



BioScore 3 – Plants

Background and pre-processing of distribution data

S.M. Hennekens, W.A. Ozinga & J.H.J. Schaminée

| WOt-technical report 106



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This document contributes to the body of knowledge which will be incorporated in more policy-oriented publications such as the National Nature Outlook and Environmental Balance reports, and thematic assessments.

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Abstract

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Together with PBL Netherlands Environmental Assessment Agency, Wageningen Environmental Research (WEnR) is developing BioScore, a biodiversity model to assess the impact of pressures like climate change, nitrogen deposition and land use change. This report highlights the selection and pre-processing procedures of data concerning the distribution of plant species and habitat types as used in BioScore 3.0 to derive dose-response functions. More than 4,500 European plant species were selected to derive a species set representative for almost all terrestrial (semi)-natural EUNIS habitat types, complemented with ten most common anthropogenic vegetation types (ruderal and arable). Data on distribution of these species were selected from the European Vegetation Archive (EVA). In total 536,900 vegetation plots, covering the 4,500 plant species were extracted from the database to serve as input for BioScore 3. To assess the reliability of environmental responses of plant species, as retrieved from BioScore 3, a comparison has been made with published ecological indicator values (Ellenberg indicator values).

Keywords: BioScore 3, Plants, EVA, European Vegetation Archive, Species distribution, Drivers, Pressures, EIV's, Ecological indicator values.

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Samen met het Planbureau voor de Leefomgeving (PBL) ontwikkelt Wageningen Environmental Research (WEnR) BioScore, een biodiversiteitsmodel om de impact te beoordelen van klimaatverandering, stikstofdepositie en verandering van landgebruik. Dit rapport belicht de selectie en voorbereidingsprocedures van gegevens over de verspreiding van plantensoorten en habitats zoals gebruikt in BioScore 3 om dosis-effect relaties af te leiden. Verspreidingsgegevens van meer dan 4.500 soorten, verdeeld over nagenoeg alle (half)natuurlijk terrestrische EUNIS-habitattypen, aangevuld met tien meest algemene sterk antropogene beïnvloede vegetatietypen (akkers en ruderaal vegetatie), zijn ontleend aan de European Vegetation Archive (EVA). In totaal zijn 536.900 opnamen geselecteerd uit de European Vegetation Archive (EVA) die de verspreiding van de 4.500 soorten representeren. Deze gegevens dienen als invoer voor BioScore 3. Om de betrouwbaarheid te toetsen van de responsies van soorten op omgevingsfactoren, zoals berekend door BioScore 3, is een vergelijking gemaakt met gepubliceerde ecologische indicatiewaarden (Ellenberg indicatiewaarden).

Trefwoorden: BioScore 3, Planten, Zoogdieren, Soortverspreiding, Multivariate regressie modellen, Univariante regressie modellen, EVA, European Vegetation Archive, Drivers, Drukfactoren, EIV's, Ecologische indicatiewaarden.

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Preface

In 2009, the BioScore biodiversity impact assessment tool was developed as part of a research project funded by EC DG Research and Technological Development FP6 (BioScore 1). This project was coordinated by European Centre for Nature Conservation (ECNC) and implemented by a consortium of nine partners. PBL Netherlands Environmental Assessment Agency, together with Wageningen Environmental Research (WEnR), was in charge of the technical development of the BioScore database and web tool. At the time of delivery, it was recognized that BioScore 1 was a first version and that there was much room for improvement. Since then, PBL has been actively using the BioScore tool for a number of Europe-wide scenario studies. Currently PBL is further developing BioScore, so that it can be used for nature assessment studies at national and European level (EU28).

PBL initiated and financed BioScore 2 from 2014 to 2016, which it developed together with some old and new partners. This consortium enabled PBL to deliver a new version of BioScore, that was tested in 2016 and applied in the Nature Outlook-project (<http://themasites.pbl.nl/natureoutlook/2016/>). Information on species distribution and sensitivity to various environmental pressures was brought together and moulded into an improved model together with the following partners:

- European Bird Census Council / Henk Sierdsema, Sovon (NL);
- Butterfly Conservation Europe / Chris van Swaay, Vlinderstichting, (NL);
- European Vegetation Survey / Stephan Hennekens & Joop Schaminée, Wageningen Environmental Research, (NL);
- European Mammal Society / Carlo Rondinini, Sapienza University, (It).

More information on BioScore 1 and 2 is on: <https://www.synbiosys.alterra.nl/bioscore/>. See also Hennekens *et al.* (2015).

In 2017, the BioScore model was further developed into version 3. Due to limited resources, the focus was solely on plant species. Data collection and pre-processing, as well as validation of modelling results, was carried out by WEnR. The work on the modelling, that is computation of statistical relations between environmental conditions and species occurrence, was carried out by PBL. Whereas the focus in BioScore 2 was on Annex I habitat types, in 2017 the EUNIS classification was taken as a broader basis for selecting data and defining biodiversity indicators. As the EUNIS classification covers all of Europe's biodiversity, whereas Annex I only focuses on vegetation types with high biodiversity value. The latter is a list of habitat types (of European importance), not a (pan-European) hierarchic classification system.

In BioScore 2, a univariate approach was chosen to determine the relation between environmental pressures and species occurrences (dose-response functions). Climate and soil predictor parameters were used for drawing up climate-soil envelopes. Dose-response functions for pressures, like N-deposition, were then defined within the boundaries of the envelope. In BioScore 3, all predictors (climate, soil, land use and pressures) are assembled applying a single multiple regression.

Stephan Hennekens, Wim Ozinga en Joop Schaminée

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Summary

Together with PBL Netherlands Environmental Assessment Agency, Wageningen Environmental Research (WEnR) is developing BioScore, a biodiversity model to assess the impact of pressures like climate change, nitrogen deposition and land use change.). This report highlights the selection and pre-processing procedures of data concerning the distribution of plant species and habitat types as used in BioScore 3.0 to derive dose-response functions. More than 4,500 European plant species were selected to derive a species set representative for almost all terrestrial (semi)-natural EUNIS habitat types, complemented with ten most common anthropogenic vegetation types (ruderal and arable).

Data on distribution of these species were selected from the European Vegetation Archive (EVA). First, by using an expert system, in which the EUNIS and additional vegetation types are defined by formal definitions, a large number of the 1.5 million vegetation plots was classified. Subsequently, statistical procedures in JUICE were applied to set up a list of indicator species for each vegetation type. As a result for all habitat types three types of indicator species have been defined; diagnostic species, frequent species and dominant species, a classification that which might be useful to set up biodiversity indicators. In total all three indicator groups comprise 4,500 plant species. Next, in total 536,900 vegetation plots (out of a total of 1,5 million), covering the 4,500 plant species were extracted to serve as input for BioScore 3.

To assess the reliability of environmental responses of plant species, as retrieved from BioScore 3, a comparison has been made with published ecological indicator values (Ellenberg indicator values). Therefore WEnR calculated mean and quartile coefficients indicator values for each of the selected species, PBL has carried out the actual comparison. The results will be published in a scientific paper next year.

Samenvatting

Samen met het Planbureau voor de Leefomgeving (PBL) ontwikkelt Wageningen Environmental Research (WEnR) BioScore, een biodiversiteitsmodel om de impact te beoordelen van klimaatverandering, stikstofdepositie en verandering van landgebruik. Dit rapport belicht de selectie en voorbereidings-procedures van gegevens over de verspreiding van plantensoorten en habitats zoals gebruikt in BioScore 3 om dosis-effect relaties af te leiden. Verspreidingsgegevens van meer dan 4.500 soorten, verdeeld over nagenoeg alle (half)natuurlijk terrestrische EUNIS-habitattypen, aangevuld met tien meest algemene sterk antropogene beïnvloede vegetatietypen (akkers en ruderaal vegetatie), zijn ontleend aan de European Vegetation Archive (EVA).

Met behulp van een expertsysteem, waarin de EUNIS-habitattypen en de aanvullende typen gedefinieerd zijn aan de hand van formele definities, is een groot deel van de 1,5 miljoen vegetatieopnamen geïnclassificeerd. Daaropvolgend is met statistische procedures een lijst van indicatorsoorten per habitatype bepaald. Als resultaat zijn voor iedere habitatype drie soortgroepen opgesteld, een groep met diagnostische soorten, een groep met meest frequente soorten en een groep met meest dominante soorten. Deze toekenning kan worden gebruikt biodiversiteitsindicatoren op te stellen. Totaal zijn op deze manier 536.900 opnamen (uit een bestand van 1,5 miljoen) geselecteerd die de verspreiding van de 4.500 soorten representeren. Deze gegevens dienen als invoer voor BioScore 3.

Om de betrouwbaarheid te toetsen van de responsies van soorten op omgevingsfactoren, zoals berekend door BioScore 3, is een vergelijking gemaakt met gepubliceerde ecologische indicatiewaarden (Ellenberg-indicatiewaarden). WEnR heeft daarvoor de berekeningen van de indicatiewaarden van alle geselecteerde soorten uitgevoerd (gemiddelden en kwartielen); PBL heeft de vergelijking gemaakt met de BioScore 3 uitkomsten. De resultaten zullen worden gepubliceerd in een wetenschappelijk artikel.

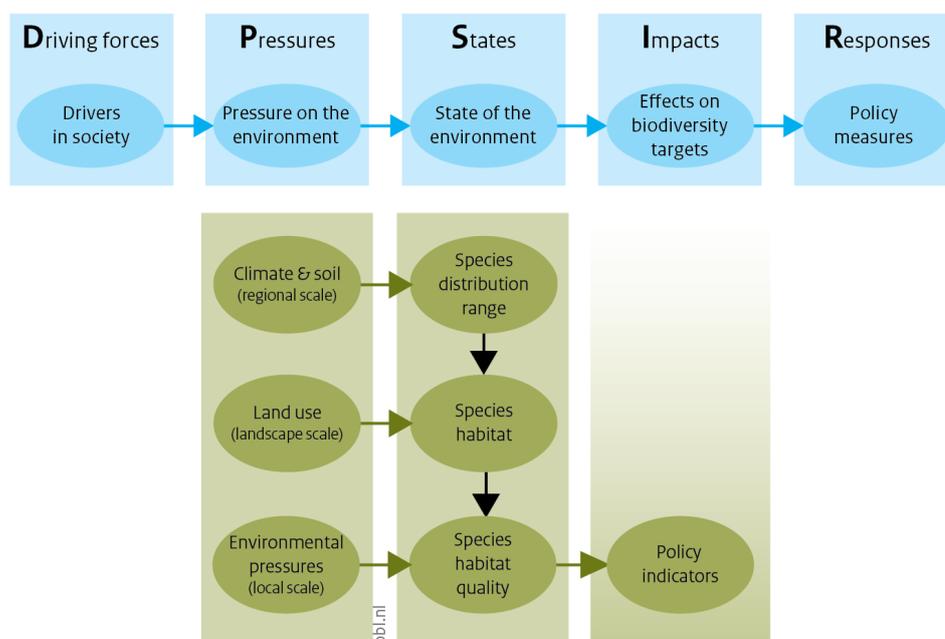
1 Introduction

Together with PBL Netherlands Environmental Assessment Agency, Wageningen Environmental Research (WEnR) is developing BioScore, a biodiversity model to assess the impact of pressures like climate change, nitrogen deposition and land use change. This report provides background information about the work on the selection of plant species and distribution data, for describing a significant part of the terrestrial EUNIS habitats and most common anthropogenic vegetation types.

