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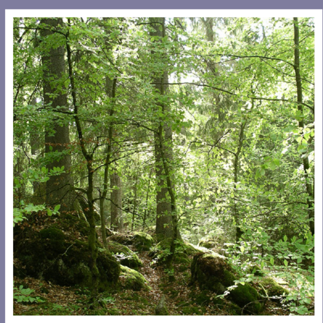

European Environment Agency

Linking *in situ* vegetation data to the EUNIS habitat classification: results for forest habitats

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Annexes 1–4 are available on http://www.eea.europa.eu/publications/eunis-habitat-classification

Acronyms and abbreviations

EEA	European Environment Agency
EFT	European Forest Type
Eionet	European Environmental Information and Observation Network
ETC/BD	European Topic Centre on Biological Diversity
EU	European Union
EUNIS	European Nature Information System (http://eunis.eea.europa.eu)
EVA	European Vegetation Archive
MAES	Mapping ecosystems and ecosystem services
NDVI	Normalised Difference Vegetation Index, an index of plant 'greenness'

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The following European Environmental Information and Observation Network (Eionet) experts participated in an Eionet expert workshop in February 2015 and contributed to the discussion of the results and the challenges regarding the maintenance of EUNIS habitat classification: Mora Aronsson (Swedish University of Agricultural Sciences (SLU), Sweden), Dimitri Brosens (Research Institute for Nature and Forest, Belgium), Laura Casella (Ispra, Italy), Raymond Delarze (BEB SA Bureau d'études biologiques, Switzerland), Vincent Gaudillat (National Museum of Natural History (MNHN), France), Aysun Demet Guvendiren (Ministry of Forestry and Water Affairs, Turkey), Tytti Kontula (Data and Information Centre, Finland), Line-Kristin Larsen (Environment Agency, Norway), Sandra Mesquita (Instituto Superior Técnico, Portugal), Johannes Petersiel (Environment Agency Austria (UBA), Austria), Matej Petkovšek (Institute for Nature Conservation, Slovenia), Slavisa Popovic (Environmental Protection Agency, Serbia), Piotr Rojek (General Directorate of Environmental Protection, Poland), Eleni Tryfon (Ministry for Environment, Energy and Climate Change, Greece), Libor Ulrych (State Nature Conservancy, Slovakia) and Juan Manuel Villares (Spanish Data Bank of Nature, Spain).

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About this report

The EUNIS habitat classification provides the context for a number of policy-related ecosystem and habitat assessments, and is a European reference to which other national or regional classifications can be cross-referenced when sharing geospatial data. Since 1995, it has been developed and managed by the European Topic Centre on Biological Diversity (ETC/BD), formerly known as the European Topic Centre on Nature Protection and Biodiversity (ETC/NPB), for the European Environment Agency (EEA) and the European Environmental Information Observation Network (Eionet). The review of terrestrial EUNIS habitat classification, on the basis of georeferenced vegetation samples, aimed to enhance the technical capacity for documenting, monitoring and assessing the quality of habitats at the European level. This review was carried out between 2012 and 2014 within the remit of the EEA Biodiversity data centre; forest habitats were used as a pilot case to test the approach. This work strengthens the knowledge base that is used for assessing progress towards the European Union (EU) and global biodiversity targets for 2020 ([1]).

Chapter 1 contains information on EUNIS habitat classification and the rationale for the review of the terrestrial part of this habitat classification. It introduces, in summary, the 2012 crosswalks between EUNIS terrestrial and freshwater habitats and vegetation syntaxa (plant communities), developed by Schaminée et al. (2012). These crosswalks are the basis on which vegetation-plot data are selected for further analysis in relation to EUNIS habitat classification. The methodology used for the review and the mapping of EUNIS habitats is also presented.

Chapter 2 presents the results of the review of EUNIS level 3 (EUNIS-3) forest habitats using vegetation-plot data, from the work by Schaminée et al. (2013). Chapter 3 presents the maps developed, showing the distribution of vegetation plots and the predicted habitat suitability for EUNIS-3 forest habitats, by Schaminée et al. (2014). It also includes information on the results obtained so far with regard to using the habitat suitability maps for revised EUNIS-3 forest habitats, in combination with land cover data from Mücher et al. (2015).

Chapter 4 presents the next steps required for the development of EUNIS-3 habitat classification, including the main points raised at an Eionet workshop, held in February 2015, involving experts from different countries. Recommendations on the use of vegetation-plot data for assessing changes in habitats over time, based on a paper by Schaminée et al. (2012), and elements of an Eionet strategy for collecting more *in situ* vegetation data for multiple purposes are also included in this chapter.

