# BioScore 3 – Plants

Background and pre-processing of distribution data

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

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**BioScore 3 - Plants**

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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.

**Referaat**

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*Trefwoorden*: BioScore 3, Planten, Zoogdieren, Soortverspreiding, Multivariate regressie modellen, Univariate regressie modellen, EVA, European Vegetation Archive, Drivers, Drukfacturen, EIV’s, Ecologische indicatiegetallen.


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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 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 envelops. Dose-response functions for pressures, like N-deposition, were then defined within the boundaries of the envelop. 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 klimaat-verandering, stikstofdepositie en verandering van landgebruik. Dit rapport belicht de selectie en voorbewerkings-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 ruderale 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 geclassificeerd. Daaropvolgend is met statistische procedures een lijst van indicatorsoorten per habitattype bepaald. Als resultaat zijn voor iedere habitattype 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.

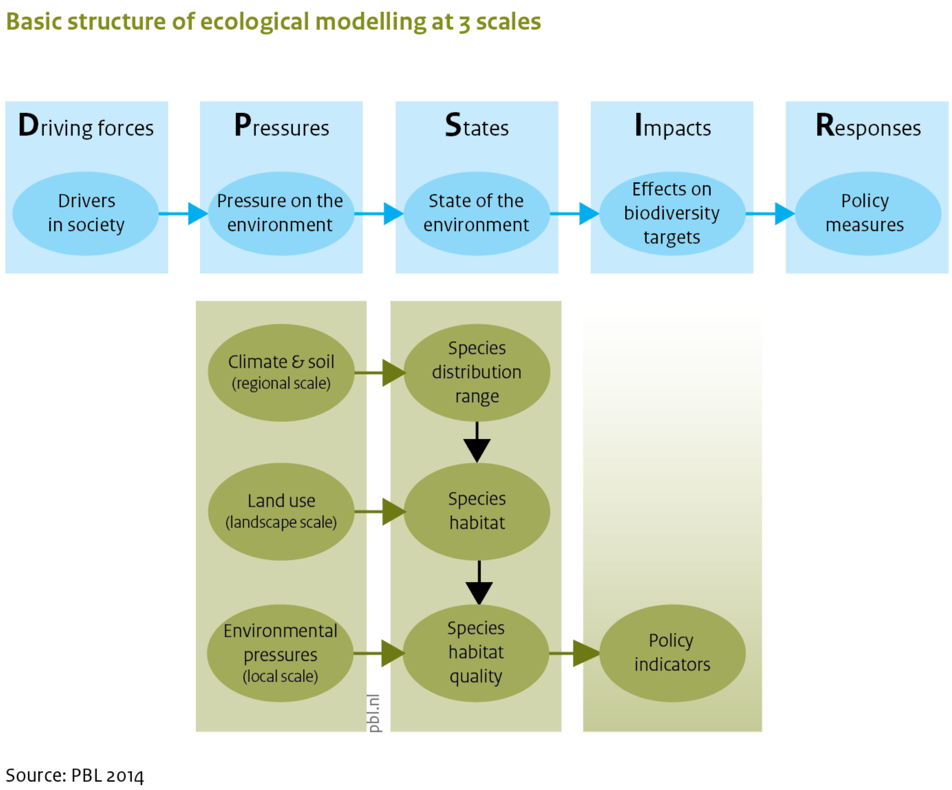


***Figure 1.1*** *Modelling the DPSIR-chain at different spatial scales. Source: Hinsberg et al. (2014).*

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.