General information on the conceptual framework of BioScore and a description of the relevant policy questions for BioScore 2.0 are explained in detail in the report 'BioScore 2.0, a tool to assess the impacts of European Community policies on Europe's biodiversity' (Hinsberg *et al.*, 2014). The 2014 report was written for the international review commission and provides background information about ongoing work. The meeting of consortium partners of the BioScore 2 project with the review commission took place on the 16th of October 2014. Another source for background information is the publication 'BIOSCORE 2.0. A species-by-species model to assess anthropogenic impacts on terrestrial biodiversity in Europe' (Hendriks *et al.*, 2016).

BioScore 1 introduced the sensitivity of individual species to a given environmental variable as the connector between a changing environmental pressure and an effect on species. By including this aspect in the DPSIR-chain (see Figure 1.1), it is assumed to derive a model which can help in revealing the links between drivers and changes in species occurrences. Transforming the sensitivity scores from BioScore 1.0 into quantitative dose-response functions, relating species occurrences to pressures and threats, it is expected that the successors of BioScore 1.0, BioScore 2.0 and BioScore 3.0, will become more suitable for assessing the effect of combinations of policy options.

Basic structure of ecological modelling at 3 scales



Source: PBL 2014

Figure 1.1 Modelling the DPSIR-chain at different spatial scales. Source: Hinsberg *et al.* (2014).

In Chapter 2 of this report, information is presented on how more than 4,500 plant indicator species for a significant part of the terrestrial semi-(natural) EUNIS types were identified, and also how occurrence data for these species was selected and pre-processed enabling derivation of dose-response functions for the BioScore 3 model.

Chapter 3 deals with the comparison of the first preliminary dose-response functions as delivered by PBL with Ellenberg ecological indicator values.

2 Selection of a set of plant species for all major European vegetation types

In order to derive a set of indicator species for all major European terrestrial (semi)natural and anthropogenic vegetation types an automated and data-driven procedure was set up, comprising the following steps:

1. All vegetation plots of the EVA database were classified to a EUNIS habitat type level 3, using an expert system (Annex 4).
2. On the basis of the classified vegetation plots lists of indicator species for each habitat type were calculated (Annex 5).
3. Based on the species indicator lists a total of 4,500 unique species taxa could be identified (Annex 5).

2.1 Selection of vegetation plot data

For the management of the vegetation data the software program Turboveg 3 has been used (see Figure 2.1). This software package is the successor of Turboveg 2 (Hennekens & Schaminée 2001) which is currently used for the storage of the majority of digital vegetation data across Europe and abroad. In Turboveg 3, several functions have been added to facilitate the selection and pre-processing of the data for the BioScore 3 modelling.

The past three years, part of the time in the BioScore–project was spent on the compilation and management of vegetation data across Europe as part of the European Vegetation Archive (Chytrý *et al.*, 2016). This work is carried out in close cooperation with Masaryk University in Brno (Czech Republic), which is in principle responsible for the data collection from the many data providers. WENR is mainly responsible for the harmonisation and integration of the data in a common data format and the development of Turboveg 3 for managing the database. At present, over 1.5 million vegetation plots (relevés) are stored in the database, in total containing over 34 million species records. About 85% of the plot data is geo-referenced and this subset provides an important and high quality data source for species distribution models at the European scale.

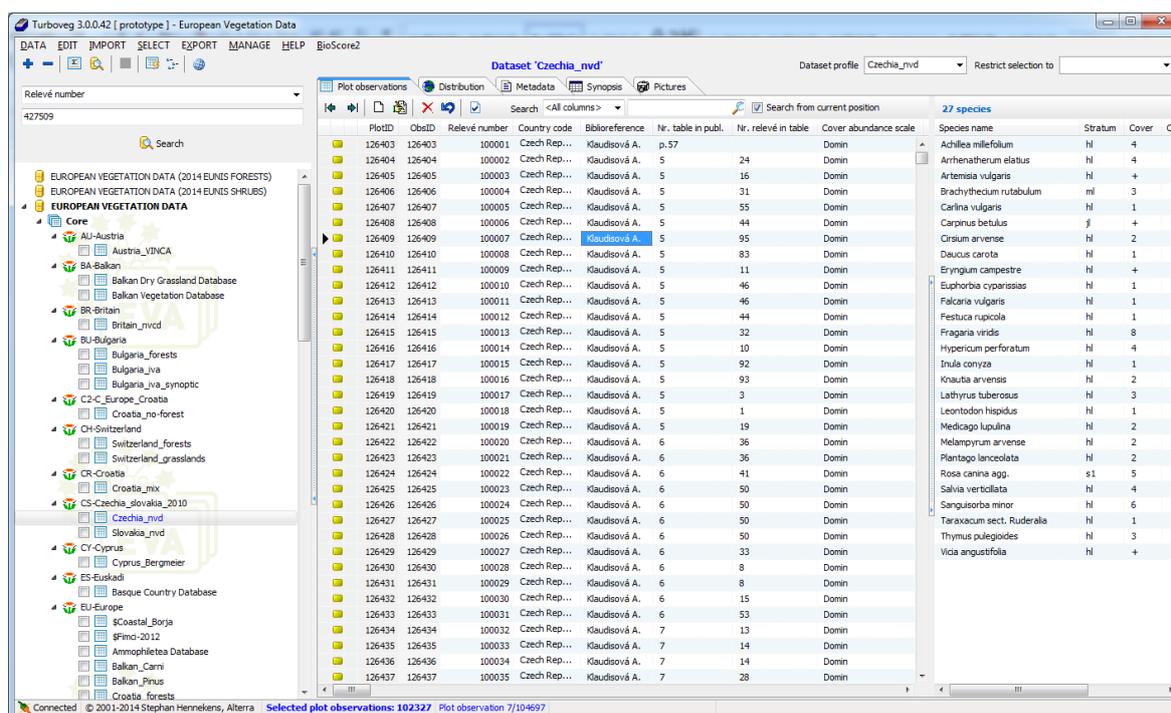


Figure 2.1 Screenshot of the Turboveg 3, a database management program for vegetation plots.

For the taxonomy at European scale, a backbone has been developed over the last ten years. This backbone (called the SynBioSys taxon database) links different national and regional species lists to a common taxonomy, the analysis of vegetation plots at European scale.

For the BioScore 3 project, the selection of plant species was based on the European Vegetation Archive (version of 10-05-2017) containing 1,518,158 vegetation plots and holding 34 million species recordings. From this pool, 188,476 plots were excluded because they have been recorded with a presence-only scale, and thus having no cover value for species making it impossible to classify them. This left 1,331,602 plots that have been classified with JUICE (Tichý, 2002) to EUNIS habitat types and an additional 10 anthropogenic vegetation classes defined in the so-called EuroVegChecklist, the recently published pan-European overview of vegetation types (Mucina *et al.*, 2016). For the assignment, the plots stored in the EVA database were exported to csv (comma delimited) files in Turboveg 3 for processing in JUICE (Figure 2.2).

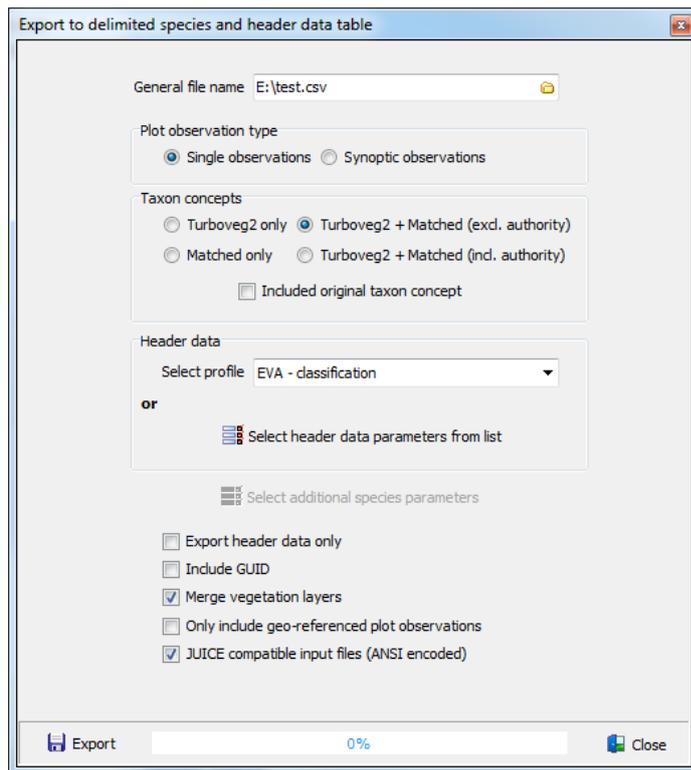


Figure 2.2 Export in Turboveg 3 to delimited species and header data table with required settings for processing in JUICE.

2.2 Classification of each vegetation plot to a vegetation type using JUICE

In JUICE, the set of 1,331,602 plots was classified applying the Expert System of 12-05-2017 (Annex 4). This version of the Expert System covers almost all the EUNIS habitat types level 3, as assessed in the project on the European Red List of Habitats, as far as the terrestrial and freshwater EUNIS habitats are concerned (Janssen *et al.*, 2016), and in addition ten anthropogenic vegetation classes from the European Vegetation Classification (Mucina *et al.*, 2017).

In Annex 2, the full list of habitat types is presented indicating which types are included in the Expert System used. The list is derived from the list set up for the Red List project (Janssen *et al.*, 2016). For the BioScore 3 project, however, also habitat types representing permanent water bodies and running water systems have been excluded. Moreover for the habitat types where no vegetation plot data was available (only 5) were likewise excluded.

In Annex 3, all EUNIS types are listed that are not included in the Red List. It mainly concerns un-vegetated habitat types or vegetation complexes that are floristically not definable like orchards, mixed woodlands, parklands and dehesa. As mentioned before, only terrestrial and fresh water habitats have been taken into account; the marine biotopes have not been considered.

