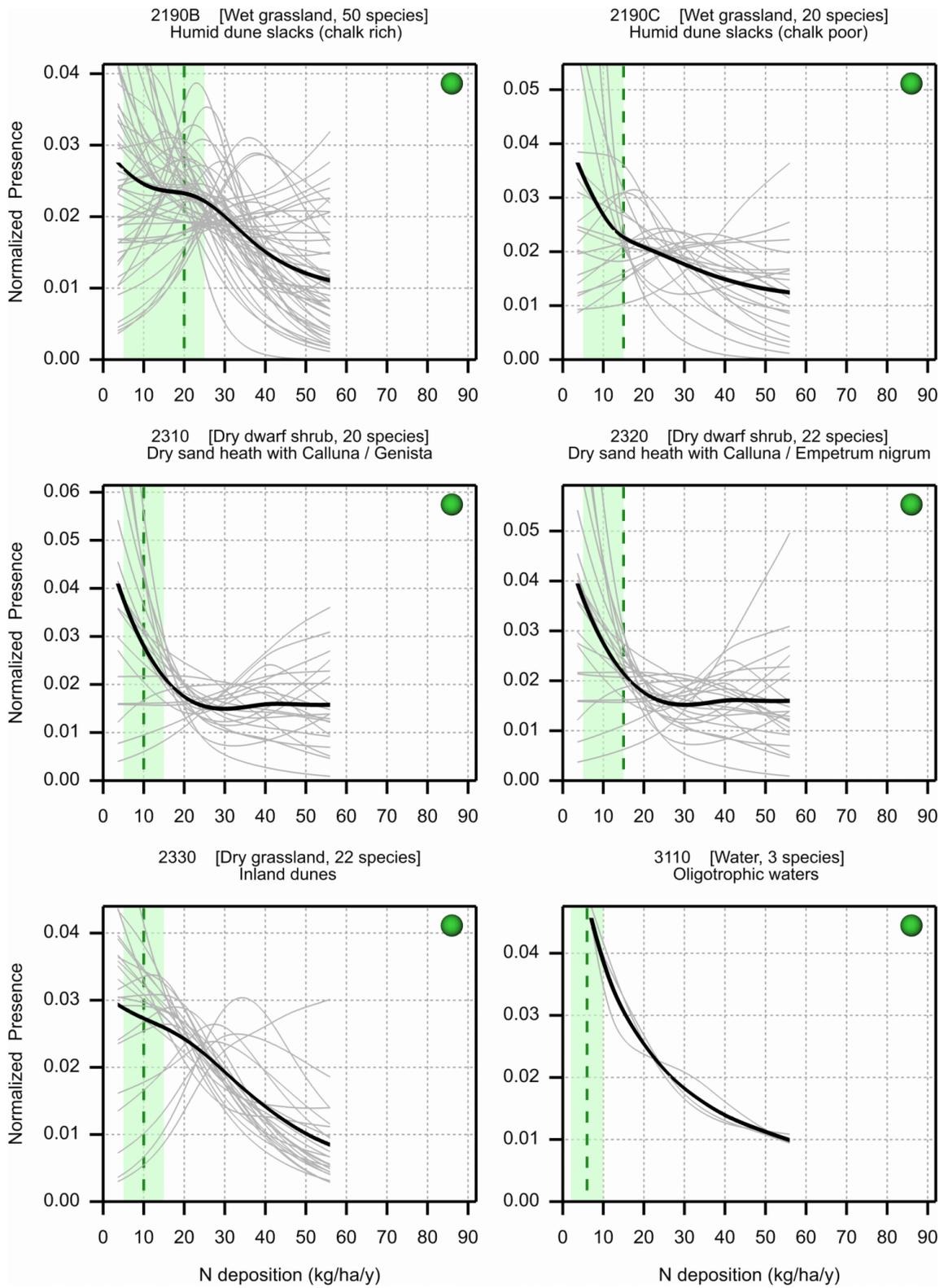
## Appendix 8 Response curves for nitrogen deposition for habitat types with the empirical critical load (Bobbink et al. 2022) and critical load (Wamelink et al. 2023)

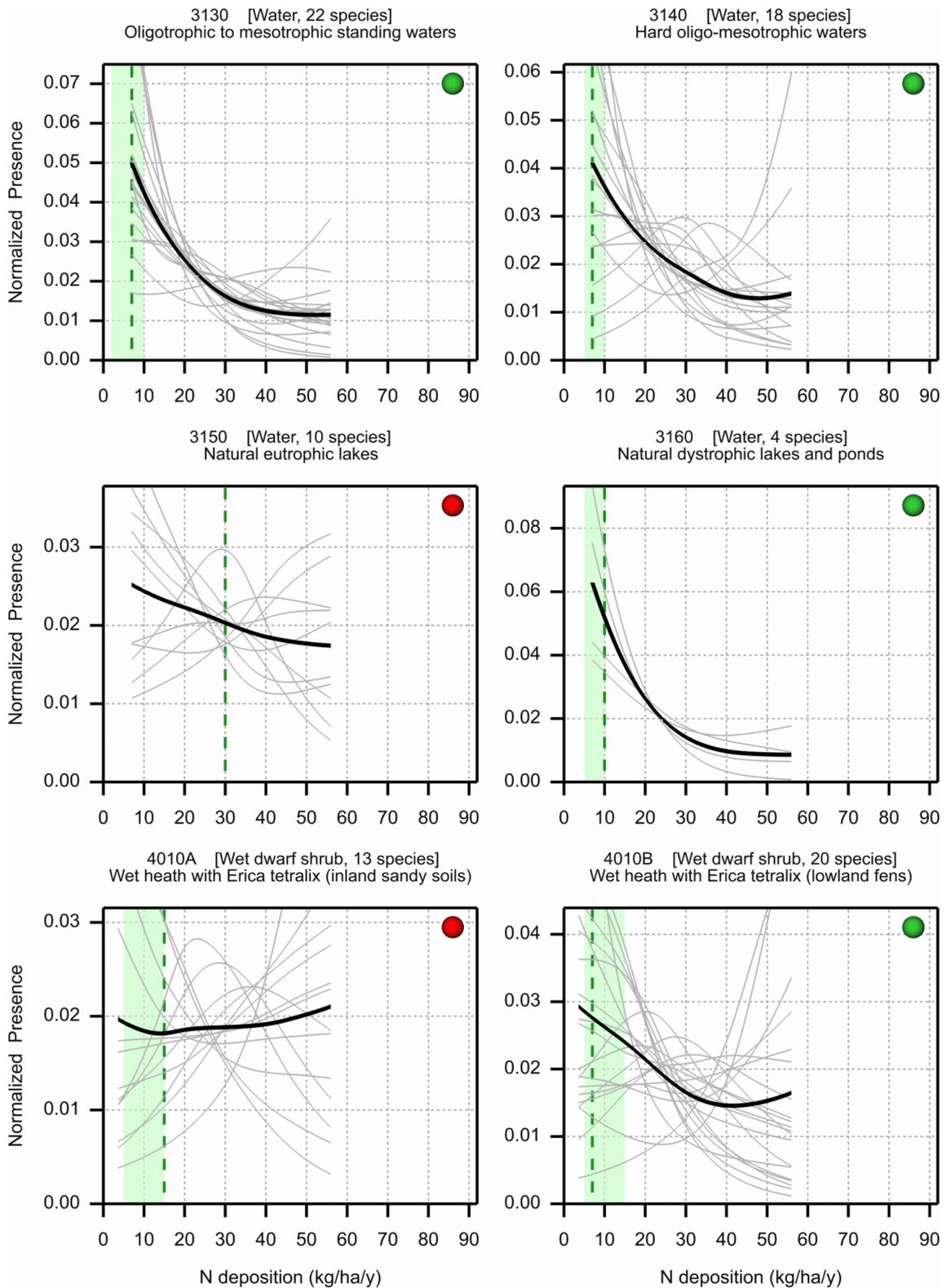
Response curves for habitat types (solid black lines) overlaid on top of the response curves of all the characteristic species (grey line) belonging to the focal habitat type. Other covariates in the model, i.e., mean annual temperature (10.6 °C), annual precipitation (876 mm) and soil type were set to constant values. The dashed vertical green line indicates the critical load (Wamelink et al. 2023), while the green rectangle outlines the empirical critical load range, if available (Bobbink et al. 2022). The heading gives the habitat type number, a short name of the type and between brackets the structure type. The coloured dots give the judgment of the curve by one expert (with green = good, yellow = fair and red = poor). Note that this assessment excludes the improvements made in Doren-2, for an overall assessment, so including new empirical ranges and CLs and improvements based on Doren-2, see Table 5 (chapter 3.3.2).