The following information is available in the report annexes:

- Annex 1 contains the complete list of forest habitats in the EUNIS habitat classification (2007) with the currently proposed revision, as discussed in Chapter 2;
- Annex 2a and 2b details the crosswalks between EUNIS forest habitats and vegetation syntaxa used in this work (2013), as explained in Chapter 2;
- Annex 3 contains data sheets with the results of the review for each forest habitat, as discussed in Chapter 2;
- Annex 4 contains the maps of distribution of vegetation plots and habitat suitability, as discussed in Chapter 3.

These information products will be available online from the EUNIS web page ([2]) and the Biodiversity data centre of the EEA ([3]). Readers interested in more specific information on the methodologies used are advised to consult the original reports from 2012, 2013 and 2014, as published on the Eionet forum ([4]).

([1]) http://biodiversity.europa.eu/policy, accessed 23 November 2015.
([2]) http://eunis.eea.europa.eu/habitats-code-browser.jsp and http://www.eea.europa.eu/themes/biodiversity/eunis/eunis-habitat-classification, both accessed 23 November 2015.
([3]) http://www.eea.europa.eu/data-and-maps/data/predicted-habitat-suitability-for-eunis, accessed 23 November 2015.
([4]) http://forum.eionet.europa.eu/nrc-biodiversity-data-and-information/library/eunis_classification, accessed 23 November 2015.

1 EUNIS habitat classification and its review on the basis of vegetation-plot data

This chapter introduces the EUNIS habitat classification and describes the processes developed for the review and the consequent habitat suitability mapping.

1.1 EUNIS habitat classification

The EUNIS habitat classification (Davies et al., 2004; updated by the EEA and ETC/BD in 2007 ([5])) is the most comprehensive hierarchical approach for describing habitats in all European ecosystems (marine, freshwater and terrestrial; natural and anthropogenic). It is the only European classification that covers all ecosystem types, and is supported and open to further development. Its aims and principles are summarised in Box 1.1.

The EUNIS habitat classification was developed by the ETC/BD, with the support of a large number of contributors, from 1995 onwards; the current version (2007) has changed only slightly since 2004. In view of the value of its coherent application at the European level, and the long-term task of its validation and maintenance, the EEA has become the 'guardian' of this classification with the support of the ETC/BD.

Box 1.1 Aims and principles of EUNIS habitat classification

Aims:

- to provide a 'common language' across countries;
- to enable mapping of units at a regional level;
- to be comprehensive and applicable at different levels of complexity;
- to allow aggregation, evaluation and monitoring of habitat units;
- to provide a common framework, new information and links to other classifications.

Principles:

- the classification is hierarchical;
- the units at a given hierarchical level are of similar importance;
- the criteria are clear for each division up to level 3;
- the units at level 4 and below follow the criteria of higher levels;
- the sequence of units is logical;
- the language is clear and non-technical;
- the ecologically distinct habitat types, which support different plant and animal communities, are separated;
- habitats from different locations that differ on the basis of only geographical range are not separated;
- the habitat units and habitat complexes are separated.

Source: Davies et al., 2004.

([5]) http://eunis.eea.europa.eu/habitats-code-browser.jsp, accessed 23 November 2015.

Key features of the EUNIS classification, which contribute to its utility, are the crosswalks made to other classifications, which make it a unique tool for translating between the different classifications used in Europe ([6]). EUNIS includes crosswalks to and from other classifications such as the Palaearctic classification, the Corine Biotopes and Corine Land Cover databases, vegetation syntaxa (the European Vegetation Survey), Nordic vegetation types, some national classifications (e.g. those used in the Czech Republic, the United Kingdom and Switzerland) and the European Forest Types (EFTs) (EEA, 2007). The crosswalk between EFTs and EUNIS-3 forest habitats will be described in more detail in a coming EEA report, which will also include complete factsheets for EUNIS forest habitats.

There is also crosswalk to the habitats listed in Annex I of the Habitats Directive (which is not a classification). This is important because it provides the opportunity for countries to understand the relationship between habitats listed in this directive and national classifications via crosswalk to EUNIS habitat classifications.

In 2011, the EEA and ETC/BD undertook a review of the practical applications of the EUNIS habitat classification and the current legislation and policy requirements which challenge its validation and maintenance.

Practical applications of the classification, before this review, included the development of European and national indicators of the impact of excess critical loads of nitrogen on ecosystems, and the identification of important plant areas and marine habitat mapping projects. The EUNIS classification has also been used in several EU-funded research projects related to biodiversity, including the ALARM ([7]) project. A number of European countries are using it for assessment work and others have developed crosswalks to EUNIS from their national and local habitat classifications (see also Chapter 4 and EEA, 2014).