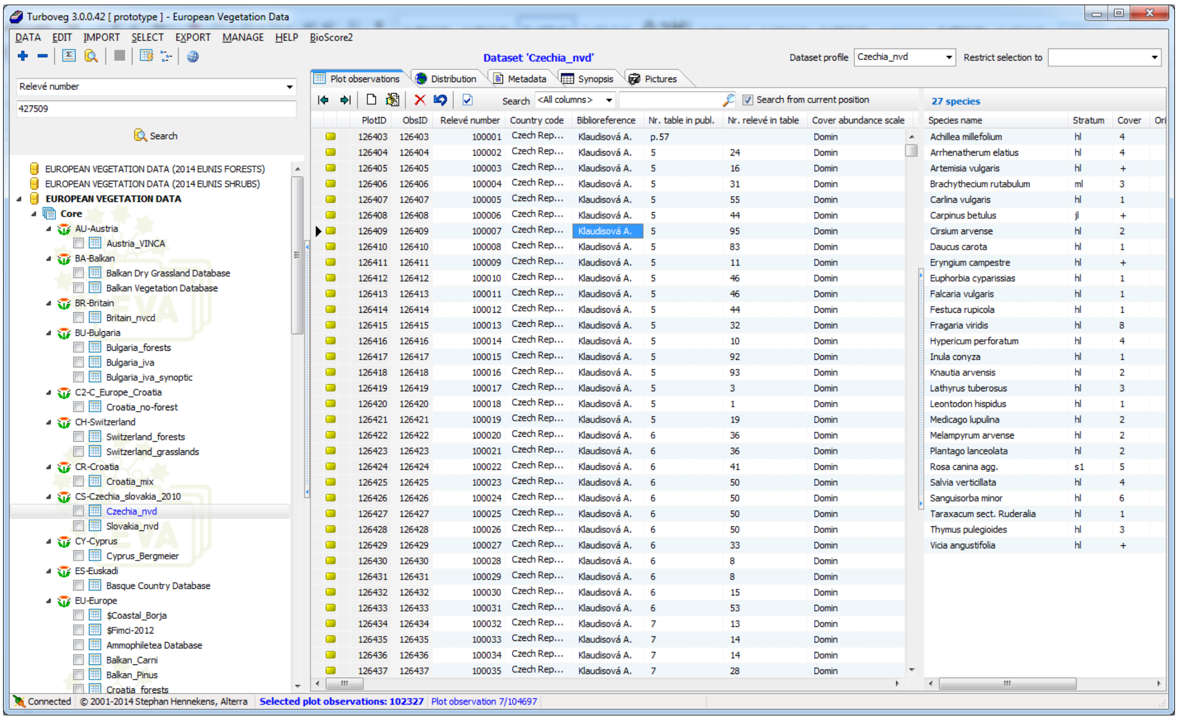

***Figure 2.1*** *Screenshot of the Turboveg 3, a database management program for vegetation plots.*

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).

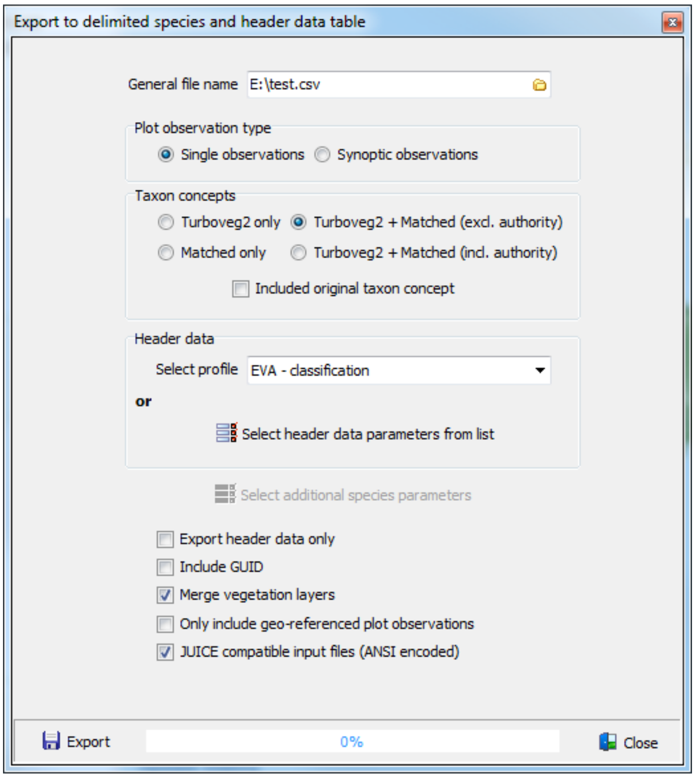


***Figure 2.2*** *Export in Turboveg 3 to delimited species and header data table with required settings for processing in JUICE.*