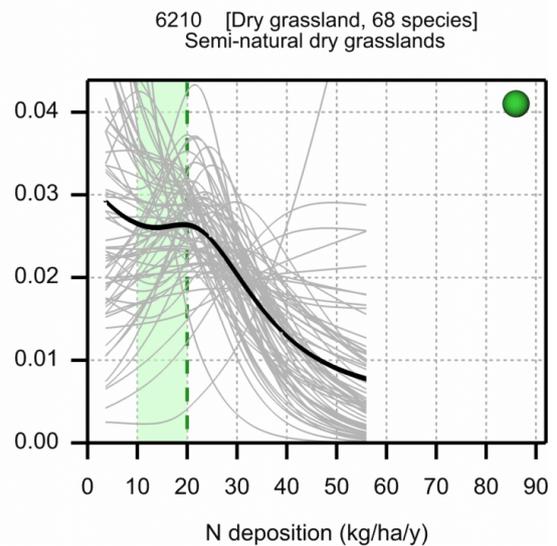
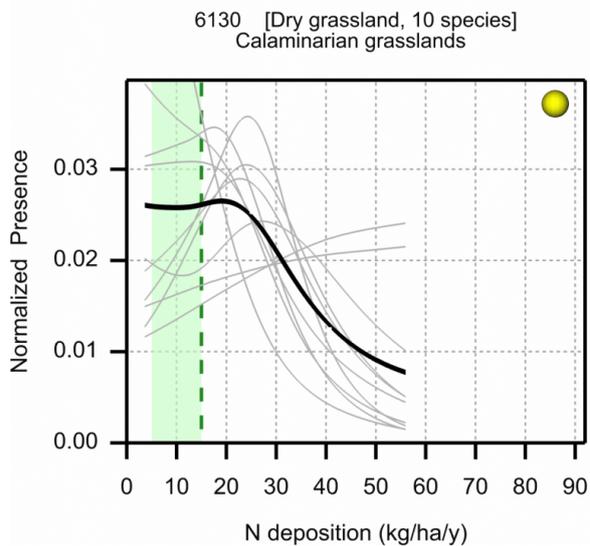
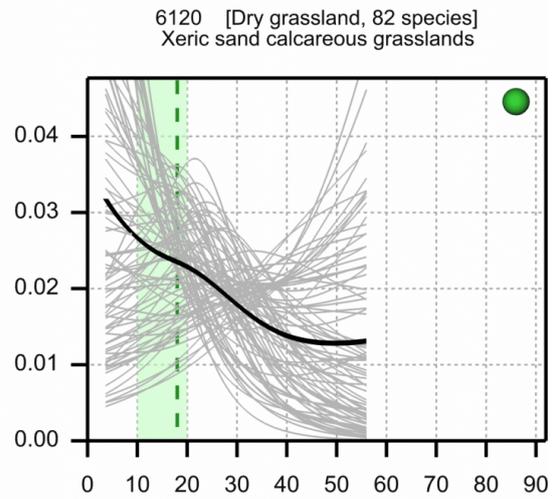
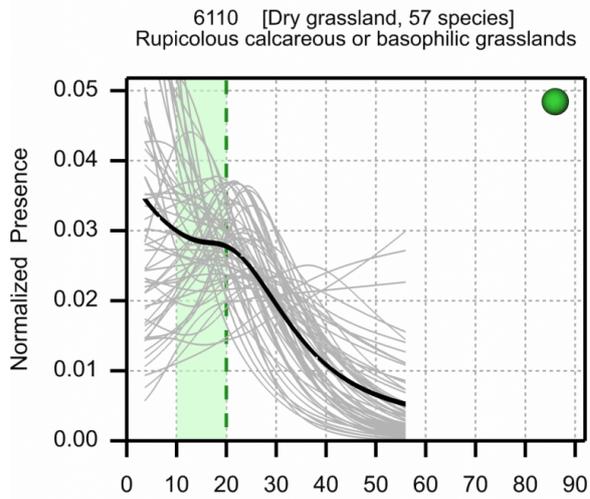
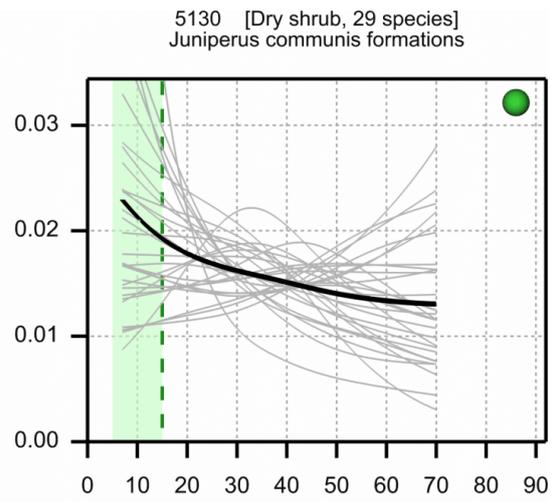
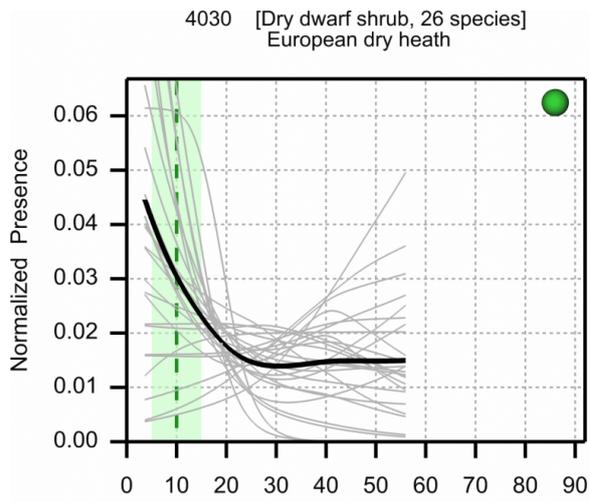