The Expert System contains formal definitions, based on expert knowledge, of individual EUNIS habitat types (see Schaminée *et al.*, 2013, 2014, 2015, 2016) and uses these to identify vegetation plots belonging to these types in the databases. Thus it (i) applies habitat classification consistently across Europe, unlike classification based on expert assignments to phytosociological alliances, which depend on subjective judgement of various experts; (ii) enables identification of vegetation plots that have not been labelled (in the available database) to one of the habitat types; and (iii) can be used to classify any vegetation plot obtained in the future using the same criteria.

In BioScore 2, the focus was on selection of Annex I habitat types that covered most of the important habitat types in Europe. For BioScore 3, the switch was made to EUNIS, because this classification covers all European vegetation types and therefore enables a better cross section of European vegetation.

For those habitat types that have been assessed in the series of EEA projects, in casu forests, heathlands, scrub and tundra, and grasslands (Schaminée *et al.*, 2013, 2014, 2015, 2016), the Expert System formulas were applied that have been defined in these projects. All other formulas () have been developed for the BioScore 3 project by Milan Chytrý (Masaryk University, Brno, Czech Republic) and Joop Schaminée (WEnR) and need to be concerned as provisional (the species groups for each habitat type have been taken from the Red List project; see [Eionet Forum –European Red List of habitats](#)).

The csv files (separate files for header and species data) created by Turboveg 3 can be imported in JUICE as 'Simple text file (Database records)'. Figure 2.3 shows the required settings to import the csv files.

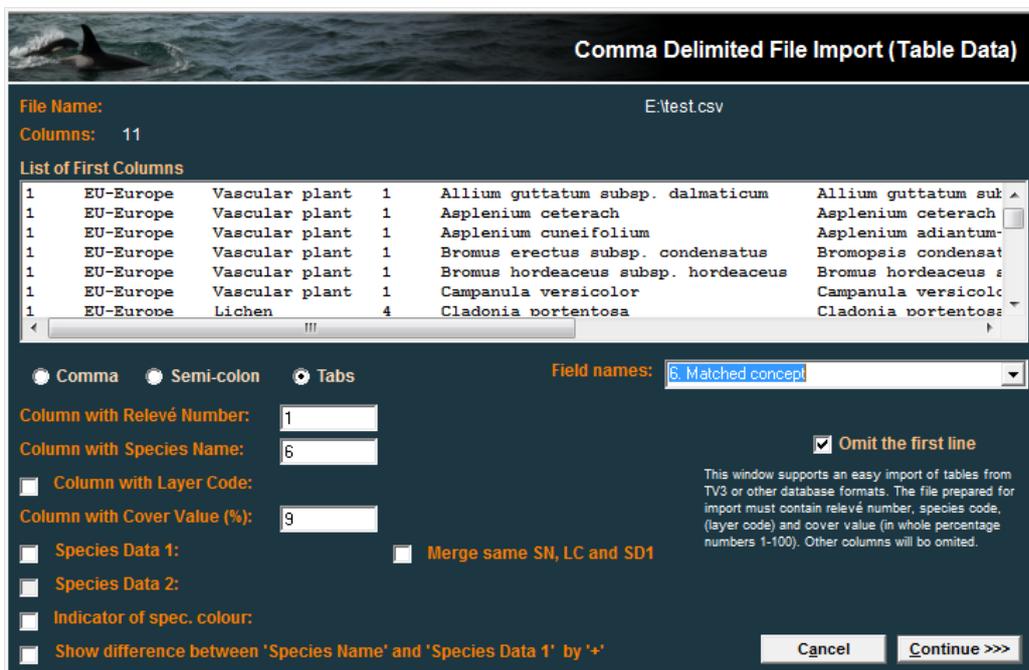


Figure 2.3 Required import settings in JUICE.

In short, the procedure in Juice is as follows.

1. To classify the imported plots in JUICE select 'Analysis', 'Expert System'. Load the Expert System file and then select the option 'Modify Species Names' first, followed by 'Merge Same Spec. Names'. Finally, execute the classification by selecting 'Classify WHITE relevés' (Figure 2.4).

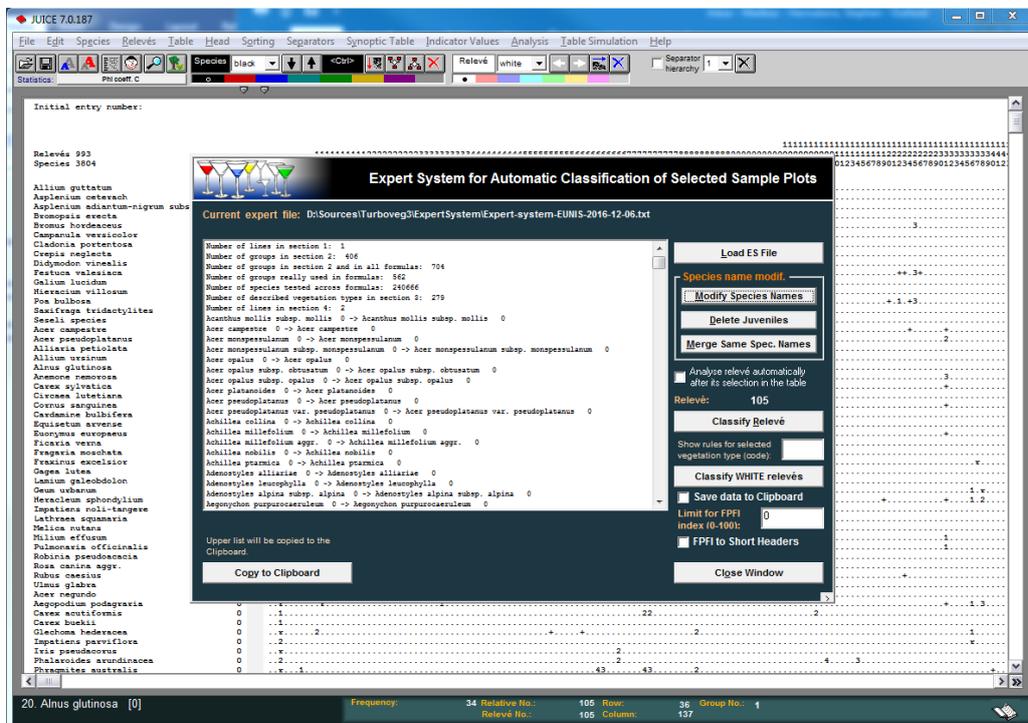


Figure 2.4 Preparation of the classification in JUICE.

- When the classification process is finished, the result (EUNIS habitat code per plot) is presented in the so-called 'short header'. Then, select 'Sorting', 'Sort short headers' in JUICE, followed by selecting 'Separators', 'Make separators', 'Within short headers', to distinguish the individual habitat types (plots with the same habitat code). Thereafter, remove the unclassified plots that are indicated in the short headers with '+' (plot assigned to more than one habitat type) or '?' (plot not assigned to any habitat type).
- For the remaining groups (habitat types), the indicator species will be determined in next steps. First, select the option 'Phi coeff. C' in the main window and define the settings in the options window as indicated in Figure 2.5.

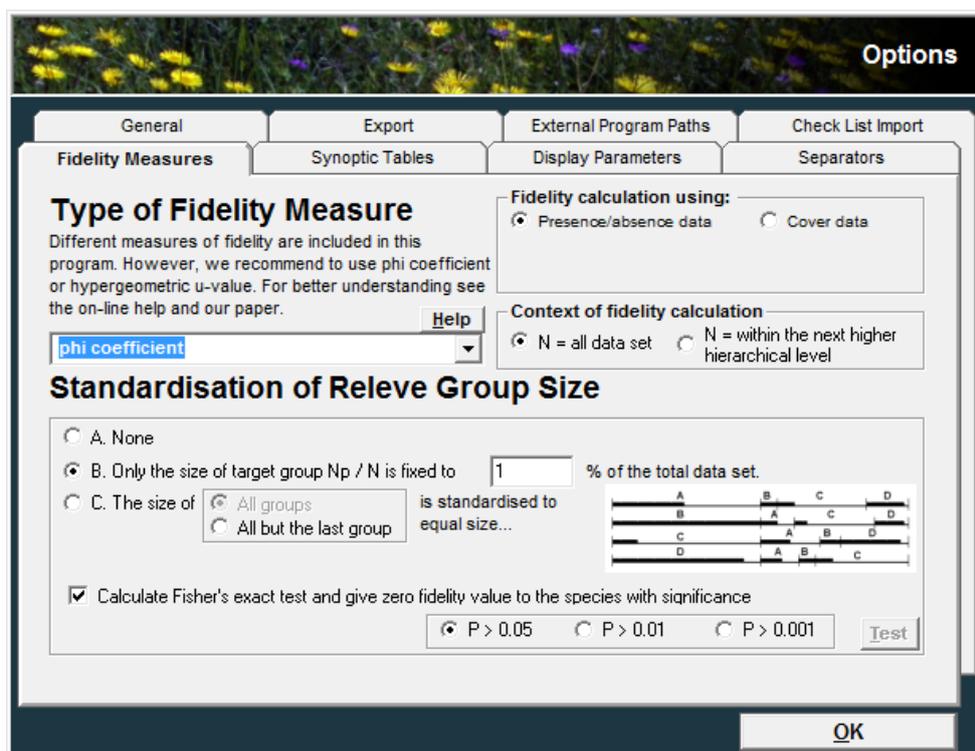


Figure 2.5 Required settings for Phi Coefficient calculation.

- Then create a synoptic table, in which each habitat type is presented by a single column. For this part of the analysis, first select 'Synoptic table', 'Percentage Frequency'. Subsequently the synoptic table is analysed to obtain the indicator species. For this, select 'Synoptic table', 'Analysis of columns of synoptic table' and define the settings as indicated in Figure 2.6.

Figure 2.6 Required settings in Analysis of Constancy Column in Synoptic Table.

- After having selected the Export option in the 'Analysis window', the following dialog window appears in which the options should be set as indicated below. Finally, select 'Export Clusters 1-xxx' (Figure 2.7).

Figure 2.7 Result of analysis.

- The result is exported to a file called 'synColExport.txt', which can be found in the JUICE installation folder. In this file for each habitat indicators are listed for three categories: diagnostic species, dominant species, and constant species. Species with a frequency of occurrence within the habitat type lower than 10% have been excluded from the list (see Table 2.1).

Table 2.1 Snapshot of the table with indicator species.