The set of requirements for updating EUNIS habitat descriptions, and updating or developing new crosswalks, are related to the implementation of the Bern Convention ([8]) (i.e. the pan-European Convention on the Conservation of Wildlife and Natural Habitats). One of the activities of the Bern Convention has been the establishment of the Emerald network ([9]), a network of protected areas across Europe that includes Natura 2000 sites in EU member States. The list of habitat types in Annex I of Resolution 4 of this convention, for which sites must be proposed and notified by non-EU countries, is now based on the EUNIS habitat classification. Further to this, distribution maps for selected EUNIS habitats are also to eventually be reported by these same countries and, in addition, all European countries for the 70 European Diploma areas, established under the Council of Europe, are requested to provide EUNIS habitat information.

Another set of requirements related to the EUNIS habitat classification derives from its adoption as one of two standard code lists for the Annex III theme habitats and biotopes of the EU INSPIRE Directive on the establishment of an infrastructure for spatial information in the European Community ([10]). As a consequence, EU Member States will have to map their national classification systems to EUNIS classifications. An example is the *Manual of terrestrial EUNIS habitats in Scotland* ([11]). Non-EU countries, such as Norway and Switzerland, are also implement INSPIRE; therefore, it is clear that the EUNIS classification needs to be maintained and reviewed, and there needs to be a well-established process in place for revisions and additions.

Current policy requirements are related to achieving the maintenance and enhancement of ecosystems and their services by establishing 'green' infrastructure and restoring at least 15% of degraded ecosystems, as stated in Target 2 of the EU Biodiversity Strategy. EUNIS level 2 habitat classifications are used by individual countries and the EEA to map and assess ecosystems and their services in the context of the mapping ecosystems and ecosystem services (MAES) initiative of the European Commission ([12]). The review of the current EUNIS-3 habitats is expected to support this exercise, as well as to support an extensive network of experts from EU Member States in the European Red List of Habitats project, funded by the European Commission.

In response to the above requirements, the review of EUNIS-3 terrestrial habitats on the basis of vegetation-plot data was considered a priority, in order

([6]) All EUNIS crosswalks can be found at http://www.eea.europa.eu/themes/biodiversity/eunis/eunis-habitat-classification#tab-documents.
([7]) http://www.alarmproject.net.
([8]) http://biodiversity.europa.eu/policy/pan-europea/pan-european-initiatives-and-european-conventions; http://www.coe.int/t/dg4/culturehertiage/nature/Bern/default_en.asp.
([9]) http://www.coe.int/t/dg4/cultureheritage/nature/econetworks/default_en.asp.
([10]) http://inspire.ec.europa.eu/index.cfm/pageid/2/list/7.
([11]) http://www.snh.gov.uk/publications-data-and-research/publications/search-the-catalogue/publication-detail/?id=2207.
([12]) http://biodiversity.europa.eu/maes.

to strengthen the scientific basis of the classification and the description of habitats. It is expected that the EUNIS-3 review will provide a good basis for decisions with regard to the review of levels 4–7, which were derived from the Palaearctic classification and are important from a country perspective (see Chapter 4).

In particular, the crosswalks between EUNIS-3 and vegetation syntaxa (EuroVegChecklist version 2012 ([13])) should greatly enhance the value of EUNIS habitat classification as a reference for other habitat schemes, notably Annex I of the Habitats Directive. It suggests that EUNIS-3 habitats could provide a sound basis for monitoring habitat condition and change, and for furnishing a typology for the habitat evaluation in the European Red List of Habitats project, as shown in Chapter 4, enabling cross-comparisons of evaluation scores between countries within the EU and beyond. Vegetation syntaxa and their EUNIS-3 crosswalks are explained in more detail in Section 1.2.

The other benefit of phytosociology, with regard to the definition of EUNIS habitats, is that alliances comprise associations that are referred to by the type of vegetation plots, and are often supported by numerous vegetation-plot data, for which the most frequent and diagnostic species provide the basis of their definition, hence leading to better definitions and descriptions. Therefore, even if EUNIS-3 habitats comprise numerous alliances, it should be possible to combine lists of such species to produce broad floristic profiles that should help to define, interpret and identify EUNIS-3 habitats. This could also provide a sound basis for using EUNIS as a framework for monitoring, by highlighting species that could serve as indicators of condition or change.