## 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 were 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.

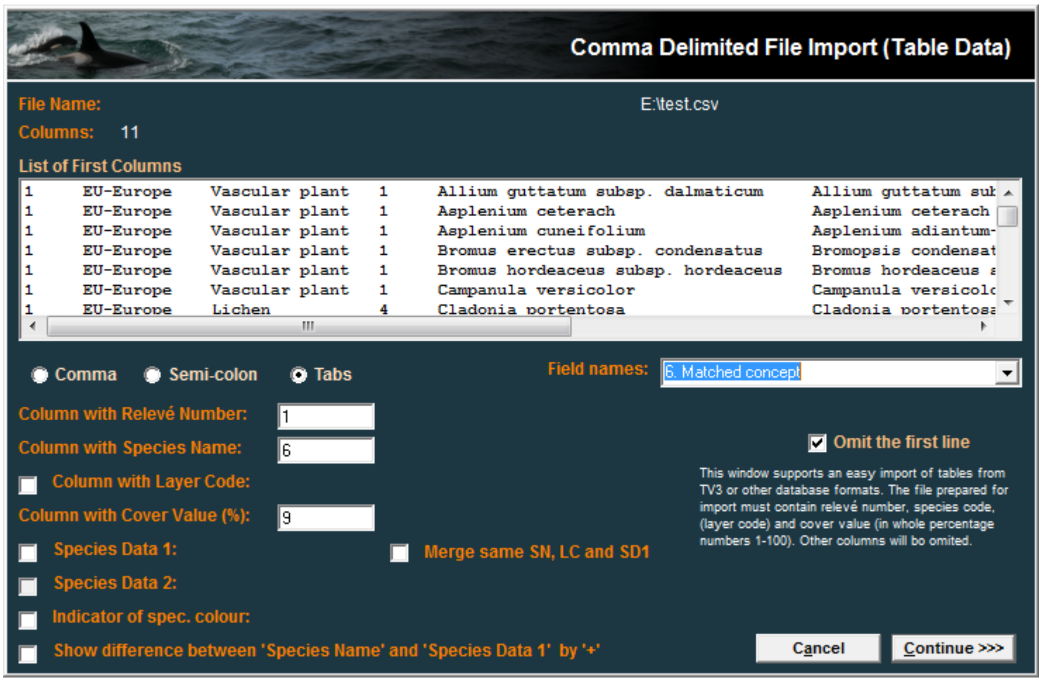


***Figure 2.3*** *Required import settings in JUICE.*

In short, the procedure in Juice is at 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).