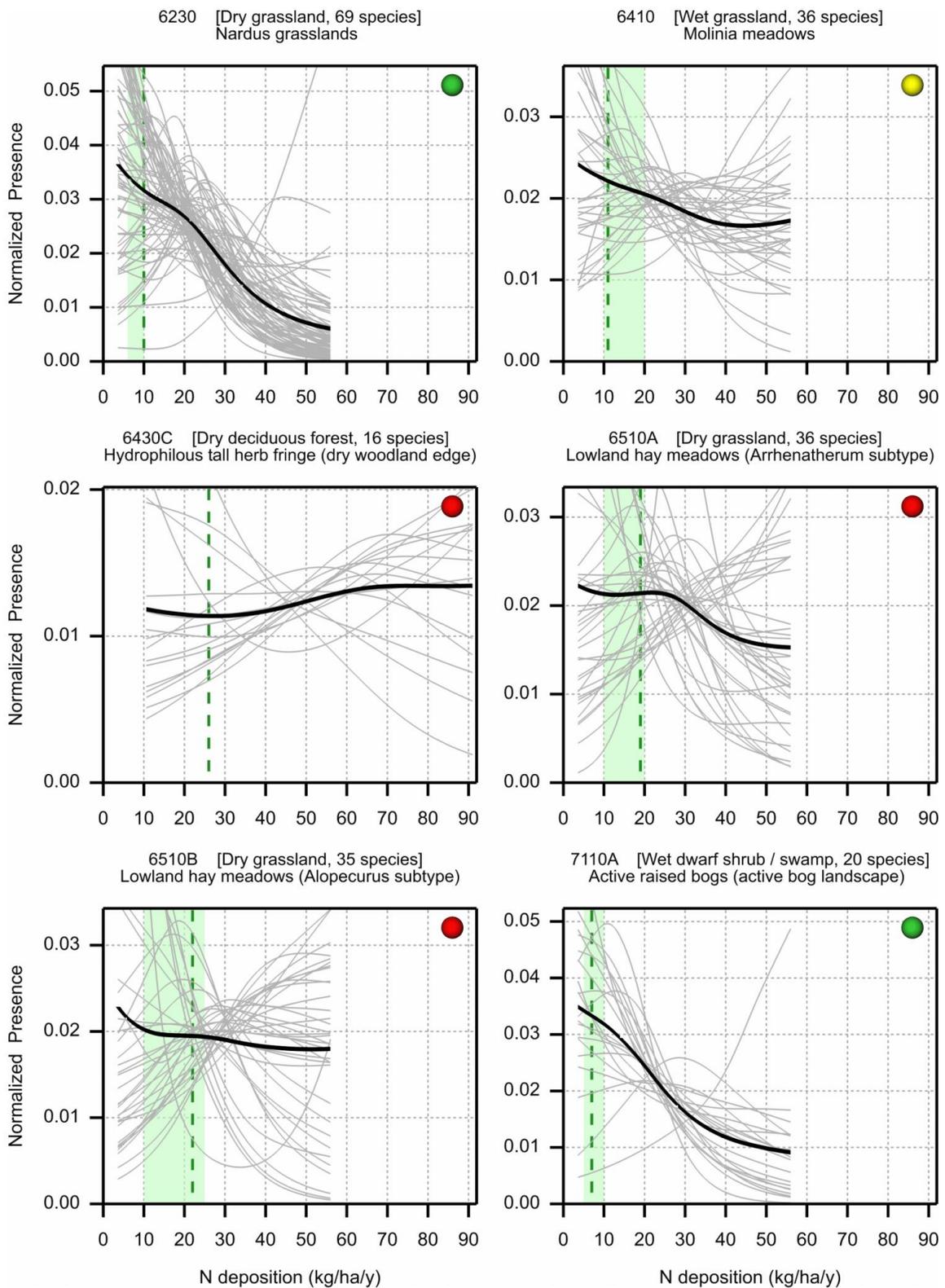


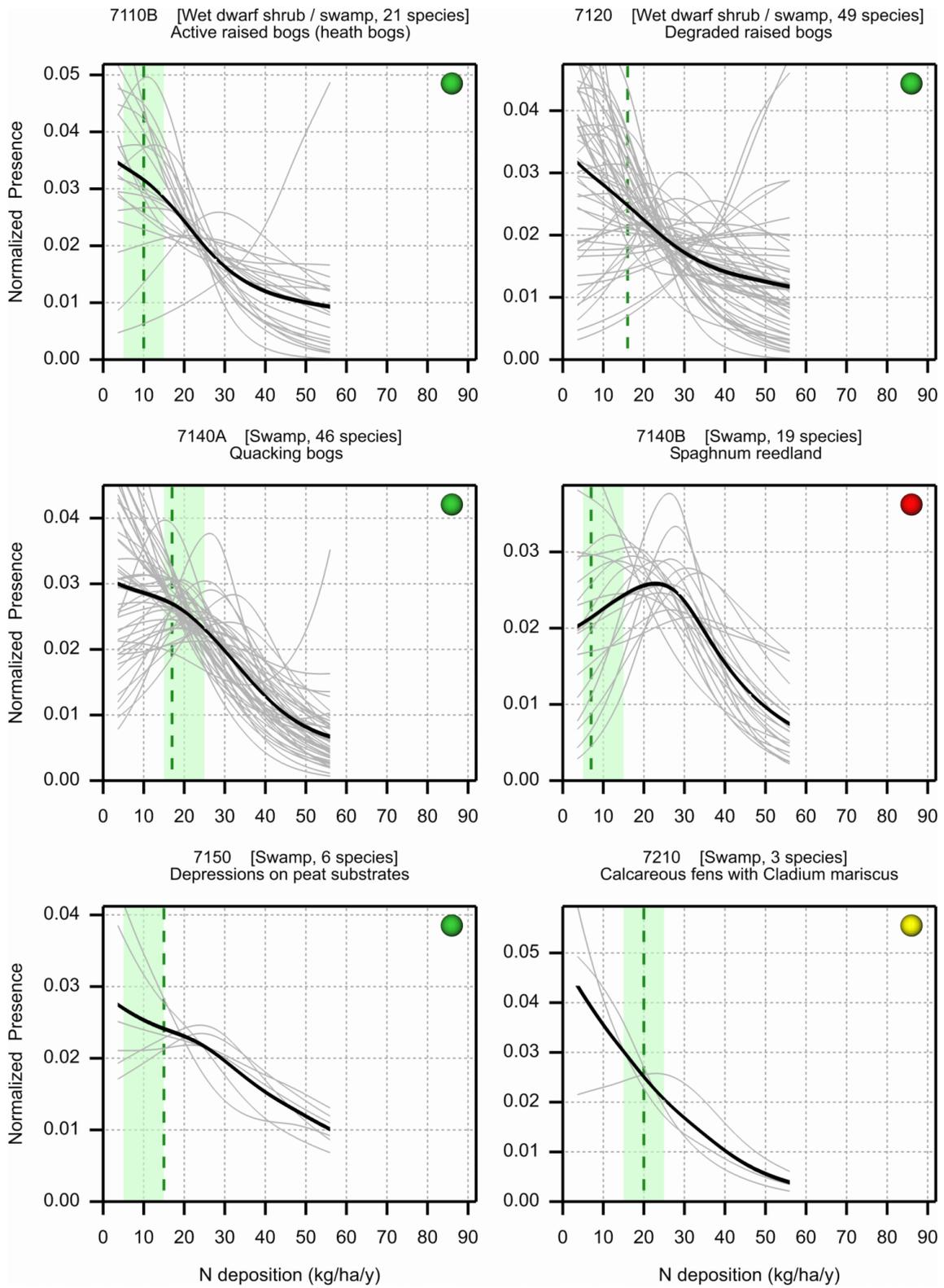


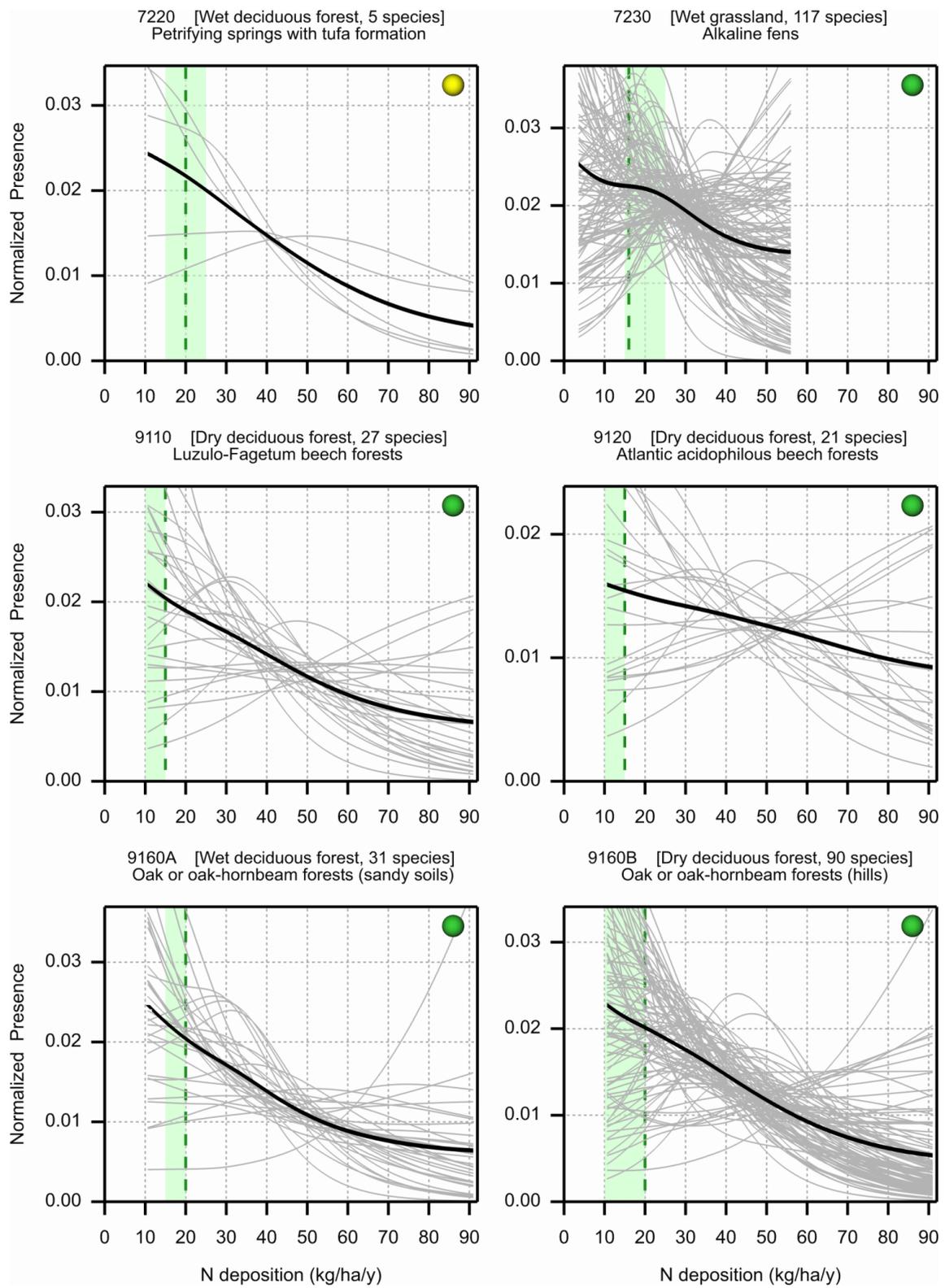


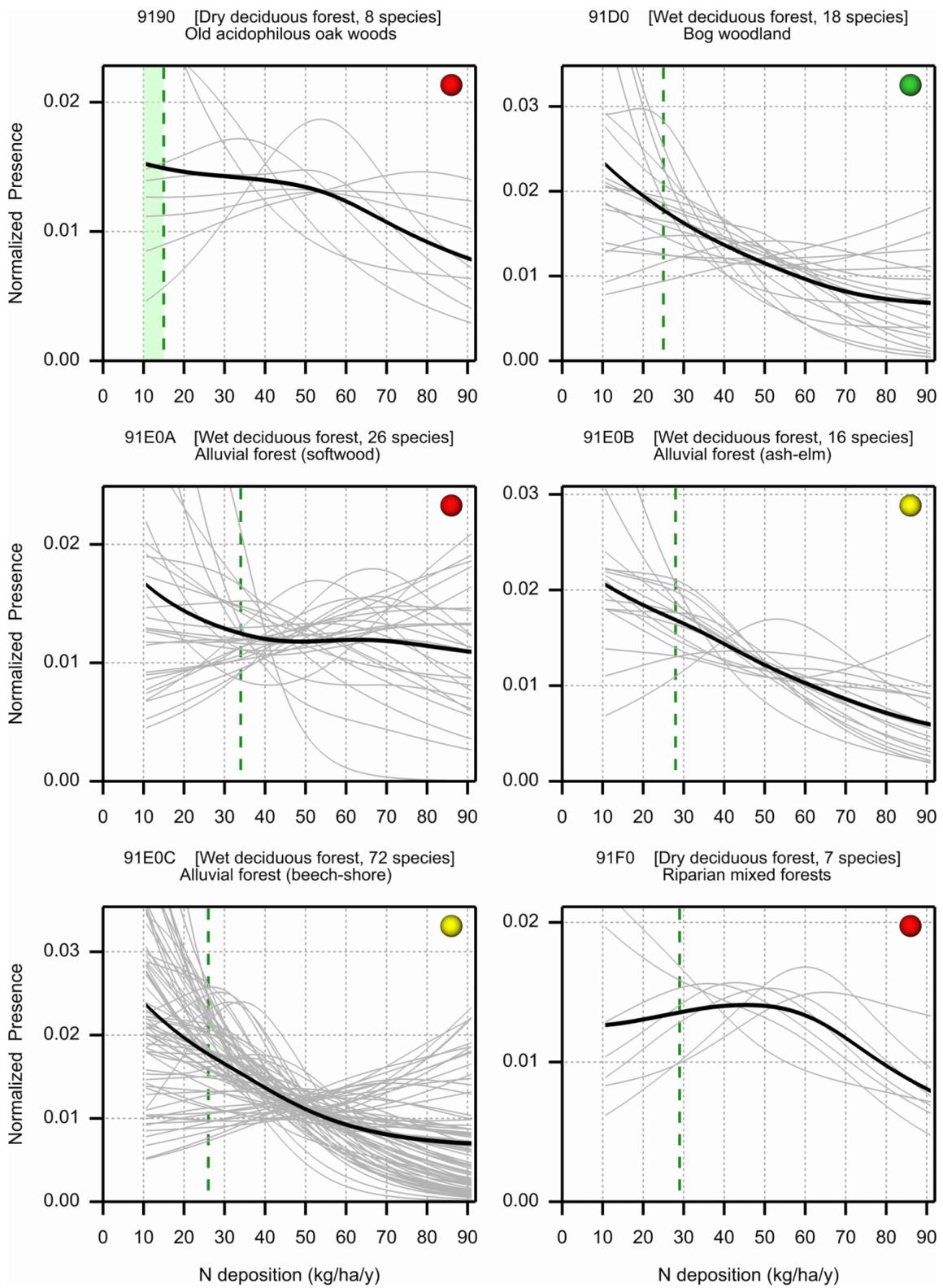