Status	Species name	Freq.	EUNIS type
CoSp	<i>Empetrum nigrum</i>	100	B1.5a
CoSp	<i>Carex arenaria</i>	93	B1.5a
CoSp	<i>Dicranum scoparium</i>	88	B1.5a
CoSp	<i>Salix repens</i>	69	B1.5a
CoSp	<i>Hypnum jutlandicum</i>	67	B1.5a
CoSp	<i>Calluna vulgaris</i>	58	B1.5a
CoSp	<i>Hieracium umbellatum</i>	55	B1.5a

The analysis resulted in lists of indicator species for 215 EUNIS habitat types (65% of all terrestrial EUNIS types), plus all 10 most common anthropogenic vegetation classes (indicated with the codes X1-X10). All these types are floristically well-defined (a distinct floristic definition is a prerequisite for running the Expert System).

2.3 Indicator status of species

Within the lists, three groups of indicator species are identified for each of the habitat types, based on vegetation plots assigned to each of the habitat types (see e.g. Schaminée *et al.*, 2016). These groups included diagnostic, constant and dominant species. Records of species identified only to the genus level and records of epiphytic lichens were removed from the lists of indicator species.

Diagnostic species (indicated as 'DgSp' in Annex 5) are determined based on the degree of concentration of their occurrences in groups of plots representing each habitat type. This degree of concentration was calculated using the phi coefficient of association (Sokal & Rohlf, 1995) standardized for the identical number of relevés across all groups, which was arbitrarily set to 1% of the total data set (Tichý & Chytrý, 2006). The species with a value of phi for the particular habitat higher than 0.15 were considered as diagnostic for this habitat type. However, for some habitat types represented by a low number of plots in the stratified dataset, the concentration of species occurrence within the type may not have been statistically significant. Therefore, statistical significance of the species-habitat type association was tested using the Fisher's exact test (Sokal & Rohlf, 1995) and, if this association was not significant at $P < 0.05$, the species was excluded from the list of diagnostic species (Tichý & Chytrý, 2006).

Constant species (indicated as 'CoSp' in Annex 5) are defined as those with constancy (= percentage occurrence frequency) in the target habitat type at least 10%.

Dominant species (indicated as 'DoSp' in Annex 5) are defined as those that occurred with a cover higher than 25% in at least 5% of vegetation plots classified to the target habitat type. This means that a species is considered as dominant even if it does not belong to the highest vegetation layer (e.g. tree layer in forests), and a single plot can have more than one dominant species, or no dominant species if vegetation is very sparse or if cover values of all species are lower than 25%.

The assignment of species to EUNIS habitat types, their indicator status, their frequency as well as the assignment to Annex I habitat types (see Annex 5) can be used in the modelling to define and fine-tune biodiversity indicators (see Hendriks *et al.*, 2016).

2.4 Selection of vegetation plots for deriving dose-response functions

With the EVA database the 4,541 plant species were assigned to the set of 225 habitat types (215 EUNIS habitat types plus 10 anthropogenic vegetation classes). However, the number observations within EVA varies strongly across individual species. To offer an indication, there are 1,976 species that occur in 1,000 plots or more; 2,561 species occur in 500 plots or more, and 3,155 species in 250 plots or more.

To derive a set of observations which can be used in statistical modelling various selections were made. First, for each of the 4,541 plant species, all vegetation plots in which they occur have selected from the European Vegetation Archive. Plots overlapping with Corine Land Cover classes of inland waters, marine waters and maritime wetlands were excluded, as well as plots recorded before 1990 and after 2016¹, and plots with a known spatial uncertainty above 1,000 meter. From this pool – for each species – one plot per km² was randomly selected to avoid spatial bias. On top of that, plots with one or more values of environmental variables² missing were excluded from the selection. With these selection criteria, 536,900 of the more than 1,5 million vegetation plots in the EVA-database remained (see Figure 2.8) and were used for the calculation of dose-response functions and/or the check of derived doses-response functions with Ellenberg indicator values.

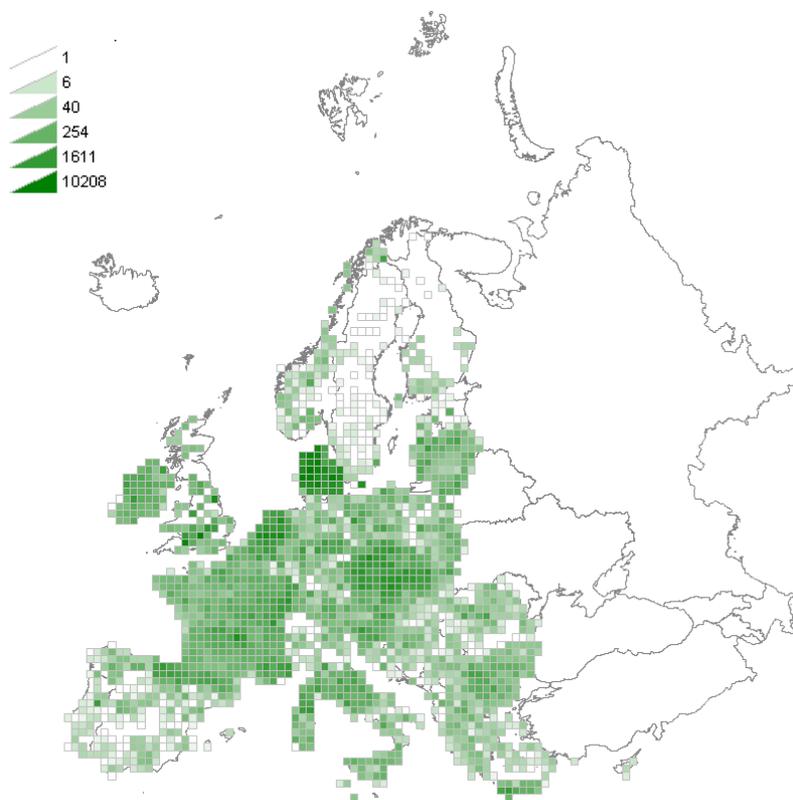


Figure 2.8 Distribution of plots used for the BioScore modelling.

¹ Vegetation plots are selected between 1990 and 2016. This time frame maximizes the fit with the time frames of the environmental variables and minimizes the spatial bias in the distribution of the plots.

² PBL has selected the following environmental predictors for the BioScore 3 model (Hendriks *et al.*, in prep.): Winter precipitation (bio18), Summer precipitation (bio19), Mean minimum temperature of the coldest month (bio6), Mean annual temperature (bio1), Annual precipitation (bio12), Temperature seasonality (bio4), Arable land (CLC-codes, 211 - 223), Pastures (CLC-code 231), Heterogeneous agricultural areas (CLC-code 241 - 244), Scrub and/or herbaceous vegetation associations (CLC-code 321 - 324), Forests (CLC-code 311 - 313), Open spaces with little or no vegetation (CLC-code 331 - 335), Inland wetlands (CLC-code 411 - 412), Organic carbon content in the top soil, Clay content in the top soil, Silt content in the top soil, Sand content in the top soil, Bulk density (fine earth) in kg / cubic-meter, Coarse fragments volumetric in %, Cation exchange capacity of soil in cmolc/kg, Soil pH x 10 in H₂O, Nitrogen deposition.

3 Check of dose-response functions with Ellenberg indicator values

3.1 Theoretical model of the relation between environmental conditions and species occurrence

Species distribution models are often validated based on the modelled species distribution ranges using a cross-validation with other distribution data, but cross-validation may provide overly optimistic estimates of the models' predictive ability due to lack of independence of the testing data (Araújo *et al.*, 2005). Moreover, lack of consistent data often limits these types validations. Regions with the same species and combinations of environmental conditions as the study area are scarce, just as independent or long term datasets, especially when considering rare species. Furthermore, all these methods validate the predicted values in the distribution maps and not the response of the individual species to changes in environmental conditions (Austin, 2007; Elith & Leathwick, 2009). The latter issue is rarely addressed, and only for individual species models (Wright *et al.*, 2006).

The species distribution ranges (either modelled or derived from observations) reflect the net effect of a complex spectrum of interrelated processes and it is challenging to quantify the response of plant species to changes in individual environmental variables. This is especially true for the effects of human-induced pressures on the occurrence and performance of plant species. Such effects are often indirect (i.e. mediated through their effects on other variables) and the effects often differ across environmental gradients (i.e. they are context dependent). Therefore, the effects of pressures on plants are difficult to incorporate into predictive models. Species distribution models that balance ecological realism with policy relevance require a good understanding of (i) the driving processes that directly influence plant performance; and (ii) the human-induced pressures that can influence these local site conditions.

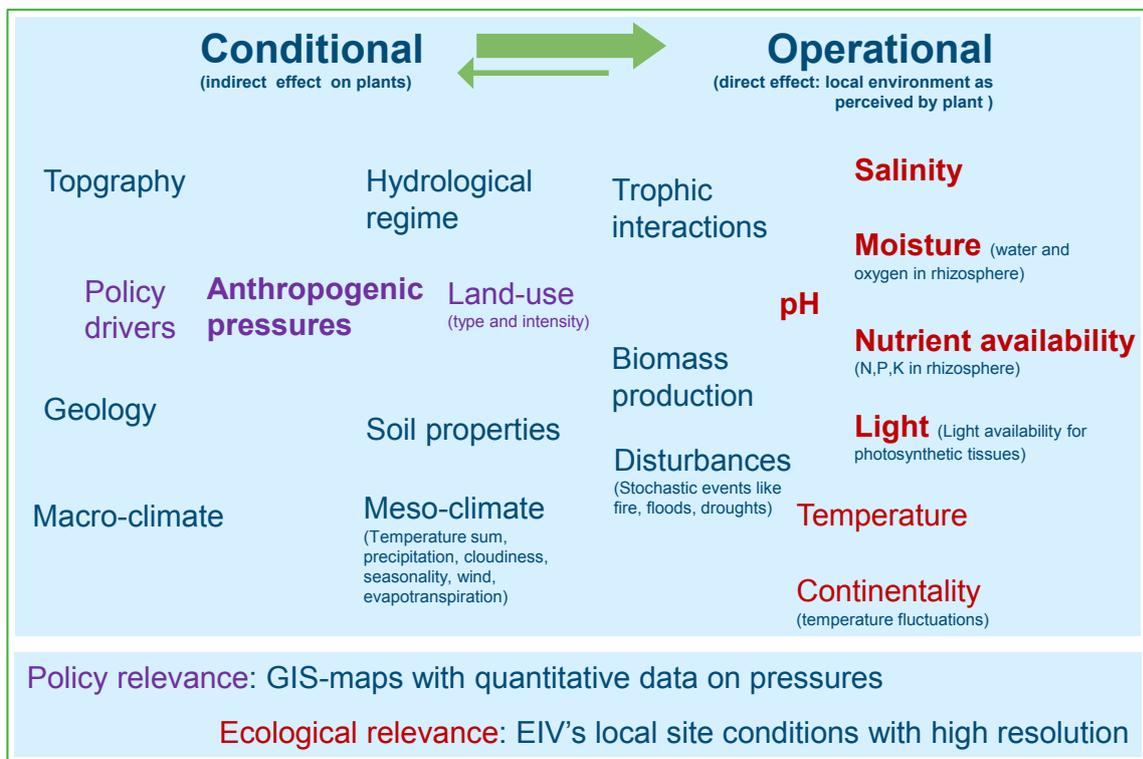


Figure 3.1 Relative ranking of environmental variables according to their direct (causal) or indirect effect on plant performance. Many variables are linked to multiple other factors, often involving complex feedback processes but these links between variables are not shown. The position of factors along the indirect-direct continuum can differ between habitats and should be regarded as indicative.