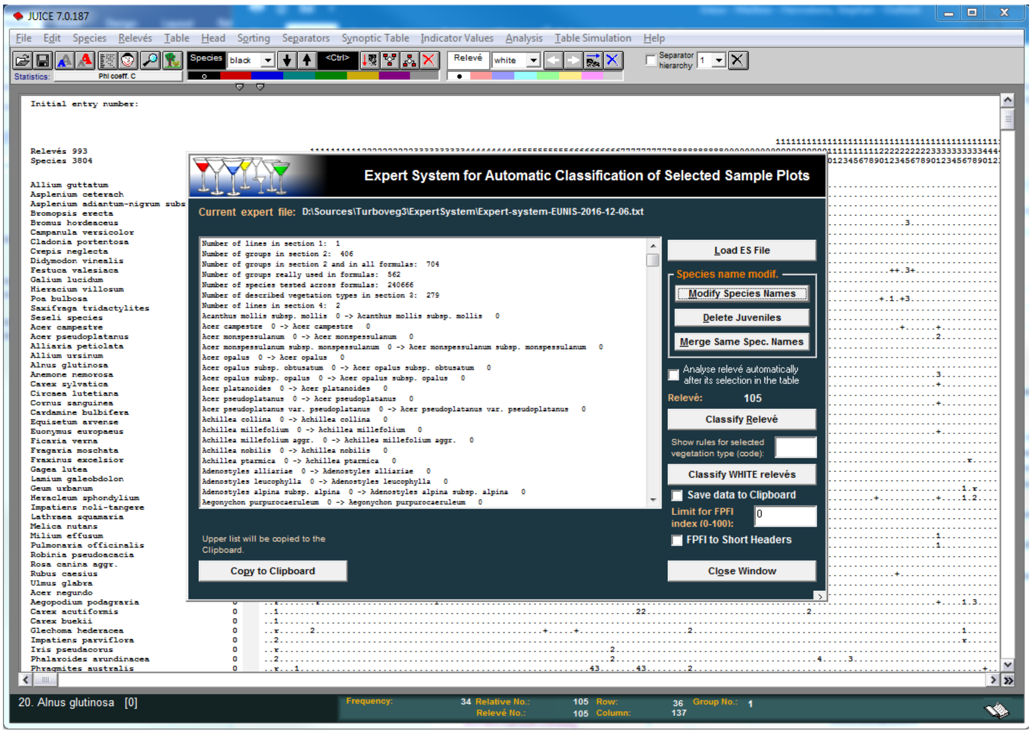


***Figure 2.4*** *Preparation of the classification in JUICE.*

2. 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).

3. 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.

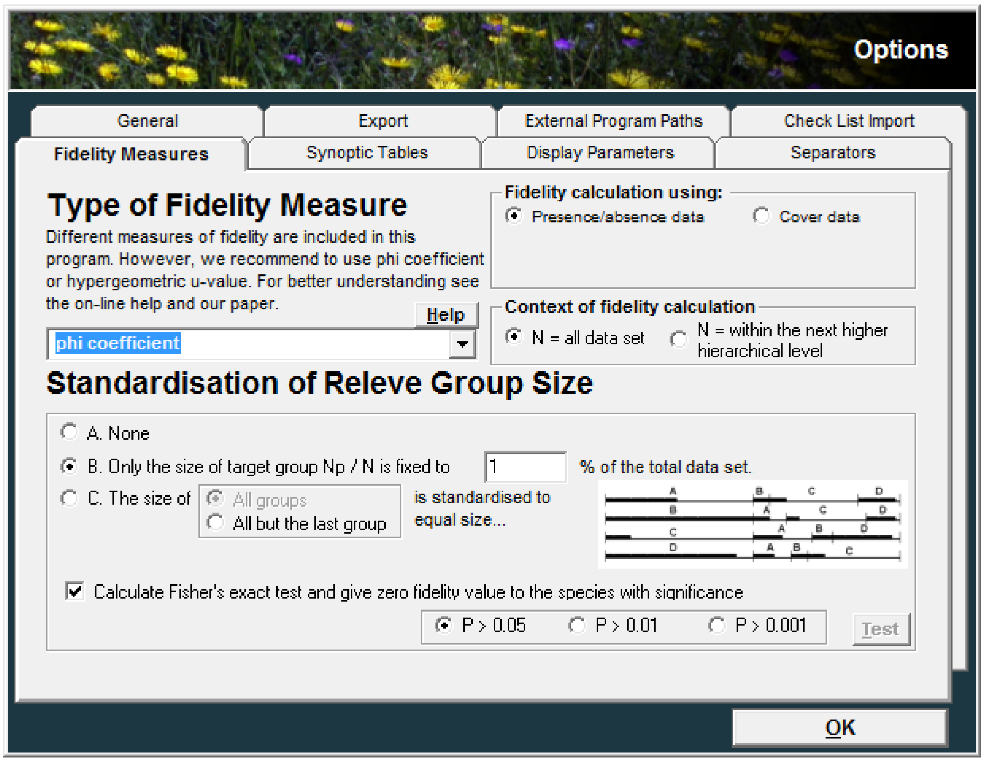


***Figure 2.5*** *Required settings for Phi Coefficient calculation.*

4. 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.