1.2 Reconstructing the crosswalks between terrestrial EUNIS-3 habitat types and phytosociological syntaxa

The first syntaxa-to-EUNIS habitat crosswalk, and an introduction to the background and application of this approach, was published by Rodwell et al. (2002). Since then, changes have been made to the EUNIS habitat classification and, much more substantially, to the overview of European syntaxa at the levels of alliance, order and class, in a detailed revision by the European Vegetation Survey (EVS) team headed by Ladislav Mucina (Mucina et al., in preparation). The resulting EuroVegChecklist (version 2015) is more up to date and thorough with regard to syntaxonomy, and is more geographically comprehensive. The version dated 8 July 2012 was used to reconstruct the crosswalks between EUNIS-3 habitats and vegetation syntaxa([14]). Documentation of each stage of this work, together with the developed crosswalks, can be found in Schaminée et al. (2012) and on the EUNIS website ([15]).

A number of points related to the reconstructed crosswalks and the review of the EUNIS habitat classification (current version 2007) are discussed below.

The most obvious limitation of the crosswalks is the uneven relationship between EUNIS-3 habitats and phytosociological units. Although described as a habitat classification, EUNIS is, in fact, a complex mixture of categories of varying character and scale. Some EUNIS-3 habitats with a biotic element have a relatively narrow definition, while others are defined more broadly. For some definitions, biogeographical distinctions are made (e.g. Atlantic, Mediterranean, Macaronesian, Continental or Alpine); for others, terrain, soil or hydrological conditions are invoked (e.g. trophic state, soil moisture levels or salinity), or aspects of management are highlighted (e.g. tillage, fertilising or coppicing); and for others, physiognomic features of the vegetation are used (open or closed swards, herbage height or kinds of woody canopies), or particular species or genera names are used, either alone (e.g. *Spartium junceum, Ilex aquifolium* or *Pinus*) or in groups (e.g. Alpine *Larix–Pinus*). The relationships between EUNIS-3 habitats and units, defined primarily in relation to species content, will, therefore, inevitably be complex.

In some cases, the results of this top-down hybrid approach coincide neatly with the outcome of the more uniform bottom-up methodology of phytosociology. Only rarely does this result in one-to-one relationships between particular EUNIS-3 habitats and single alliances (and then not always exclusively); more frequently, for almost one-third of EUNIS-3 habitats, there is a useful simplicity of equivalence, expressed in links at class level. Even if large numbers of alliances are involved in such equivalences, this indicates some measure of coherence in the character of the vegetation represented within the EUNIS-3 habitats.

In cases in which EUNIS-3 habitats are more heterogeneous in their phytosociological relationships, with many equivalent alliances or even different classes,

([13]) http://eunis.eea.europa.eu/externalglobal?query=syntaxa.
([14]) An updated version of the EuroVegChecklist (May 2013 version), has been consequently developed for the forest review and, at present, the latest version of the EuroVegChecklist (version 2015) has been submitted for publication.
([15]) The 2012 crosswalks can be found on the EUNIS website (http://eunis.eea.europa.eu/externalglobal?query=syntaxa).

the crosswalks can help to resolve problems of habitat definition. In some cases, this heterogeneity occurs because EUNIS-3 habitats are obviously broadly defined habitats for which internal vegetation patterns are widely acknowledged and understood. In other cases, heterogeneity reflects the occurrence, within a EUNIS-3 habitat, of analogous vegetation types occurring in different climatic regions. Sometimes both of these scenarios coincide. In such cases, the phytosociological relationships revealed by the crosswalks could be used to further divide EUNIS-3 habitats, in order to reflect habitat or biogeographical distinctions.

In fact, phytosociological alliances are not themselves equal in content or weight in the syntaxonomic hierarchy. Some alliances comprise few associations,

Box 1.2 Vegetation-plot databases across European countries

Vegetation plots are records of plant species composition, in plots of 1 m^2 to a few hundred m^2, which have been collected by phytosociologists — scientists that study plant communities—in Europe since the early 20th century (Braun-Blanquet, 1928; Mueller-Dombois and Ellenberg, 1974). They typically include a complete list of vascular (and often non-vascular) plant species, cover-abundance estimates for each species, and basic geographical and environmental data. Most plots are dated and spatially located, although with variable accuracy. Most vegetation plots were established to document the diversity of vegetation types or as a source of data for vegetation classification. These are also known as phytosociological plots or *relevés*. However, some vegetation plots were established for other purposes, most notably for monitoring vegetation change over time, and are known as permanent plots. Vegetation plots have also been collected as part of various national forest inventories.