In Figure 3.1, a selection of environmental variables is ranked according to the degree to which they influence plant performance directly. Towards the right-hand side of the figure, the degree of causality increases and the so-called 'operational variables' have a (relatively) direct influence on plant growth. These operational variables in turn are often influenced by several 'conditional variables'. If one aims at models with a high predictive ability in future scenarios, then it is desirable to predict the distribution of species on the basis of parameters that are believed to be related to causal factors, i.e. operational variables in the right-hand part of Figure 3.1.

3.2 Calculation of species specific ecological indicator values which can be used for testing dose-response functions

Ellenberg indicator values (EIVs) can be used for testing computed dose-response functions, as they describe the preferences of individual plant species for the main operational environmental variables (expressed on an ordinal scale from 1 to 9 or 12; Ellenberg *et al.*, 1991, 2001). The environmental variables covered by EIVs are marked red in Figure 3.1., i.e.: temperature, continentality, light availability, soil moisture, soil pH, soil nutrient availability and salinity.

The original list with indicator values is available for Central European plant species (Ellenberg *et al.*, 1991, 2001). This was supplemented with scores from additional species from former DDR (Frank & Klotz, 1990), Great Britain (Hill *et al.*, 1999), Italy (Pignatti, 2005) and Switzerland (Landolt, 1977).

Although the EIVs are ordinal scores, it has been shown that in practice they can be treated as if they were quantitative (i.e. measured on an interval scale; Ter Braak & Gremmen, 1987), thus allowing numeric analyses. Plot-level Ellenberg indicator values were calculated based on averaging the Ellenberg indicator values of all co-occurring plant species (not taking cover abundance of species into account). These plot-level EIV's provide a proxy for the local environmental conditions as perceived by the local vegetation. In contrast to soil measurements, these EIVs integrate spatial and temporal information on a scale as perceived by plants. Although EIVs are largely based on expert judgement, several studies reported a close correlation between average indicator values at the plot-level and corresponding measurements of environmental variables (Thompson *et al.*, 1993; Schaffers & Sýkora, 2000; Diekmann, 2003). For a more detailed discussion on the reliability and limitations of Ellenberg indicator values, we refer to Diekmann (2003).

In contrast to the raw EIVs, that only provide information on the niche optima of species, the use of plot-level EIVs allows the quantification of the variation in environmental conditions across all plots in which a given species occurs. Information on the average/median and variation of plot EVI's, can be used for testing the computed dose-response functions (SDM's) from BioScore.

A test set of species plot-EVI's was derived based on the same set of plots from the European Vegetation Archive (EVA) as was used as for fitting the SDMs. The optimum and range of the plot-level Ellenberg indicator values can be calculated taking the median and inter-quartile range of all occupied plots. For a given species, this information describes the realized niche in a multidimensional space (*sensu* Hutchinson, 1957). For this comparison, a selection of species representative for the main vegetated terrestrial EUNIS habitat types (see Chapter 2) was used. Out of this set, 1956 vascular plant species (i.e. excluding mosses and lichens) were selected with at least 100 plots in the EVA database. An additional constraint is that plots should at least have five species with a given indicator value.

Annex 5 provides the list of species and their calculated EVI-values. For each species, the original Ellenberg indicator value is given (if available), the number of plots in which the species occurs, the mean value and the quartile coefficients.

3.3 Proposed analysis on doses-response functions and Ellenberg indicator values

This section provides a proposal for the analysis of the dose-response functions from Bioscore and the EIVs. To assess correlation structures between variables a principal component analysis (PCA) can be performed on all species including the optimal values of all variables included in the SDM and all Ellenberg indicator values (based on the plot level EIVs for the plots in which they occur). The pair wise correlation between the environmental variables included in the SDM and the Ellenberg indicator values can be analysed by means of a Pearson correlation separately for the optimal values and the range values. Subsequently, scatterplots of the corresponding combinations of environmental variables and indicator values can be calculated for all species and for subsets of species based on (i) the main biogeographical region in which they occur³; (ii) the degree of specialist-generalist; and (iii) preferred habitat type. The main biogeographical region will be defined as the biogeographical region where the species occupies most 5 km grid cells. The degree of specialist-generalist can be measured by the number of biogeographical regions where a species occupies at least ten 5 km grid cells. The preferred habitat type can be expressed as the EUNIS or EVC habitat type for which the species is an indicator species (see section on Species selection and monitoring data). It is suggested to distinguish habitat types based on EUNIS habitat types level 1. Furthermore, boxplots can be calculated of the corresponding combinations of environmental variables and raw indicator values including all species.

The actual comparison between EIVs and environmental responses of plant species as retrieved from BioScore 3 will be carried out by PBL. The results will be published in a scientific paper, expected to be published in 2018.

³ A list of species and their monitoring intensity related to Biogeographical regions is included in Annex 7.

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Justification

The work carried out by Wageningen Environmental Research (WEnR) in 2017 is part of the development of the BioScore 3 model by PBL Netherlands Environmental Assessment Agency. In this technical report the focus is solely on plant species and their habitats.

The project was supervised by Arjen van Hinsberg and Marjon Hendriks, both working at PBL, and Bart de Knegt (WEnR) and the results of the project will be used by PBL to develop the BioScore 3 model itself.

Part of the work was on the selection of plant species, the classification of the plots to EUNIS habitat types, the extraction of distribution data from the European Vegetation Archive (EVA) as input for the modelling, and the calculation of ecological indicator statistics of plant species. This task was the responsibility of Stephan Hennekens and Joop Schaminée.

A comparison of model results with expert based ecological indicator values (Chapter 3) was carried out by Wim Ozinga.

Special thanks for the custodians of the various vegetation databases across Europe who gave permission to use their data, as included in EVA (European Vegetation Archive) for this project. A list of data providers is included in Annex 1

Annex 1 Data providers

Database	Custodian	Deputy custodian
Austrian Vegetation Database	Wolfgang Willner	
Balkan Dry Grasslands Database	Kiril Vassilev	
Balkan Vegetation Database	Kiril Vassilev	Hristo Pedashenko
Beech Forest Vegetation Database of SE Balkan	Aleksander Marinšek	
Bulgarian Vegetation Database	Iva Apostolova	Desislava Sopotlieva
CoenoDat Hungarian Phytosociological Database	János Csiky	Zoltán Botta-Dukát
Croatian Vegetation Database	Željko Škvorc	Daniel Krstonošić
Czech National Phytosociological Database	Milan Chytrý	Dana Michalcová
Database of Forest Vegetation in Republic of Serbia + Vegetation Database of Pannonian part of Serbia	Mirjana Krstivojević Ćuk	
Dutch National Vegetation Database	Joop H.J. Schaminée	Stephan Hennekens
European Coastal Vegetation Database	John Janssen	
European Mire Vegetation Database	Tomáš Peterka	Martin Jiroušek
European Mire Vegetation Database	Tomáš Peterka	Martin Jiroušek
Forest Vegetation Database of Turkey - FVDT	Ali Kavgacı	
German Grassland Vegetation Database (GrassVeg.DE)	Jürgen Dengler	Thomas Becker
German Vegetation Reference Database (GVRD)	Ute Jandt	Helge Bruelheide
Gravel bar vegetation database	Veronika Kalníková	Helmut Kudrnovsky
Hellenic Natura 2000 Vegetation Database (HelNatVeg)	Panayotis Dimopoulos	Ioannis Tsiripidis
Hellenic Woodland Database + Hellenic Beech Forests Database	Ioannis Tsiripidis	
Iberian and Macaronesian Vegetation Information System (SIVIM)	Xavier Font	
Iberian and Macaronesian Vegetation Information System (SIVIM); Alpine	Borja Jiménez-Alfaro	Xavier Font
Iberian and Macaronesian Vegetation Information System (SIVIM); Catalonia	Xavier Font	
Iberian and Macaronesian Vegetation Information System (SIVIM); Forest	Juan Antonio Campos	Xavier Font
Iberian and Macaronesian Vegetation Information System (SIVIM); Graslands	Maria Pilar Rodríguez-Rojo	Xavier Font
Iberian and Macaronesian Vegetation Information System (SIVIM); Scrubs	Rosario G Gavilán	Xavier Font
Iberian and Macaronesian Vegetation Information System (SIVIM); Wetlands	Aaron Pérez-Haase	Xavier Font
INBOVEG	Els De Bie	
Irish Vegetation Database	Úna FitzPatrick	Lynda Weekes
Italian National Vegetation Database (BVN/ISPRA)	Laura Casella	Pierangela Angelini
KRITI	Erwin Bergmeier	
Lithuanian vegetation Database	Valerius Rašomavičius	Domas Uogintas
Lower Volga Valley Phytosociological Database	Valentin Golub	Viktoria Bondareva
Mediterranean Ammophiletea database	Corrado Marcenò	Borja Jiménez-Alfaro
National Vegetation Database of Denmark	Jesper Erenskjold Moeslund	Rasmus Ejrnæs