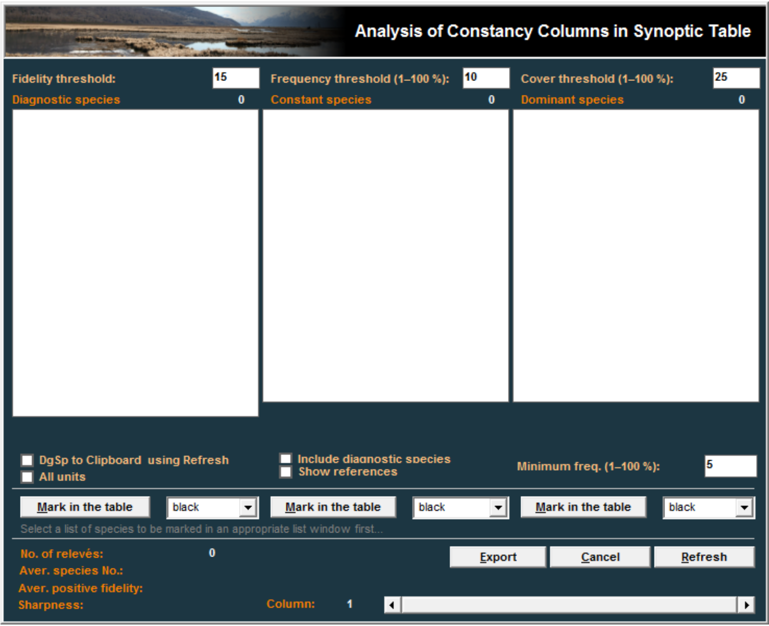


***Figure 2.6*** *Required settings in Analysis of Constancy Column in Synoptic Table.*

5. 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).

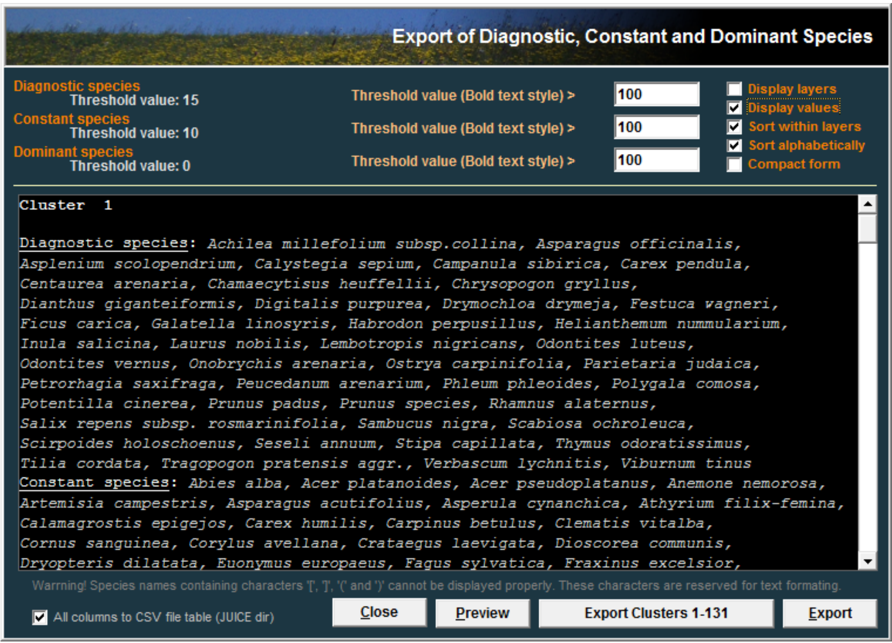


***Figure 2.7*** *Result of analysis.*

6. The result is exported to a file called 'synColExport.txt', which can be found in de 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 | Empetrum nigrum | 100 | B1.5a |
| CoSp | Carex arenaria | 93 | B1.5a |
| CoSp | Dicranum scoparium | 88 | B1.5a |
| CoSp | Salix repens | 69 | B1.5a |
| CoSp | Hypnum jutlandicum | 67 | B1.5a |
| CoSp | Calluna vulgaris | 58 | B1.5a |
| CoSp | Hieracium umbellatum | 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, there indicator status, there frequency as well as the assignment to Annex I habitat types (see Annex 5) can be used in the modelling to define and fine-tine 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 2016[1], and plots with a known spatial uncertainty above 1,000 meter. From this pool – for each species – one plot per $km^2$ was randomly selected to avoid spatial bias. On top of that, plots with one or more values of environmental variables[2] 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.