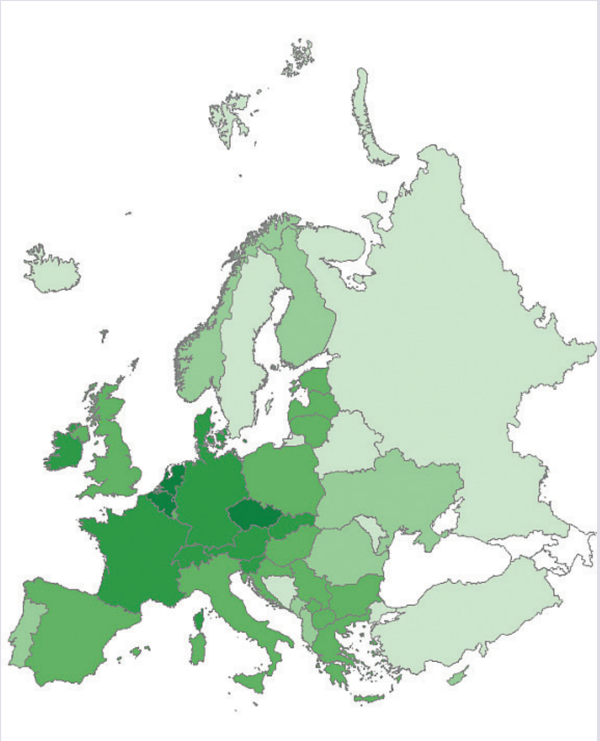
The development of compatible software tools has greatly encouraged the development of national and regional vegetation databases. The major software tool that has been used for database development is Turboveg (Hennekens and Schaminée, 2001). Turboveg is now accepted as an international standard for data input, storage, management and retrieval, and is currently used by over 30 countries in Europe and beyond. The JUICE program is complementary to Turboveg and has a wide range of analytical tools for use with data sets that may comprise hundreds of thousands of vegetation plots (Tichý, 2002).

Based on data from 32 countries, Schaminée et al. (2009) suggested that more than 4.3 million vegetation plots had been recorded in Europe by 2009. Most of these plots were sampled in the countries of central and western Europe, particularly Germany, the Netherlands and France, but considerable numbers of existing vegetation plots were also reported for Poland, Spain, the Czech Republic, Italy, the United Kingdom and Austria. Of these 4.3 million vegetation plots, more than

1.8 million had already been computerised in 2009, and 59% were available in Turboveg format.

Very recently, Chytrý et al. (2015) referred to the European Vegetation Archive (EVA), which contains 61 databases covering all European regions. These databases contribute a total of 1 027 376 vegetation plots, 82% of which have geographic coordinates, from 57 countries, and they provide a unique data source for large-scale analyses of European vegetation diversity, both for fundamental research and for nature conservation applications ([16]). Figure 1.1 shows the plot density across Europe, according to these databases.

Figure 1.1 Vegetation plot density in European countries



Note: The darker shades of green refer to higher vegetation plot density.

Source: EVA, 2015.

([16]) Updated information on the EVA is available http://euroveg.org/eva-database.

while others include many, and the range of variation with regard to their floristic compositions is very variable. However, alliances are mutually exclusive, each comprising distinct vegetation types with a unique relationship to a particular combination of climatic, soil and biotic influences, including land use. Inevitably, for a classification like EUNIS, in which habitats are defined broadly or by using different criteria in different groups, vegetation of the same alliance may be represented in several EUNIS-3 habitats. The crosswalks can help to identify situations in which EUNIS-3 habitats are not defined in a mutually exclusive fashion, and suggest further improvements for the classification.

For cases in which clearly different alliances are linked to a single EUNIS-3 habitat, or in which the linkage seems inappropriate, the crosswalks can help to identify possible additions or other changes to EUNIS habitat classification.