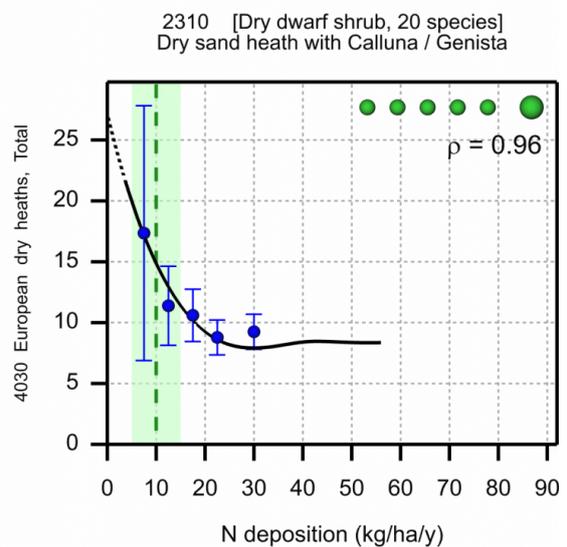
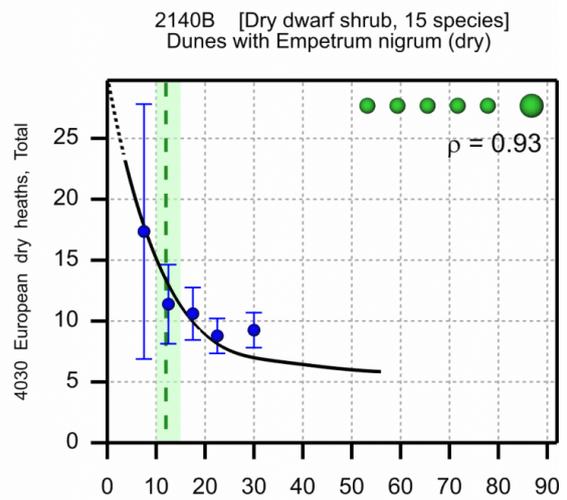
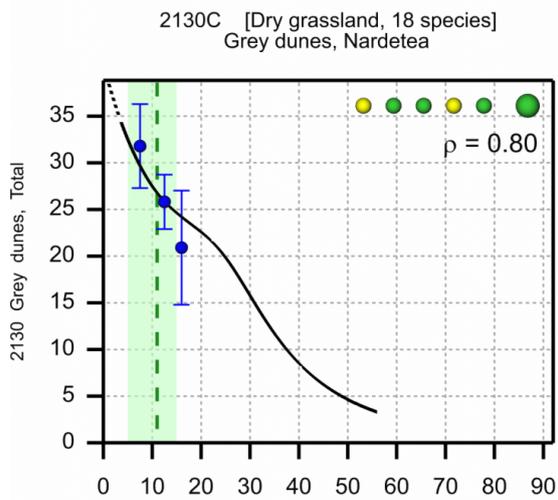
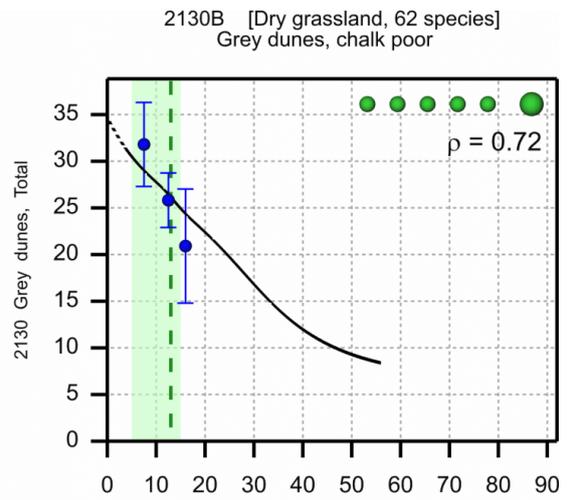
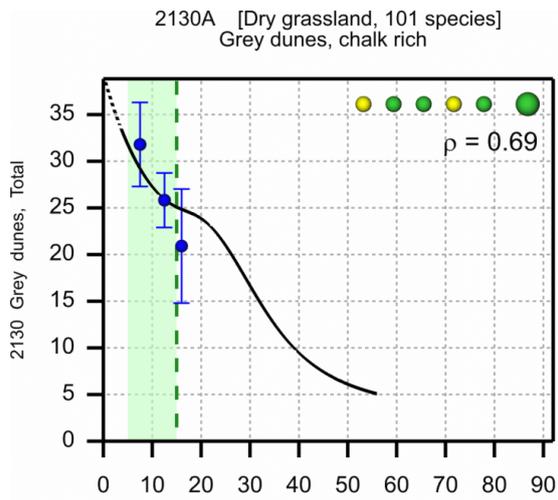