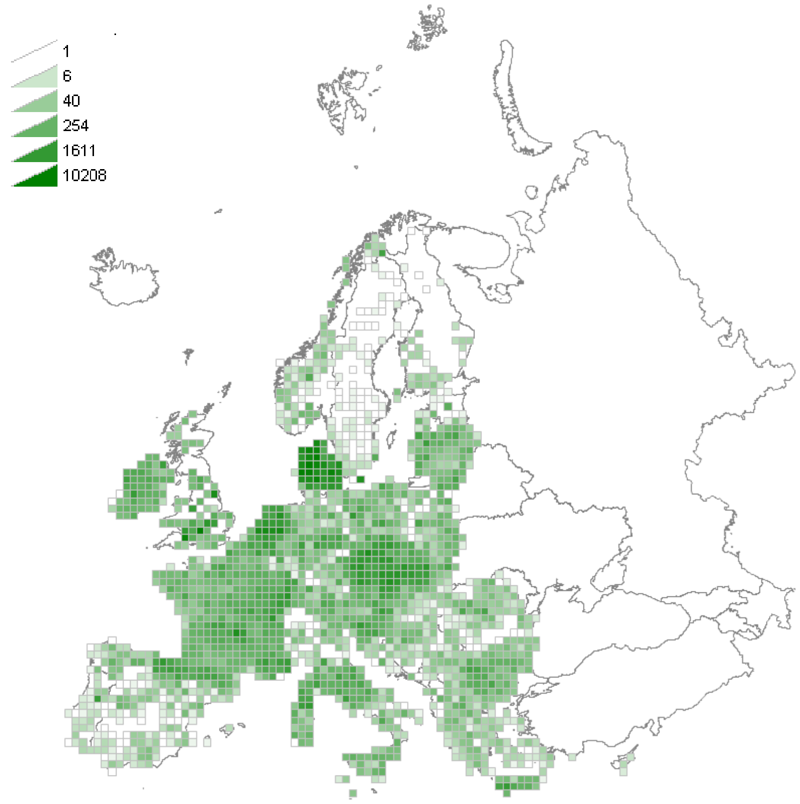


***Figure 2.8*** *Distribution of plots used for the BioScore modelling.*

[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.