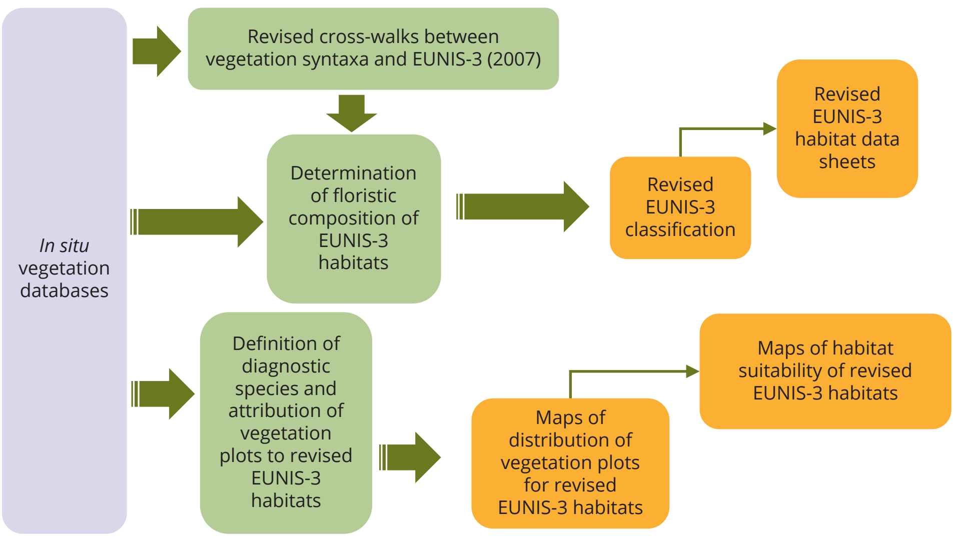
In conclusion, the new crosswalks provide a more comprehensive and up-to-date scientific basis in phytosociology for the EUNIS habitat classification, and suggest that EUNIS-3 could be revised and improved by clarifying the definition of habitats, by dividing existing units and by adding further units. The systematic cataloguing of relationships among the EUNIS-3 habitats and alliances, in both directions, renders the EUNIS habitat classification more meaningful and appealing to a widely dispersed constituency of users, already familiar with phytosociology, within and beyond Europe. On the basis of the crosswalks, the wealth of digitised vegetation plots can be used for the review of the EUNIS-3 terrestrial habitats.

1.3 The EUNIS habitat review and mapping methodology

The methodology for the review, update and mapping of EUNIS-3 habitat classification using *in situ* vegetation data, was developed over a 3-year period (2012–2014). In recent years, the number of georeferenced vegetation samples, also known as vegetation plots or *relevés*, available in digital format has increased immensely through the work of the European Vegetation Survey team, a working group of the International Association for Vegetation Science, and, in particular, as a result of its database, the EVA. Because of this, and the development of common standards and widely used software tools, such as Turboveg and JUICE (Hennekens, 1996; Hennekens and Schaminée, 2001; Tichý, 2002), there is, for the first time, an opportunity to link *in situ* vegetation data with the assessment of terrestrial habitats at a European scale.

The simplified steps of the review and mapping methodology are shown in a schematic form in Figure 1.2.

Figure 1.2 Simplified overview of the methodology for linking *in situ* vegetation data to EUNIS habitat classification



Note: The review steps are in green and final products are in orange. Final products will be accessible from the EEA Biodiversity data centre (http://www.eea.europa.eu/themes/biodiversity/dc).

1.3.1 *Reviewing and improving the EUNIS habitat classification*

The starting point for the selection of vegetation plots to be analysed for the EUNIS review are the 2012 crosswalks between EUNIS-3 habitats and vegetation syntaxa. From the outset, it is necessary to update the relevant parts of the crosswalks (in the context of the current report, the relevant part is the forest element), in order to correspond with the the EuroVegChecklist (version 2103). This update reflects the merging of some alliances, the dividing of others, the introduction of new alliances and changes in the delimitation of some alliances, which influence established matches with EUNIS-3 habitats.

The detailed steps of the review process are illustrated in Figure 1.3.

The first step of the procedure is to compile a database in Turboveg format of publically available plots from the EVA database, containing data sets from a wide range of data providers throughout Europe. Vegetation plots of regional and national data sets are classified at the level of EuroVegChecklist alliances, by matching the regional and national classification systems with the European overview. At present, it is possible to assign about 40% (236 000) of 670 000 public vegetation plots to one of the alliances accepted in the EuroVegChecklist (version 2013).