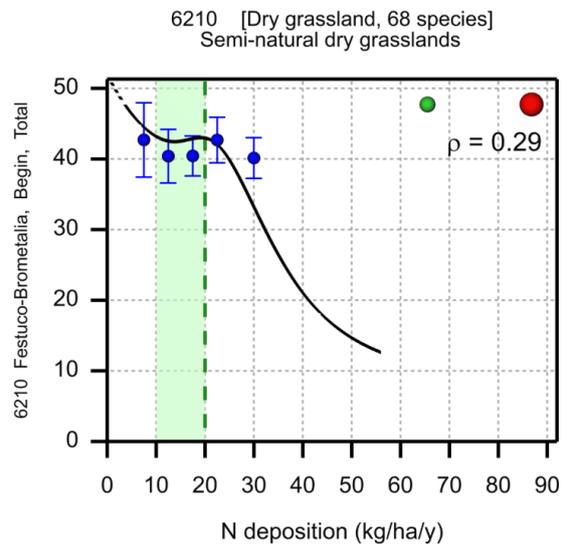
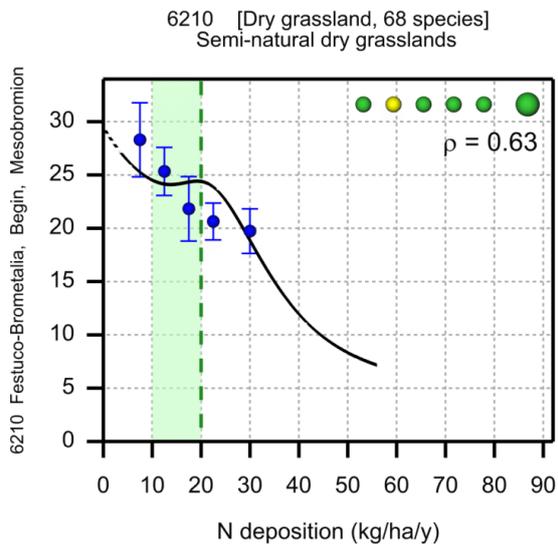
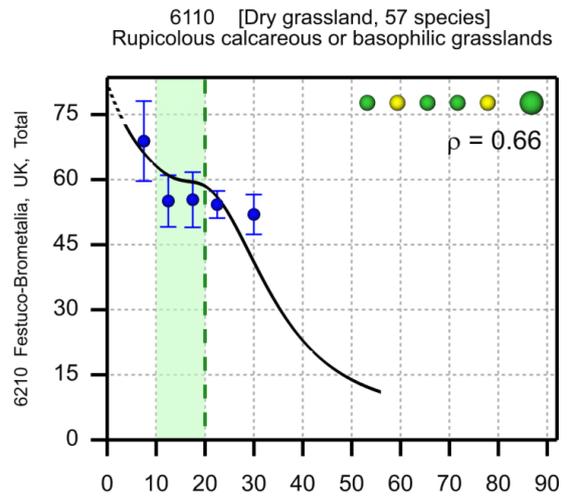
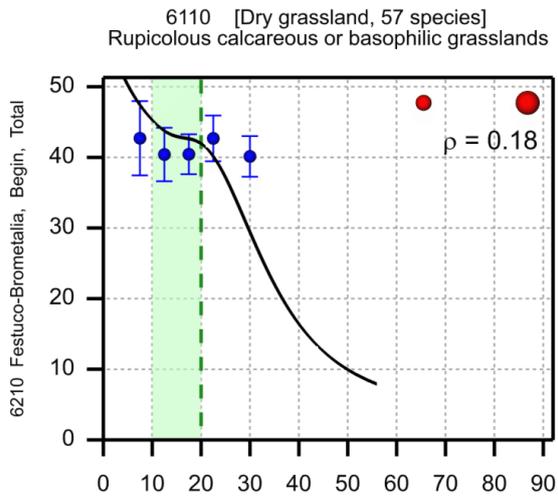
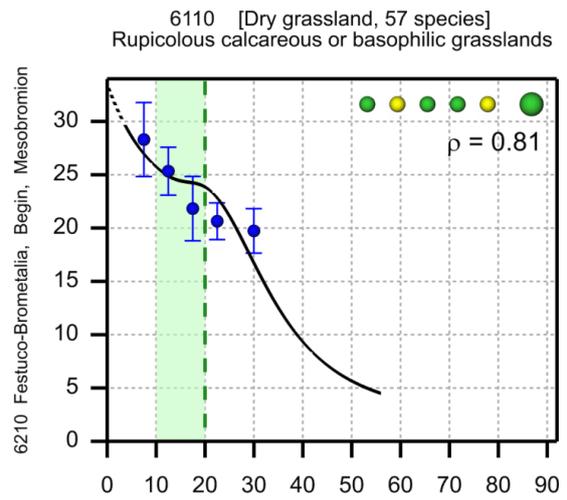
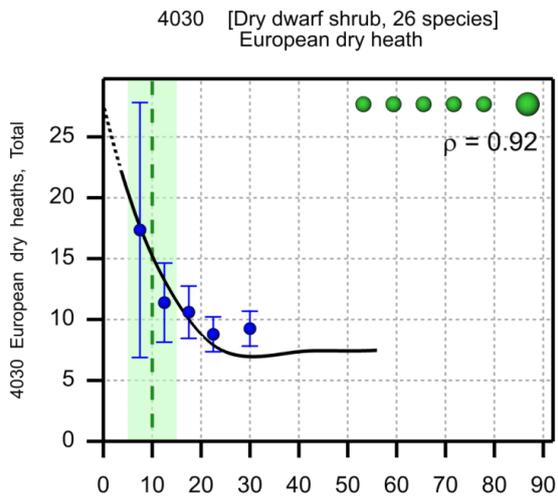