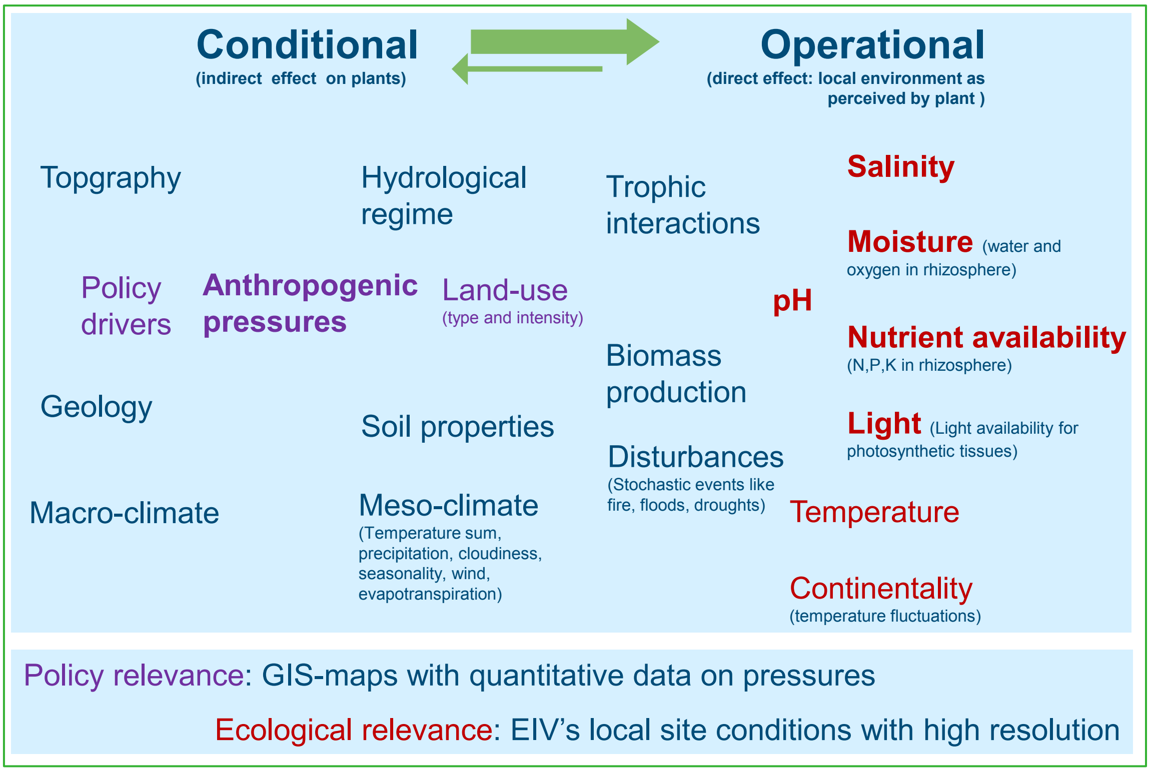


***Figure 3.1*** *Relative ranking of environmental variables according to their direct (causal) or indirect effect on plant performance. Many variables are linked to multiple other factors, often involving complex feedback processes but these links between variables are not shown. The position of factors 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 derives 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 constrain 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 occur[3]; (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 Kącki | 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 Ćušterevska | |
| 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 Ranunculus 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 Nardus 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 | Pteridium aquilinum 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 Salix scrub | |
| F2.2a | Alpine and subalpine ericoid heath | 4060 |
| F2.2b | Alpine and subalpine Juniperus scrub | 4060 |
| F2.2c | Balkan subalpine genistoid scrub | 4060 |
| F2.3 | Subalpine deciduous scrub | |
| F2.4 | Subalpine Pinus mugo scrub | 4070 |
| F3.1a | Lowland to montane temperate and submediterranean Juniperus 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 [Juncus effusus] or other large [Juncus] 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 [Artemisia] 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 | [Olea europaea] - [Ceratonia siliqua] woodland |
| G2.7 | Canary Island heath woodland |
| G2.8 | Highly artificial broadleaved evergreen forestry plantations |
| G2.9 | Evergreen orchards and groves |
| G3.5 | [Pinus nigra] woodland |
| G3.A | [Picea] taiga woodland |
| G3.B | [Pinus] taiga woodland |
| G3.Da | Pinus mire woodland |
| G3.Db | Picea 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 [Betula] |
| G4.3 | Mixed sub-taiga woodland with acidophilous [Quercus] |
| G4.4 | Mixed [Pinus sylvestris] - [Betula] woodland |
| G4.5 | Mixed [Pinus sylvestris] - [Fagus] woodland |
| G4.6 | Mixed [Abies] - [Picea] - [Fagus] woodland |
| G4.7 | Mixed [Pinus sylvestris] - acidophilous [Quercus] woodland |
| G4.8 | Mixed non-riverine deciduous and coniferous woodland |
| G4.9 | Mixed deciduous woodland with [Cupressaceae] or [Taxaceae] |
| G4.A | Mixed woodland with [Cupressaceae], [Taxaceae] and evergreen oak |
| G4.B | Mixed mediterranean [Pinus] - thermophilous [Quercus] woodland |
| G4.C | Mixed [Pinus sylvestris] - thermophilous [Quercus] woodland |
| G4.D | Mixed [Pinus nigra] - evergreen [Quercus] 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 checks 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_monitoringintensty.zip*

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