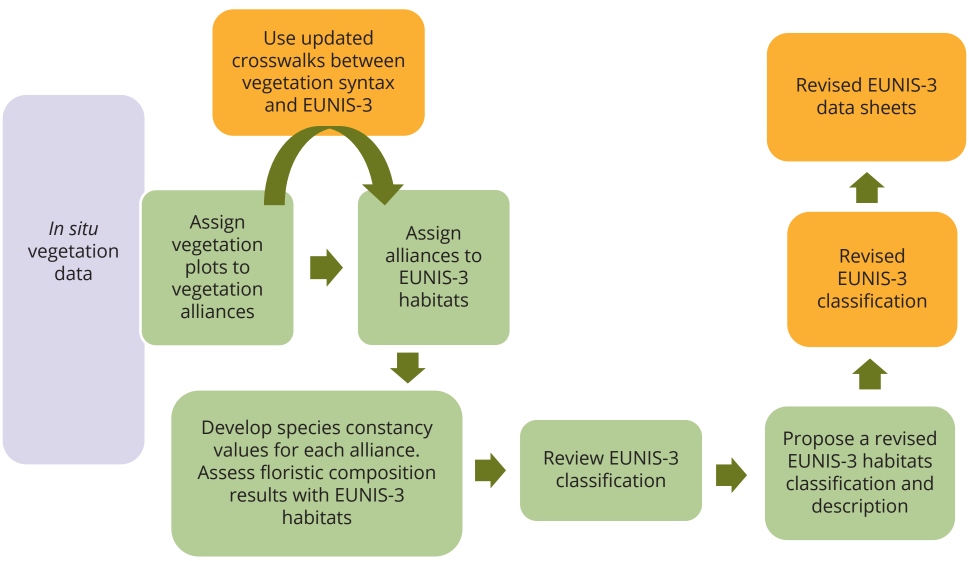
In a second step, the assignment to EUNIS habitat types is performed by merging the data sets of the alliances to the corresponding EUNIS type, according to the updated crosswalks between EUNIS-3 and syntaxa.

The third step is to calculate species constancy values in the vegetation plots assigned for each alliance. Using the updated crosswalks, the resulting species frequencies that are above 10% are attributed to each EUNIS-3 habitat.

Based on this, two types of recommendations for improving the EUNIS habitat classification can be proposed: one relates to the content of the habitat types and one to their naming. The proposals to improve the content of EUNIS habitat types are derived as a result of comparing the existing EUNIS classification with the phytosociological content of the assigned syntaxa.

With regard to the names of the EUNIS habitat types, a set of general recommendations was derived and, if relevant, were clarified by one or more examples which were applied to the existing classification (see Box 1.3).

Figure 1.3 Detailed overview of the review of EUNIS-3 habitats on the basis of vegetation-plot data



Box 1.3 General recommendations for improving the naming of EUNIS-3 habitats

1. Adopt brief and clear names for habitat types.
2. If possible, ensure that the names are recognisable to users of related existing classifications.
3. Names within a group of related habitats should be mutually exclusive with regard to, for example, biogeographical zones, soil conditions and dominant species.
   - *Example*: G1.1 (Broadleaved deciduous woodland) and G1.2 (Mixed riparian floodplain and gallery woodland) relate only to the temperate and boreal zone and are defined against G1.3 (Mediterranean riparian woodland) for the Mediterranean and Macaronesian zone.
   - *Example*: G1.4 (Broadleaved swamp woodland not on acid peat) should be changed, because the original name implies that it could also occur on mineral soils, which is not the case, and, therefore, another forest habitat type is proposed (G1.B: Non-riverine *Alnus* woodland).
4. Square brackets should not be used to indicate scientific names. If included, scientific taxon names should be in italics.
5. A standardised naming system should be used.
   - *Example*: leave out the word 'dominant' in G1.8 (Acidophilous [Quercus]-dominated woodland), as it is not used in other places. 'Highly artificial' is vague and should be replaced by 'non site-specific', as used in the EFT classificiation.
   - *Example*: it is better to use the word 'temperate' rather than 'nemoral'.
6. Geographical epithets in the names must be accurate.
   - *Example*: the epithet Canary Island in G2.7 should be changed to Macaronesian, as this habitat type also occurs in Madeira.
7. Names should not confuse climatic, geographical or biogeograhical meanings; in this regard, the use of 'alpine' should be avoided.
   - *Example*: for G3.2, subalpine would be the correct term.

From the start, the aim of European habitat classifications has been to provide a comprehensive and definitive reference list that is scientific, unambiguous and easily understood (Moss and Roy, 1998; Moss, 2008). To this end, an integral feature of the EUNIS habitat classification is that the habitat text descriptions are incorporated into the underlying database, accessible as an interface via the EUNIS website portal, and are available for download in the classification published by Davies et al. (2004).

There is a glossary appended to the EUNIS habitat classification list (Davies et al., 2004; updated in 2006 to a version supplied by Doug Evans of the ETC/BD), and this was derived from various sources: for terrestrial habitats, 28% of the terms originate from the Institut Royal des Sciences Naturelles de Belgique (presumably based on the Palaearctic Habitats Classification glossary that is included in Moss and Roy, 1998 (Annex III)); 16% are from the General Multilingual Environmental Thesaurus of Eionet; and the remainder are from a variety of published dictionaries on the environment, ecology, and science and technology in general.