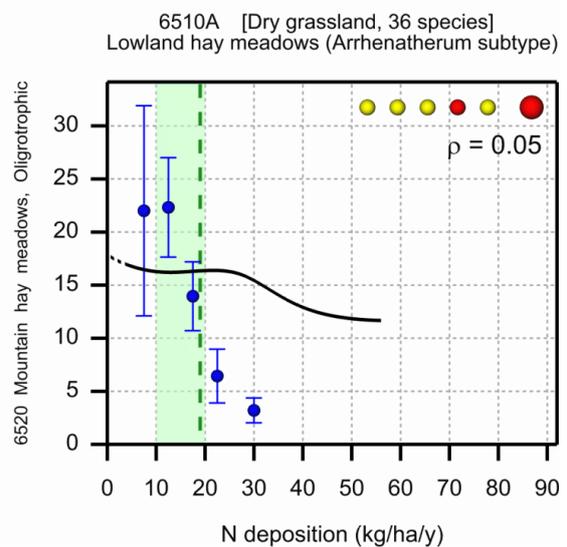
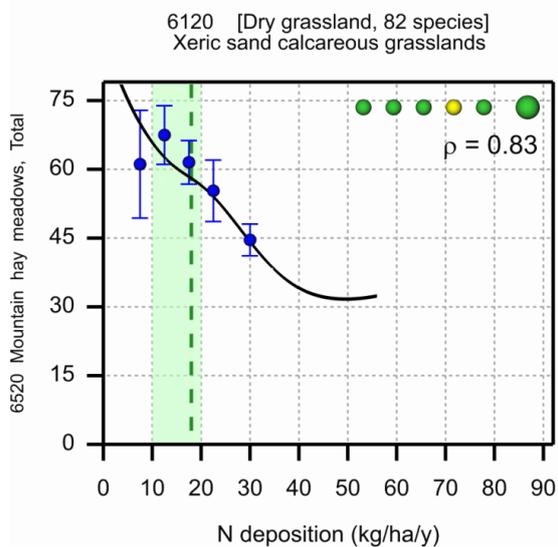
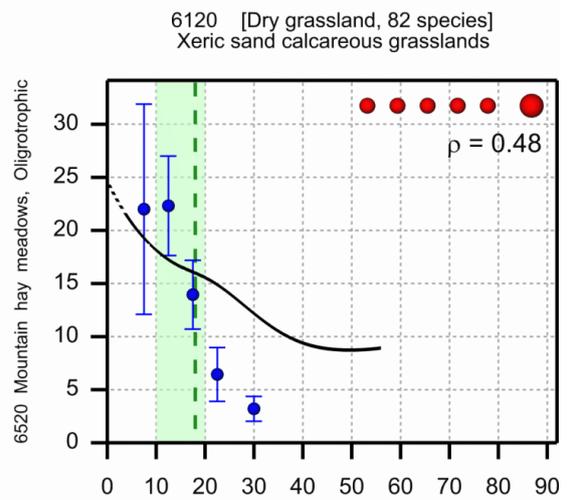
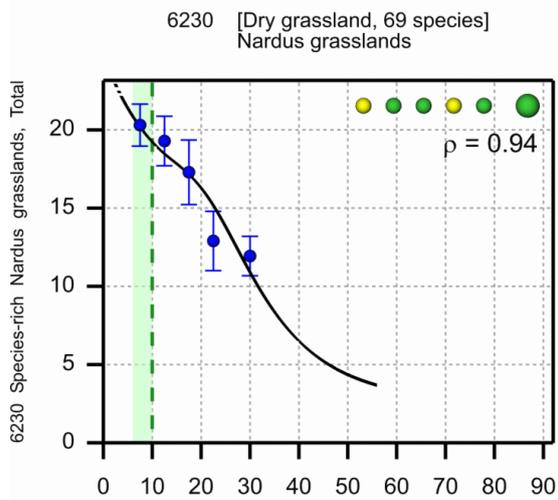
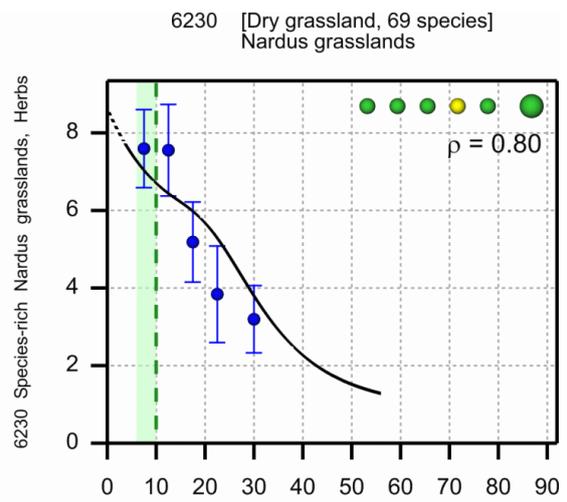
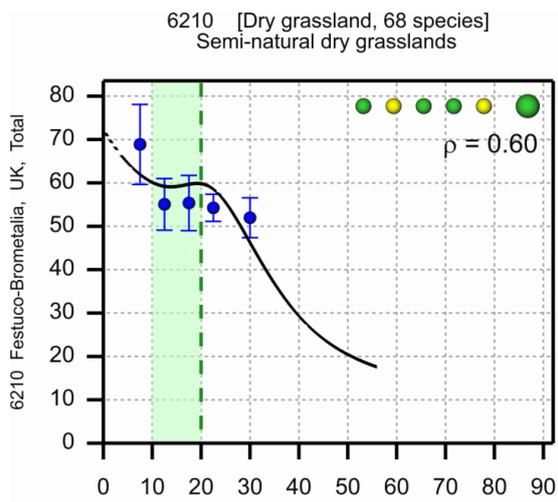
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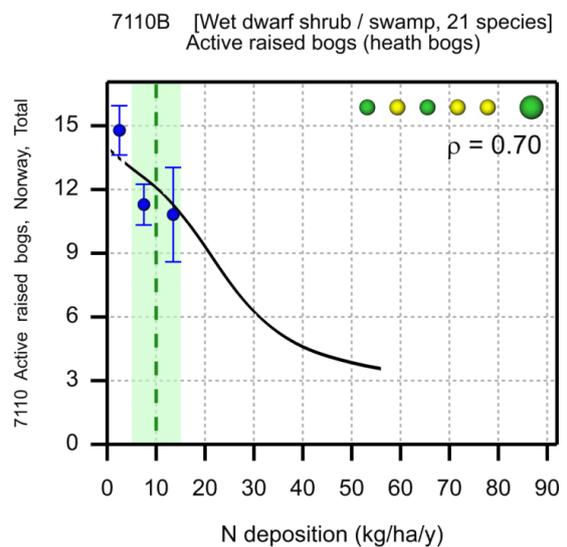
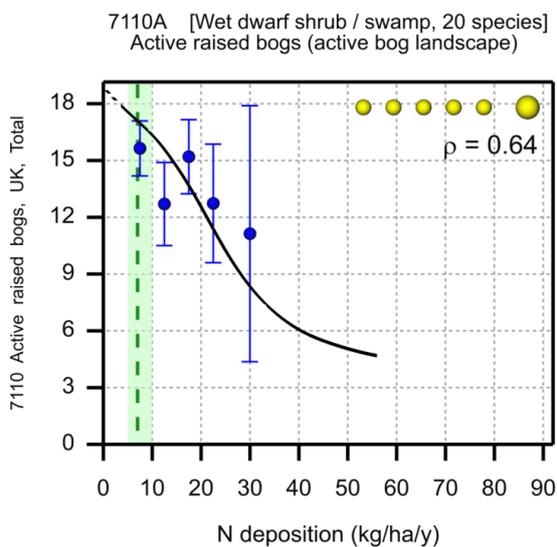
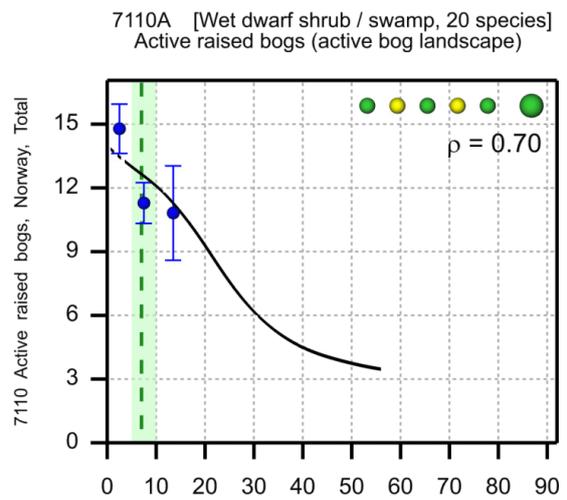
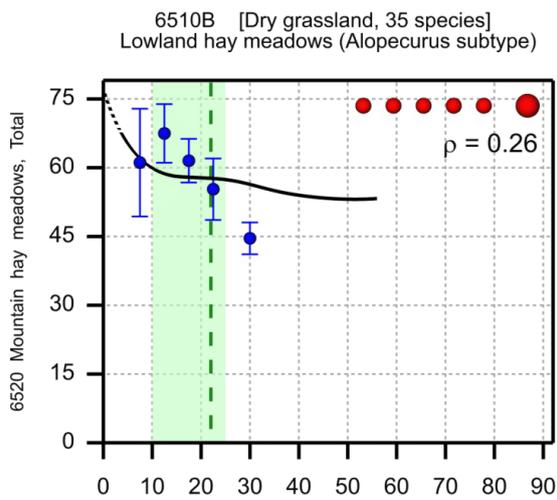
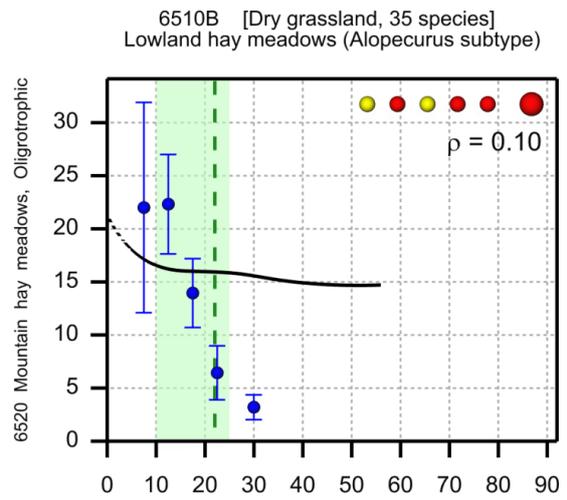
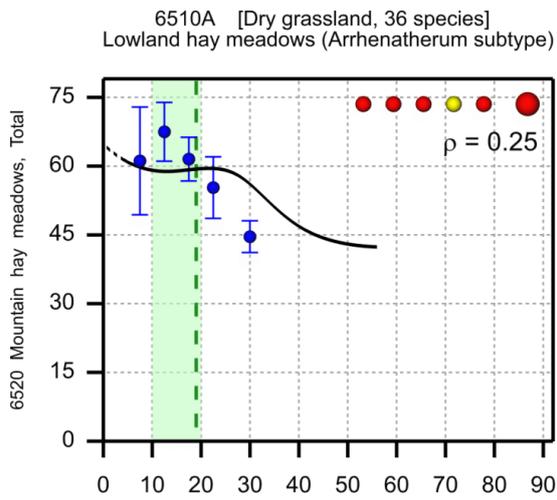
## Appendix 9 Evaluation of the response per habitat type with empirical field data