Database	Custodian	Deputy custodian
Nordic-Baltic Grassland Vegetation Database (NBGVD)	Jürgen Dengler	Łukasz Kozub
Polish Vegetation Database	Zygmunt Kaćki	Grzegorz Swacha
Romanian Forest Database	Adrian Indreica	Pavel Dan Turtureanu
Romanian Grassland Database	Eszter Ruprecht	Kiril Vassilev
SE Europe forest database	Andraž Čarni	
Semi-natural Grassland Vegetation Database of Latvia	Solvita Rūsiņa	
Slovak Vegetation Database	Milan Valachovič	Jozef Šibík
Swiss Forest Vegetation Database	Thomas Wohlgemuth	
The Nordic Vegetation Database	Jonathan Lenoir	Jens-Christian Svenning
The Nordic Vegetation Database	Jonathan Lenoir	Jens-Christian Svenning
UK National Vegetation Classification Database	John S. Rodwell	
UK_Floodplain meadows	Irina Tatarenko	
Ukrainian Grassland Database	Anna Kuzemko	Yulia Vashenyak
Vegetation Database Grassland Vegetation of Serbia	Svetlana Aćić	Zora Dajić Stevanović
Vegetation Database of Albania	Michele De Sanctis	Giuliano Fanelli
Vegetation database of Mecklenburg-Vorpommern	Florian Jansen	Christian Berg
Vegetation Database of Slovenia	Urban Šilc	
Vegetation Database of the Republic of Macedonia	Renata Čušterevska	
Vegetation Plot Database - Sapienza University of Rome	Emiliano Agrillo	Fabio Attorre
Vegetation-Plot Database of the University of the Basque Country (BIOVEG)	Idoia Biurrun	Itziar García-Mijangos
VegetWeb Germany	Jörg Ewald	Martin Kleikamp
VegItaly	Roberto Venanzoni	Flavia Landucci
VIOLA	Angela Stanisci	Alberto Evangelista
WetVegEurope	Flavia Landucci	

Annex 2 Habitat types included in the analysis and their relation to Annex I

Code	Name	Annex I
Coastal Habitats (B)		
A2.5a	Arctic coastal salt marsh	1330
A2.5b	Baltic coastal meadow	1330
A2.5c	Atlantic coastal salt marsh	1330
A2.5d	Mediterranean and Black Sea coastal salt marsh	1330
B1.1a	Atlantic, Baltic and Arctic sand beach	
B1.1b	Mediterranean and Black Sea sand beach	
B1.3a	Atlantic and Baltic shifting coastal dune	2120
B1.3b	Mediterranean and Black Sea shifting coastal dune	2120
B1.4a	Atlantic and baltic coastal dune grassland (grey dune)	2130, 2210
B1.4b	Mediterranean and Macaronesian coastal dune grassland (grey dune)	2130, 2210
B1.4c	Black Sea coastal dune grassland (grey dune)	2130, 2210
B1.5a	Atlantic and Baltic coastal Empetrum heath	
B1.5b	Atlantic coastal Calluna and Ulex heath	
B1.6a	Atlantic and Baltic coastal dune scrub	2160
B1.6b	Mediterranean and Black Sea coastal dune scrub	2160
B1.6c	Macaronesian coastal dune scrub	2160
B1.7a	Atlantic and Baltic broad-leaved coastal dune woodland	
B1.7b	Black Sea broad-leaved coastal dune woodland	
B1.7c	Baltic coniferous coastal dune woodland	
B1.8a	Atlantic and Baltic moist and wet dune slack	
B1.8b	Mediterranean and Black Sea moist and wet dune slack	
B1.9	Machair	
B2.1a	Atlantic, Baltic and Arctic coastal shingle beach	
B2.1b	Mediterranean and Black Sea coastal shingle beach	
B3.1a	Atlantic and Baltic rocky sea cliff and shore	
B3.1b	Mediterranean and Black Sea rocky sea cliff and shore	
B3.1c	Macaronesian rocky sea cliff and shore	
B3.4a	Atlantic and Baltic soft sea cliff	
B3.4b	Mediterranean and Black Sea soft sea cliff	
Freshwater Habitats (C)		
C1.1a	Permanent oligotrophic waterbody with very soft-water species	3110
C1.1b	Permanent oligotrophic to mesotrophic waterbody with soft-water species	3110
C1.2a	Permanent oligotrophic to mesotrophic waterbody with Characeae	3130
C1.2b	Mesotrophic to eutrophic waterbody with vascular plants	3130
C1.4	Permanent dystrophic waterbody	
C1.5	Permanent inland saline and brackish waterbody	
C1.6a	Temperate temporary waterbody	
C1.6b	Mediterranean temporary waterbody	
C2.1a	Base-poor spring and spring brook	

Code	Name	Annex I
C2.1b	Calcareous spring and spring brook	
C2.2b	Permanent non-tidal, fast, turbulent watercourse of plains and montane regions with <i>Ranunculus</i> spp.	
C2.3	Permanent non-tidal, smooth-flowing watercourse	
C2.4	Tidal river, upstream from the estuary	
C2.5a	Temperate temporary running watercourse	
C3.5a	Periodically exposed shore with stable, eutrophic sediments with pioneer or ephemeral vegetation	3130
C3.5b	Periodically exposed shore with stable, mesotrophic sediments with pioneer or ephemeral vegetation	3130
C3.5c	Periodically exposed saline shore with pioneer or ephemeral vegetation	3130
C3.5d	Unvegetated or sparsely vegetated shore with mobile sediments in montane and alpine regions	3130
C3.5e	Unvegetated or sparsely vegetated shore with mobile sediments in the Mediterranean region	3130
C5.1a	Tall-helophyte bed	
C5.1b	Small-helophyte bed	
C5.2	Tall-sedge bed	
C5.4	Inland saline or brackish helophyte bed	
Mires and bogs (D)		
D1.1	Raised bog	7110
D1.2	Blanket bog	7130
D2.1	Oceanic valley bog	
D2.2a	Poor fen	
D2.2b	Relict mire of Mediterranean mountains	
D2.2c	Intermediate fen and soft-water spring mire	
D2.3a	Non-calcareous quaking mire	7140, 7150
D3.1	Palsa mire	
D3.2	Aapa mire	
D4.1a	Small-sedge base-rich fen and calcareous spring mire	7230
D4.1b	Tall-sedge base-rich fen	7230
D4.1c	Calcareous quaking mire	7230
D4.2	Arctic-alpine rich fen	
Grasslands (E)		
E1.1a	Pannonian and Pontic sandy steppe	6110, 6120
E1.1b	Cryptogam- and annual-dominated vegetation on siliceous rock outcrops	6110, 6120
E1.1d	Cryptogam- and annual-dominated vegetation on calcareous and ultramafic rock outcrops	6110, 6120
E1.1e	Perennial rocky grassland of the Italian Peninsula	6110, 6120
E1.1g	Perennial rocky grassland of Central Europe and the Carpathians	6110 6120
E1.1h	Heavy-metal dry grassland of the Balkans	6110, 6120
E1.1i	Perennial rocky calcareous grassland of subatlantic-submediterranean Europe	6110, 6120
E1.1j	Dry steppic, submediterranean pasture of South-Eastern Europe	6110, 6120
E1.2a	Semi-dry perennial calcareous grassland	6210, 6240
E1.2b	Continental dry steppe	6210, 6240
E1.3a	Mediterranean closely grazed dry grassland	6220
E1.3b	Mediterranean tall perennial dry grassland	6220

Code	Name	Annex I
E1.3c	Mediterranean annual-rich dry grassland	6220
E1.5a	Iberian oromediterranean siliceous dry grassland	
E1.5b	Iberian oromediterranean basiphilous dry grassland	
E1.5c	Cyrno-Sardean oromediterranean siliceous dry grassland	
E1.5d	Greek and Anatolian oromediterranean siliceous dry grassland	
E1.5e	Madeiran oromediterranean siliceous dry grassland	
E1.7	Lowland to submontane, dry to mesic <i>Nardus</i> grassland	6230
E1.8	Open Iberian supramediterranean dry acid and neutral grassland	
E1.9a	Oceanic to subcontinental inland sand grassland on dry acid and neutral soils	
E1.9b	Inland sanddrift and dune with siliceous grassland	
E1.A	Mediterranean to Atlantic open, dry, acid and neutral grassland	
E1.B	Heavy-metal grassland in Western and Central Europe	
E1.F	Azorean open dry, acid to neutral grassland	
E2.1a	Mesic permanent pasture of lowlands and mountains	
E2.2	Low and medium altitude hay meadow	6510
E2.3	Mountain hay meadow	6520
E2.4	Iberian summer pasture (vallicar)	
E3.1a	Mediterranean tall humid inland grassland	
E3.2a	Mediterranean short moist grassland of lowlands	
E3.2b	Mediterranean short moist grassland of mountains	
E3.3	Submediterranean moist meadow	
E3.4a	Moist or wet mesotrophic to eutrophic hay meadow	
E3.4b	Moist or wet mesotrophic to eutrophic pasture	
E3.5	Temperate and boreal moist or wet oligotrophic grassland	6410
E4.1	Vegetated snow patch	
E4.3a	Boreal and arctic acidophilous alpine grassland	6150, 6230
E4.3b	Temperate acidophilous alpine grassland	6150, 6230
E4.4a	Arctic-alpine calcareous grassland	6170
E4.4b	Alpine and subalpine calcareous grassland of the Balkan and Apennines	6170
E5.2a	Thermophilous woodland fringe of base-rich soils	
E5.2b	Thermophilous woodland fringe of acidic soils	
E5.2c	Macaronesian thermophilous woodland fringe	
E5.3	<i>Pteridium aquilinum</i> stand	
E5.4	Lowland moist or wet tall-herb and fern fringe	6430
E5.5	Subalpine moist or wet tall-herb and fern fringe	
E6.1	Mediterranean inland salt steppe	
E6.2	Continental inland salt steppe	1340
E6.3	Temperate inland salt marsh	1340
Heathlands and scrub (F)		
F1.1	Shrub tundra	
F1.2	Moss and lichen tundra	
F2.1	Subarctic and alpine dwarf <i>Salix</i> scrub	
F2.2a	Alpine and subalpine ericoid heath	4060
F2.2b	Alpine and subalpine <i>Juniperus</i> scrub	4060
F2.2c	Balkan subalpine genistoid scrub	4060
F2.3	Subalpine deciduous scrub	
F2.4	Subalpine <i>Pinus mugo</i> scrub	4070
F3.1a	Lowland to montane temperate and submediterranean <i>Juniperus</i> scrub	5110, 5130