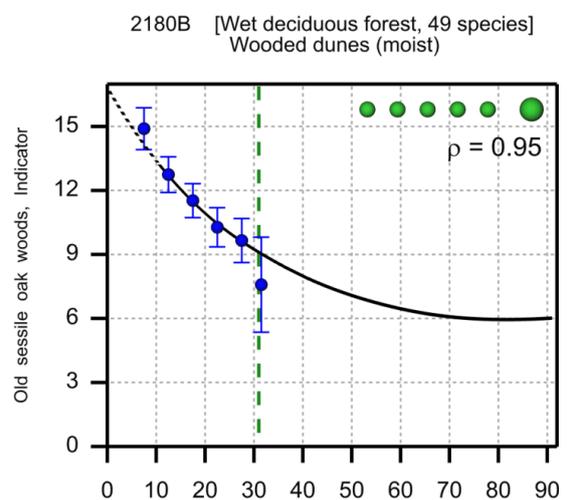
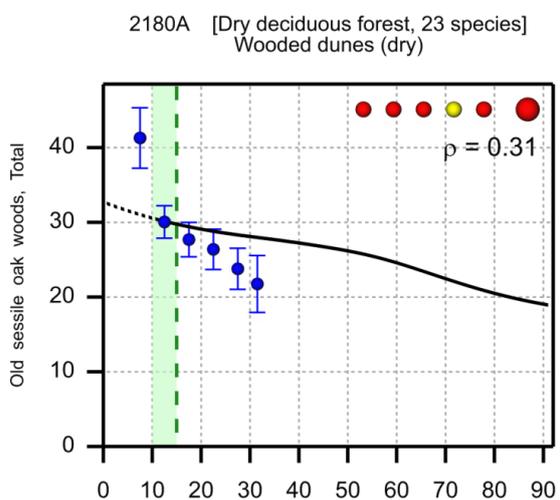
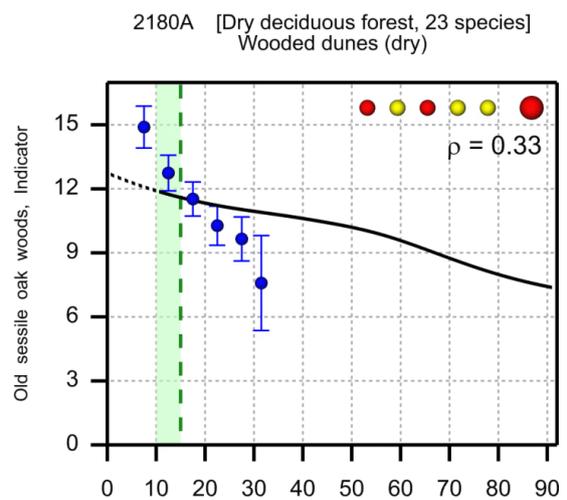
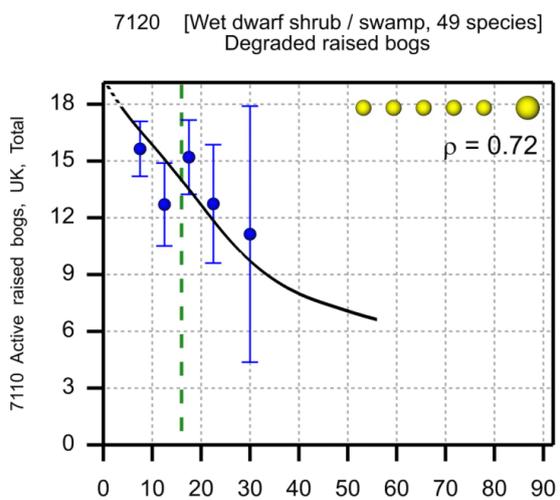
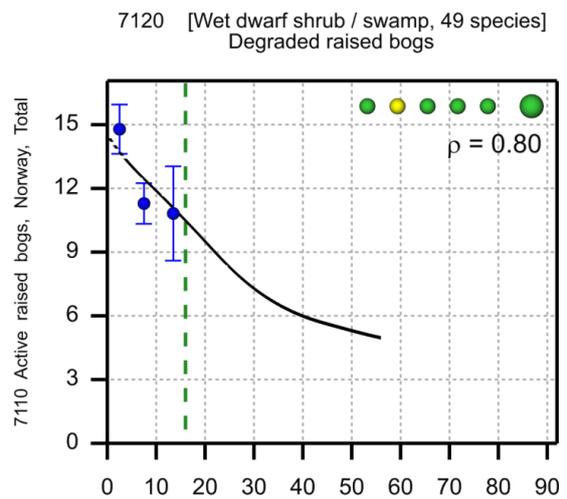
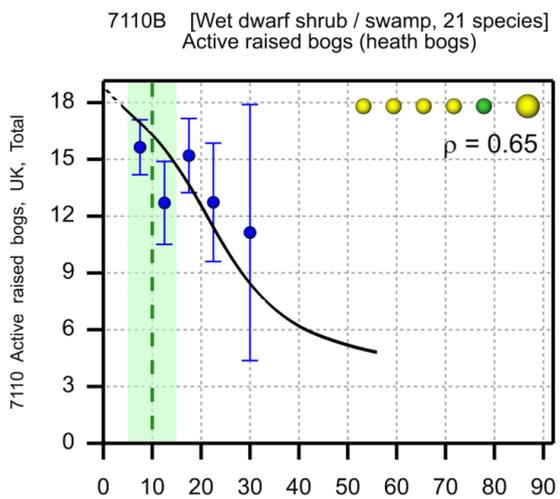
The coloured dots in the upper right corner give the judgement of five experts (green=good, yellow=fair and red=poor) and with a bigger dot for the final score. Also given is Lin's correlation coefficient  $\rho$  of concordance. The dashed vertical green line indicates the critical load (Wamelink et al. 2023), while the green rectangle outlines the empirical critical load range, if available (Bobbink et al. 2022). The blue dots indicate the field data (including 95% uncertainty interval).