Code	Name	Annex I
F3.1b	Temperate Rubus scrub	5110, 5130
F3.1c	Lowland to montane temperate and submediterranean genistoid scrub	5110, 5130
F3.1d	Balkan-Anatolian submontane genistoid scrub	5110, 5130
F3.1e	Temperate and submediterranean thorn scrub	5110, 5130
F3.1f	Low steppic scrub	5110, 5130
F3.1g	Corylus avellana scrub	5110, 5130
F4.1	Wet heath	4010
F4.2	Dry heath	4030
F4.3	Macaronesian heath	
F5.1	Mediterranean maquis and arborescent matorral	5210
F5.3	Submediterranean pseudomaquis	
F5.5	Thermomediterranean scrub	
F6.1a	Western basiphilous garrigue	
F6.1b	Western acidophilous garrigue	
F6.2	Eastern garrigue	
F6.6	Supramediterranean garrigue	
F6.7	Mediterranean gypsum scrub	
F6.8	Mediterranean halo-nitrophilous scrub	
F7.1	Western Mediterranean spiny heath	
F7.3	Eastern Mediterranean spiny heath (phrygana)	5420
F7.4a	Western Mediterranean mountain hedgehog-heath	
F7.4b	Central Mediterranean mountain hedgehog-heath	
F7.4c	Eastern Mediterranean mountain hedgehog-heath	
F7.4d	Canarian mountain hedgehog-heath	
F8.1	Canarian xerophytic scrub	
F8.2	Madeiran xerophytic scrub	
F9.1	Temperate and boreal riparian scrub	
F9.2	Salix fen scrub	
F9.3	Mediterranean riparian scrub	
Forests (G)		
G1.1	Temperate and boreal softwood riparian woodland	91E0
G1.2a	Alnus woodland on riparian and upland soils	91E0
G1.2b	Temperate and boreal hardwood riparian woodland	91E0
G1.3	Mediterranean and Macaronesian riparian woodland	
G1.4	Broadleaved swamp woodland on non-acid peat	
G1.5	Broadleaved bog woodland on acid peat	
G1.6a	Fagus woodland on non-acid soils	9150, 9110
G1.6b	Fagus woodland on acid soils	9150, 9110
G1.7a	Temperate and submediterranean thermophilous deciduous woodland	91H0
G1.7b	Mediterranean thermophilous deciduous woodland	91H0
G1.8	Acidophilous Quercus woodland	9190
G1.9a	Temperate and boreal mountain Betula and Populus tremula woodland on mineral soils	
G1.9b	Mediterranean mountain Betula and Populus tremula woodland on mineral soils	
G1.Aa	Carpinus and Quercus mesic deciduous woodland	9160
G1.Ab	Ravine woodland	9160
G1.Ba	Alnus cordata woodland	
G2.1	Mediterranean evergreen Quercus woodland	

Code	Name	Annex I
G2.2	Mainland laurophyllous woodland	
G2.3	Macaronesian laurophyllous woodland	
G2.5a	South-Aegean Phoenix grove	
G2.5b	Canarian Phoenix grove	
G2.6	Ilex aquifolium woodland	
G3.1a	Temperate mountain Picea woodland	9410
G3.1b	Temperate mountain Abies woodland	9410
G3.1c	Mediterranean mountain Abies woodland	9410
G3.2	Temperate subalpine Larix, Pinus cembra and Pinus uncinata woodland	
G3.4a	Temperate and continental Pinus sylvestris woodland	
G3.4b	Temperate and submediterranean montane Pinus sylvestris-Pinus nigra woodland	
G3.4c	Mediterranean montane Pinus sylvestris-Pinus nigra woodland	
G3.4d	Mediterranean montane Cedrus woodland	
G3.6	Mediterranean and Balkan subalpine Pinus heldreichii-Pinus peuce woodland	
G3.7	Mediterranean lowland to submontane Pinus woodland	
G3.8	Pinus canariensis woodland	
G3.9a	Taxus baccata woodland	
G3.9b	Mediterranean Cupressaceae woodland	
G3.9c	Macaronesian Juniperus woodland	
G3.B	Pinus sylvestris taiga woodland	
Sparsely Vegetated Habitats (H, I)		
H2.1	Boreal and arctic siliceous scree and block field	
H2.2	Boreal and arctic base-rich scree	
H2.3	Temperate high-mountain siliceous scree	
H2.4	Temperate high-mountain base-rich scree	
H2.5	Temperate, lowland to montane siliceous scree	
H2.6a	Temperate, lowland to montane base-rich scree	
H2.6b	Western Mediterranean base-rich scree	
H2.6c	Eastern Mediterranean base-rich scree	
H3.1a	Boreal and arctic siliceous inland cliff	8220
H3.1b	Temperate high-mountain siliceous inland cliff	8220
H3.1c	Temperate, lowland to montane siliceous inland cliff	8220
H3.1d	Mediterranean siliceous inland cliff	8220
H3.2a	Boreal and arctic base-rich inland cliff	8210
H3.2b	Temperate high-mountain base-rich inland cliff	8210
H3.2c	Temperate, lowland to montane base-rich inland cliff	8210
H3.2d	Mediterranean base-rich inland cliff	8210
H3.2e	Boreal ultramafic inland cliff	8210
H3.2f	Temperate ultramafic inland cliff	8210
H3.2g	Mediterranean ultramafic inland cliff	8210
H3.3	Macaronesian inland cliff	
H3.4	Wet inland cliff	
H5.1a	Fjell field	
H5.1b	Polar desert	
H6.1	Mediterranean and temperate volcanic field	

Code	Name	Annex I
Anthropogenic vegetation classes (X)		
X01	Papaveretea rhoeadis	
X02	Sisymbrietea	
X03	Chenopodietea	
X04	Digitario sanguinalis-Eragrostietea minoris	
X05	Polygono-Poetea annuae	
X06	Artemisietea vulgaris	
X07	Epilobietea angustifolii	
X08	Matricario-Poetea arcticae	
X09	Bidentetea	
X10	Oryzetea sativae	

Annex 3 EUNIS level 3 habitat types not included in the analysis

Code	Name
A1.1	High energy littoral rock
A1.2	Moderate energy littoral rock
A1.3	Low energy littoral rock
A1.4	Features of littoral rock
A2.1	Littoral coarse sediment
A2.2	Littoral sand and muddy sand
A2.3	Littoral mud
A2.4	Littoral mixed sediments
A2.6	Littoral sediments dominated by aquatic angiosperms
A2.7	Littoral biogenic reefs
A2.8	Features of littoral sediment
A3.1	Atlantic and Mediterranean high energy infralittoral rock
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock
A3.3	Atlantic and Mediterranean low energy infralittoral rock
A3.4	Baltic exposed infralittoral rock
A3.5	Baltic moderately exposed infralittoral rock
A3.6	Baltic sheltered infralittoral rock
A3.7	Features of infralittoral rock
A4.1	Atlantic and Mediterranean high energy circalittoral rock
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock
A4.3	Atlantic and Mediterranean low energy circalittoral rock
A4.4	Baltic exposed circalittoral rock
A4.5	Baltic moderately exposed circalittoral rock
A4.6	Baltic sheltered circalittoral rock
A4.7	Features of circalittoral rock
A5.1	Sublittoral coarse sediment
A5.2	Sublittoral sand
A5.3	Sublittoral mud
A5.4	Sublittoral mixed sediments
A5.5	Sublittoral macrophyte-dominated sediment
A5.6	Sublittoral biogenic reefs
A5.7	Features of sublittoral sediments
A6.1	Deep-sea rock and artificial hard substrata
A6.2	Deep-sea mixed substrata
A6.3	Deep-sea sand
A6.4	Deep-sea muddy sand
A6.5	Deep-sea mud
A6.6	Deep-sea bioherms
A6.7	Raised features of the deep-sea bed
A6.8	Deep-sea trenches and canyons, channels, slope failures and slumps on the continental slope
A6.9	Vents, seeps, hypoxic and anoxic habitats of the deep sea
A7.1	Neuston
A7.2	Completely mixed water column with reduced salinity

Code	Name
A7.3	Completely mixed water column with full salinity
A7.4	Partially mixed water column with reduced salinity and medium or long residence time
A7.5	Unstratified water column with reduced salinity
A7.6	Vertically stratified water column with reduced salinity
A7.7	Fronts in reduced salinity water column
A7.8	Unstratified water column with full salinity
A7.9	Vertically stratified water column with full salinity
A7.A	Fronts in full salinity water column
A8.1	Sea ice
A8.2	Freshwater ice
A8.3	Brine channels
A8.4	Under-ice habitat
B1.7d	Mediterranean coniferous coastal dune woodland
B1.2	Sand beaches above the driftline
B2.2	Unvegetated mobile shingle beaches above the driftline
B2.3	Upper shingle beaches with open vegetation
B2.4	Fixed shingle beaches, with herbaceous vegetation
B2.5	Shingle and gravel beaches with scrub
B2.6	Shingle and gravel beach woodland
B3.2	Unvegetated rock cliffs, ledges, shores and islets
B3.3	Rock cliffs, ledges and shores, with angiosperms
C1.3	Permanent eutrophic lakes, ponds and pools
C1.7	Permanent lake ice
C2.2a	Permanent non-tidal, fast, turbulent watercourse of montane to alpine regions with mosses
C2.6	Films of water flowing over rocky watercourse margins
C3.1	Species-rich helophyte beds
C3.2	Water-fringing reedbeds and tall helophytes other than canes
C3.3	Water-fringing beds of tall canes
C3.4	Species-poor beds of low-growing water-fringing or amphibious vegetation
C3.6	Unvegetated or sparsely vegetated shores with soft or mobile sediments
C3.7	Unvegetated or sparsely vegetated shores with non-mobile substrates
C3.8	Inland spray- and steam-dependent habitats
C6.1	Underground standing and running waterbody
D3.3	Polygon mires
D5.1	Reedbeds normally without free-standing water
D5.2	Beds of large sedges normally without free-standing water
D5.3	Swamps and marshes dominated by [<i>Juncus effusus</i>] or other large [<i>Juncus</i>] spp.
D6.1	Inland saltmarshes
D6.2	Inland saline or brackish species-poor helophyte beds normally without free-standing water
E1.4	Mediterranean tall-grass and [<i>Artemisia</i>] steppes
E1.6	Subnitrophilous annual grassland
E1.C	Dry mediterranean lands with unpalatable non-vernal herbaceous vegetation
E1.D	Unmanaged xeric grassland
E1.E	Trampled xeric grasslands with annuals
E2.5	Meadows of the steppe zone
E2.6	Agriculturally-improved, re-seeded and heavily fertilised grassland, including sports fields and grass lawns
E2.7	Unmanaged mesic grassland
E2.8	Trampled mesophilous grasslands with annuals
E4.2	Moss and lichen dominated mountain summits, ridges and exposed slopes

Code	Name
E4.5	Alpine and subalpine enriched grassland
E5.1	Anthropogenic herb stands
E7.1	Atlantic parkland
E7.2	Sub-continental parkland
E7.3	Dehesa
F3.2	Submediterranean deciduous thickets and brushes
F5.2	Maquis
F6.3	Illyrian garrigues
F6.4	Black Sea garrigues
F6.5	Macaronesian garrigues
F7.2	Central Mediterranean spiny heaths
FA.1	Hedgerows of non-native species
FA.2	Highly-managed hedgerows of native species
FA.3	Species-rich hedgerows of native species
FA.4	Species-poor hedgerows of native species
FB.1	Shrub plantations for whole-plant harvesting
FB.2	Shrub plantations for leaf or branch harvest
FB.3	Shrub plantations for ornamental purposes or for fruit, other than vineyards
FB.4	Vineyards
G1.C	Highly artificial broadleaved deciduous forestry plantations
G1.D	Fruit and nut tree orchards
G2.4	[<i>Olea europaea</i>] - [<i>Ceratonia siliqua</i>] woodland
G2.7	Canary Island heath woodland
G2.8	Highly artificial broadleaved evergreen forestry plantations
G2.9	Evergreen orchards and groves
G3.5	[<i>Pinus nigra</i>] woodland
G3.A	[<i>Picea</i>] taiga woodland
G3.B	[<i>Pinus</i>] taiga woodland
G3.Da	<i>Pinus</i> mire woodland
G3.Db	<i>Picea</i> mire woodland
G3.E	Nemoral bog conifer woodland
G3.F	Highly artificial coniferous plantations
G4.1	Mixed swamp woodland
G4.2	Mixed taiga woodland with [<i>Betula</i>]
G4.3	Mixed sub-taiga woodland with acidophilous [<i>Quercus</i>]
G4.4	Mixed [<i>Pinus sylvestris</i>] - [<i>Betula</i>] woodland
G4.5	Mixed [<i>Pinus sylvestris</i>] - [<i>Fagus</i>] woodland
G4.6	Mixed [<i>Abies</i>] - [<i>Picea</i>] - [<i>Fagus</i>] woodland
G4.7	Mixed [<i>Pinus sylvestris</i>] - acidophilous [<i>Quercus</i>] woodland
G4.8	Mixed non-riverine deciduous and coniferous woodland
G4.9	Mixed deciduous woodland with [<i>Cupressaceae</i>] or [<i>Taxaceae</i>]
G4.A	Mixed woodland with [<i>Cupressaceae</i>], [<i>Taxaceae</i>] and evergreen oak
G4.B	Mixed mediterranean [<i>Pinus</i>] - thermophilous [<i>Quercus</i>] woodland
G4.C	Mixed [<i>Pinus sylvestris</i>] - thermophilous [<i>Quercus</i>] woodland
G4.D	Mixed [<i>Pinus nigra</i>] - evergreen [<i>Quercus</i>] woodland
G4.E	Mixed mediterranean pine - evergreen oak woodland
G4.F	Mixed forestry plantations
G5.1	Lines of trees
G5.2	Small broadleaved deciduous anthropogenic woodlands
G5.3	Small broadleaved evergreen anthropogenic woodlands

Code	Name
G5.4	Small coniferous anthropogenic woodlands
G5.5	Small mixed broadleaved and coniferous anthropogenic woodlands
G5.6	Early-stage natural and semi-natural woodlands and regrowth
G5.7	Coppice and early-stage plantations
G5.8	Recently felled areas
H1.1	Cave entrances
H1.2	Cave interiors
H1.3	Dark underground passages
H1.4	Lava tubes
H1.5	Underground standing waterbodies
H1.6	Underground running waterbodies
H1.7	Disused underground mines and tunnels
H3.5	Almost bare rock pavements, including limestone pavements
H3.6	Weathered rock and outcrop habitats
H4.1	Snow packs
H4.2	Ice caps and true glaciers
H4.3	Rock glaciers and unvegetated ice-dominated moraines
H5.2	Glacial moraines with very sparse or no vegetation
H5.3	Sparsely- or un-vegetated habitats on mineral substrates not resulting from recent ice activity
H5.4	Dry organic substrates with very sparse or no vegetation
H5.5	Burnt areas with very sparse or no vegetation
H5.6	Trampled areas
H6.2	Inactive recent volcanic features
I1.1	Intensive unmixed crops
I1.2	Mixed crops of market gardens and horticulture
I1.3	Arable land with unmixed crops grown by low-intensity agricultural methods
I1.4	Inundated or inundatable croplands, including rice fields
I1.5	Bare tilled, fallow or recently abandoned arable land
I2.1	Large-scale ornamental garden areas
I2.2	Small-scale ornamental and domestic garden areas
I2.3	Recently abandoned garden areas

Annex 4 Expert System for classifying vegetation plots to EUNIS habitat types

The Expert System for classifying vegetation plots to EUNIS habitat types is included in the file [BioScore3-Expert-system-EUNIS-2017-12-05.zip](#).

The expert system is divided into three sections. The first section contains the species synonymisation. Any species found in the plots will be checked against the synonyms. The second section comprises the species groups, and the third section the expert system rules (formulas).

The information used by the expert system includes the species composition of vegetation plots and percentage cover of species. Species composition is identified using groups of species that are similar in their ecology or distribution ranges. Each group is indicated by a three-character string which indicates how the group is used in the expert system. The basic types of species groups are the following:

Sociological species groups. The concept of sociological species groups follows Bruelheide (1997, 2000) and Kočí *et al.* (2003). A species group of this type is considered to be present in a vegetation plot if more than a specified number of species of the group is present in the plot. In the expert system file these groups are defined with the string ### followed by the group name. When the ### string is used in the formula defining the habitat type, the minimum number of species is by default set to half of the total number of species of this group. This default setting is useful especially for classification to finely-divided habitat types that is based on small sociological groups that contain few species. However, broad habitat types such as those used in the revised EUNIS classification are usually characterized by many species, but only few of them co-occur at particular sites representing the habitat type. Therefore, smaller thresholds can be specified by replacing two hashes by the minimum number of species required. For example, #03 followed by the group name used in the formula means that occurrence of at least three species of the group is required for the group to be considered as present in the plot.

Total-cover groups. The concept of total-cover groups follows Landucci *et al.* (2015). A species group of this type is considered to be present in a vegetation plot if the total cover of all species of the group exceeds a specified threshold. In the expert system file these groups are defined with the string ### followed by the group name, i.e. in the same way as the sociological species groups. The same species group can be therefore used both as a sociological species group and a total-cover group. The use of the group as a total-cover group is defined in the formulas by coding them with the string #TC and specifying the threshold cover. For example, <#TC Group-name GR 25> means that a group is considered to be present in the plot if its species have a total cover higher than 25% in this plot. This group can be represented by a single species with a cover higher than 25%, or several species, each with an individual cover lower than 25%, but with a cover exceeding 25% if their individual covers are combined.

Covers are combined based on an algorithm implemented in the Juice program, assuming random overlap of covers of individual species. This algorithm was proposed by Chytrý *et al.* (2005) and recently formally described by Fischer (2015). Alternatively, a cover of single species can be used instead of the total cover of a species group. The total-cover groups or covers of single species are especially useful to identify habitat types that are defined based on the dominant species, e.g. heathland is a habitat determined by the dominance of a few species of ericoid dwarf shrubs. Therefore the total-cover groups and covers of single species were extensively used in the expert system to define forests and scrub habitats (Schaminée *et al.*, 2016), but they are not useful for defining habitat types with weak and irregular dominance, particularly for grasslands.

Diagnostic species groups. The concept of diagnostic species groups follows Dengler *et al.* (2006) and Mucina *et al.* (2016). If this type of species group is used, each habitat type in the classification is represented by a single species group of this type, which includes its diagnostic species. One species can be assigned to more than one of these groups. The lists of the diagnostic for the expert system are initially prepared by compilation of the species lists published in the literature, which can be further modified based on statistical analysis of plots assigned to the habitat type. In the expert system file these groups are defined with the string `##D` followed by the group name. A plot is assigned to that habitat type whose diagnostic species group is most represented in this plot. The measure of representation can be the number of species of the group (in that case the `##D` string is used in the formulas), the total percentage cover of the group, based on the assumption of random overlap of individual species covers (`##C`) or the sum of square-rooted percentage covers of individual species (`##Q`). The last mentioned method provides an intermediate solution between the emphasis on species numbers and the emphasis on total species cover, which can, in some cases, lead to counter-intuitive classification (especially when a plot contain several species of one habitat type with small cover and one species of another habitat type with high cover).

These three types of species groups can be combined in single formulas defining the habitat types. In the formulas the conditions defined by species groups are combined using the logical operators AND, OR and NOT, following the proposals of Bruelheide (1997), and also relational operators GR (= greater than) or GE (= greater than or equal to). To define habitat types characterised by dominance of single species or species groups (e.g. forests, scrub, marshes, aquatic vegetation), total-cover groups are often sufficient. For grasslands, however, the use of diagnostic species groups is necessary.

The expert system can be used in a hierarchical mode. In that case, the definitions with the highest priority are applied to the dataset first, resulting in habitat assignment of some plots, while other plots remain unclassified. Then, the definitions with lower priority are applied only to the plots that have not been classified by the plots of higher priority. Consequently, one habitat type can have two definitions. The definition applied at a higher priority level can be based on the occurrence of sociological species groups or total-cover groups that include species narrowly specialized to this habitat. This definition usually classifies those plots that are very typical examples of the habitat, but it leaves many less typical plots of this habitat unclassified. Subsequently a definition at a lower priority level, based on diagnostic species groups, is applied to unclassified plots. This definition classifies plots that are less typical examples of the habitat but still exhibit a higher degree of membership to this habitat than to any other habitat. For example, on the first priority level of classification the habitat type E11a Pannonian and Pontic sandy steppe is defined by the formula:

```
<#TC E11a-Pannonian-and-Pontic-sandy-steppe-specialists GR15> NOT (<#TC Trees GR05> OR <#TC Shrubs GR05>)
```

which means that total cover of the species group E11a-Pannonian-and-Pontic-sandy-steppe-specialists, including a selection of narrow specialists of this habitat, must have a cover greater than 15% and neither the groups of trees nor the group of shrubs can have a cover higher than 5%. Then, the following formula defining the same habitat is applied to the plots that were not classified by the formulas on the first priority level:

```
(<##Q E11a-Pannonian-and-Pontic-sandy-steppe> AND <#03 E11a-Pannonian-and-Pontic-sandy-steppe>) NOT (<#TC Trees GR05> OR <#TC Shrubs GR05>)
```

which means that the sum of square-rooted percentage covers of a group of typical species of this habitat (including both the narrow specialists and frequently occurring less specialized species) is higher than the sum of square-rooted percentage covers of any other diagnostic species group and the plot contains at least three species of this group and the total cover of both trees and shrubs does not exceed 5%.

Annex 5 Lists of species

Status and frequency of occurrence in EUNIS habitats

The list of species, their status and frequency of occurrence in EUNIS habitats is included in the file [BioScore3-Species_classification.zip](#)

Calculated species indicator values

The list of species with their calculated indicator values is included in the file [BioScore 3-Species indicator values.zip](#)

Distribution of species over BGR's

The list of species and their distribution over Biogeographical Regions (BGR's) is included in the file [BioScore3-Species BGR_monitoringintensity.zip](#)

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