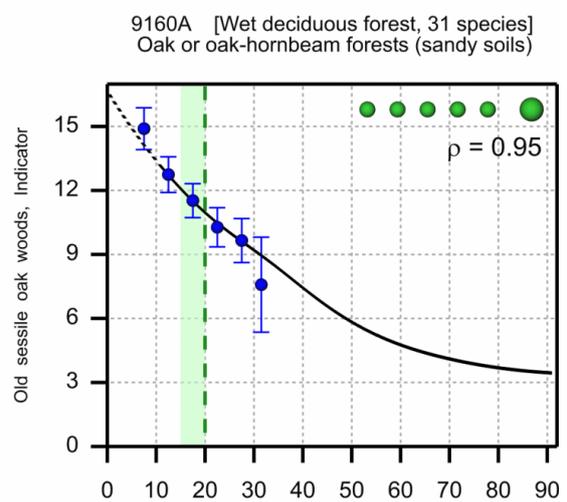
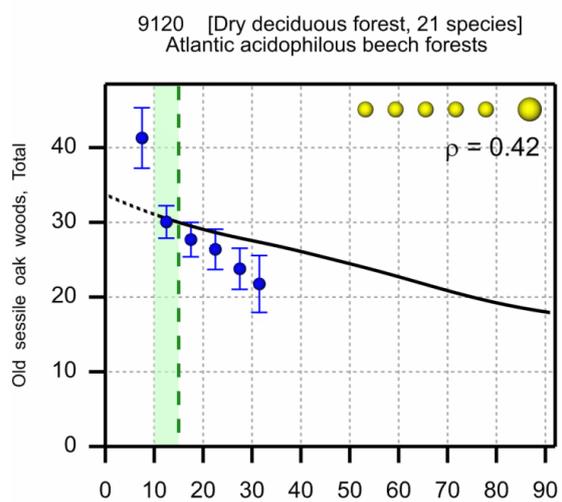
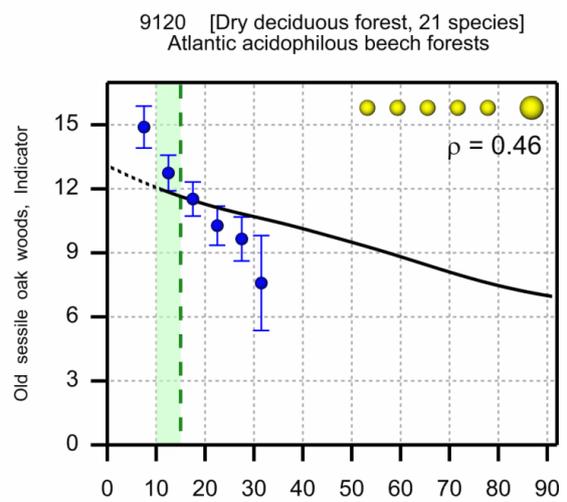
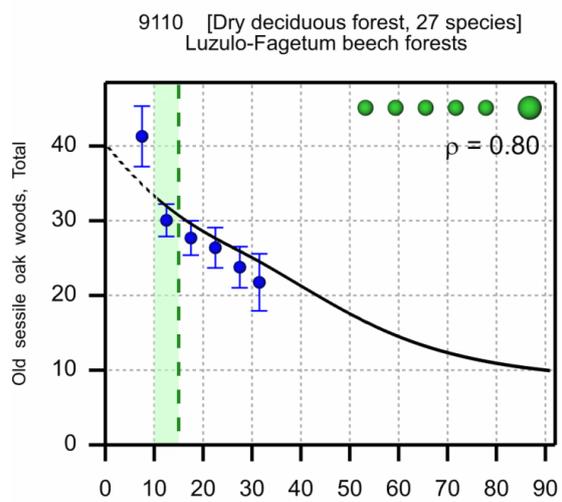
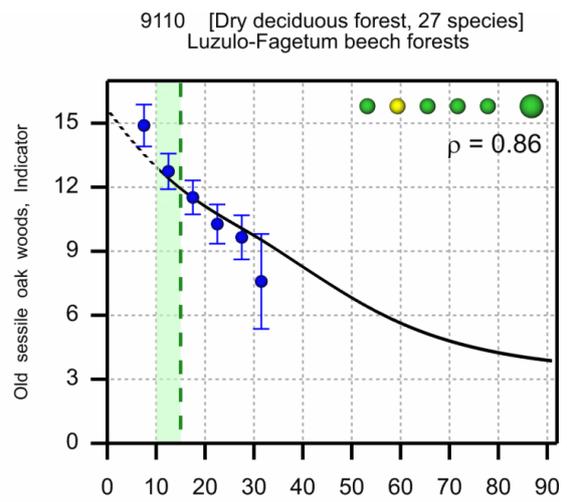
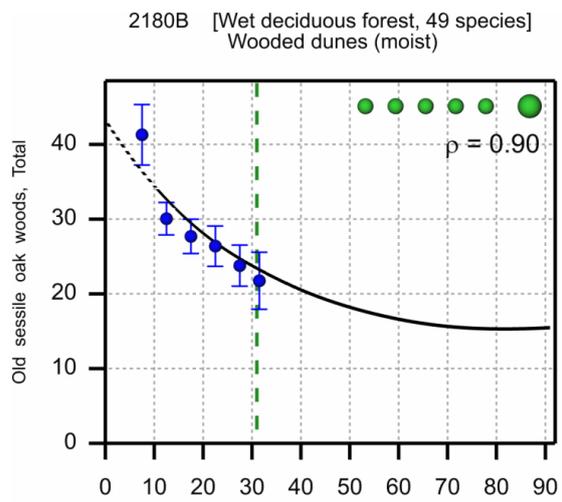






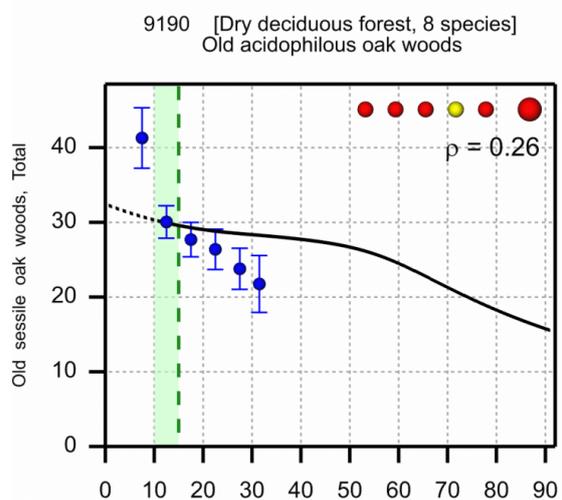
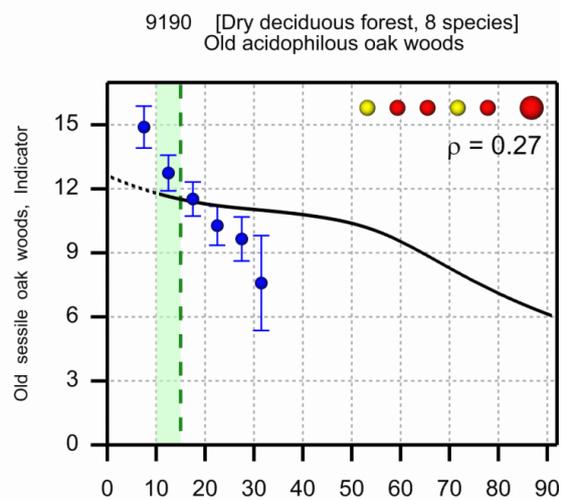
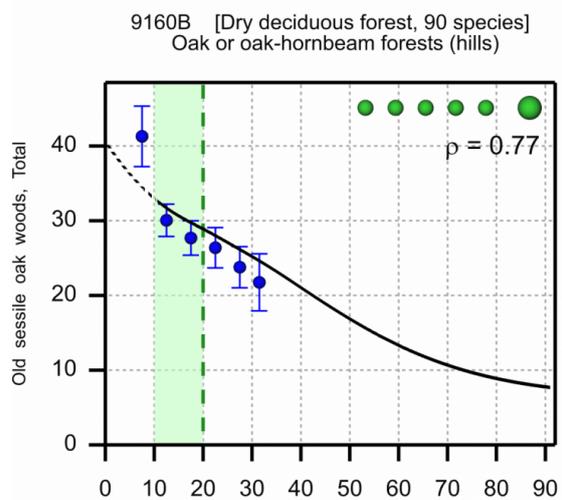
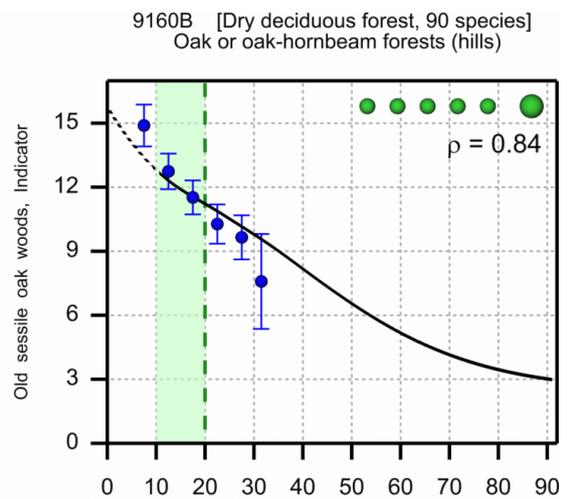
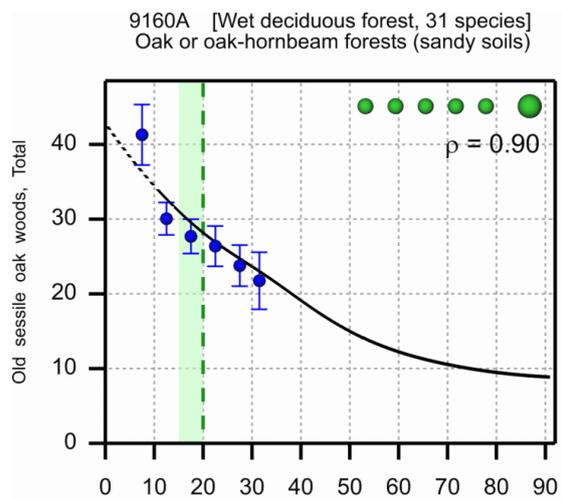






N deposition (kg/ha/y)

N deposition (kg/ha/y)



N deposition (kg/ha/y)

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Wageningen Environmental Research  
P.O. Box 47  
6700 AA Wageningen  
The Netherlands  
T 0317 48 07 00  
[wur.eu/environmental-research](http://wur.eu/environmental-research)

Report 3414  
ISSN 1566-7197



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quality of life



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Wageningen Environmental Research  
P.O. Box 47  
6700 AB Wageningen  
The Netherlands  
T +31 (0) 317 48 07 00  
[wur.eu/environmental-research](http://wur.eu/environmental-research)

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