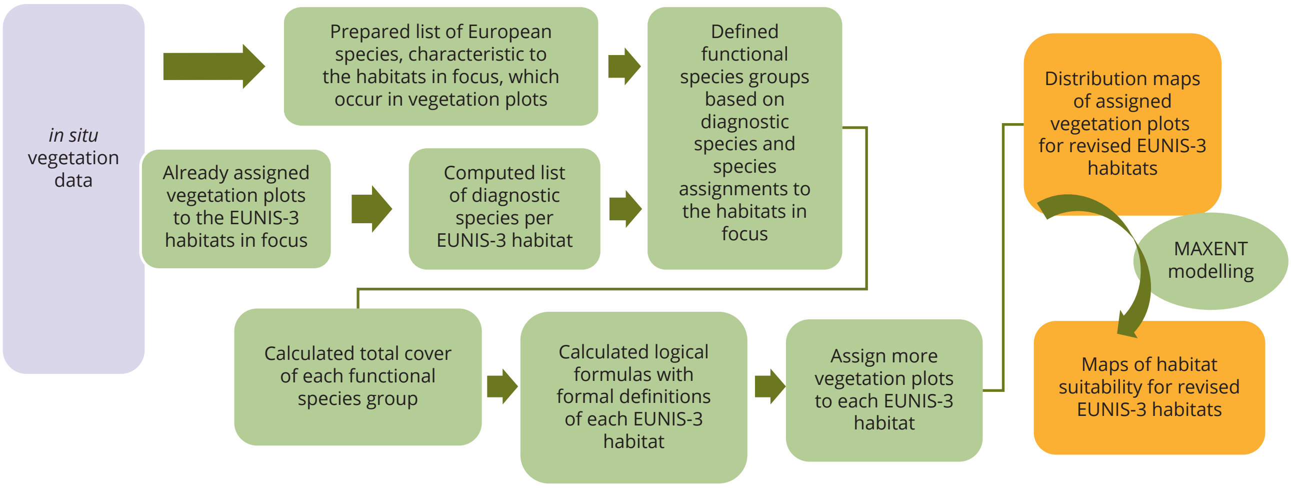
For the purposes of the review, it is recommended that the descriptions are regarded, essentially, as definitions: they should provide, as accurately, briefly and precisely as possible, the key distinguishing features of the habitat. Lengthy descriptions of ecology or status are not appropriate in this context, particularly if the habitat is readily recognisable. In general, any detail provided should reflect the variability in the habitat, not its species richness or structural complexity.

1.3.2 Developing spatial information on the distribution of vegetation plots and habitat suitability maps for EUNIS habitat types

The methodological steps for the development of spatial information and, eventually, of maps of the distribution of vegetation plots and predicted habitat suitability for the revised EUNIS-3 habitat types are shown in Figure 1.4.

In situ vegetation data can be used, not only to determine the floristic composition of habitat types, but also as an excellent repository for ecosystem and habitat distribution mapping and modelling. In conjunction with other data sets (e.g. on soil type or digital terrain models), these data can help with the interpretation of remote sensing imagery.

Figure 1.4 Steps for the preparation of modelled suitability maps, which show areas in which conditions are favourable for the EUNIS-3 habitat types



The locations of the vegetation plots available for the Braun-Blanquet project ([17]) were used for the habitat suitability modelling of EUNIS habitat types. The selection of vegetation plots belonging to the individual EUNIS types was based on a supervised classification of more than 500 000 vegetation plots in JUICE 7.0 (Tichý, 2002). This supervised classification was performed to identify vegetation plots belonging to the individual EUNIS types. This procedure followed the steps indicated below.

1. Vegetation plots, identified during the preparation of the 2013 report (Schaminée et al., 2013), deemed to belong to particular EUNIS habitat types, based on their syntaxon assignment, were marked and grouped in this data set.

2. The degree of occurrence of each species within each group of vegetation plots (i.e. each EUNIS type) was calculated using the phi (φ) coefficient of association (Sokal and Rohlf, 1995) and standardised for an identical number of vegetation plots across all groups, which was arbitrarily set to 1% of the total data set (Tichý and Chytrý, 2006). The species with the highest phi values were considered diagnostic for each EUNIS type.

3. Lists of European species, characteristic to the part of the EUNIS classification in the scope of this data set, were compiled (e.g. for forest habitats, these lists would comprise tree and shrub species).

4. Functional species groups were created using expert judgement based on the lists of diagnostic species for EUNIS types and on the lists generated as described in step 3 above. These functional groups were defined in such a way that they could clearly separate EUNIS habitat types based on their occurrence and the total cover of their species. Each group includes species with similar ecology and distribution. The concept of functional species groups used here is described in Landucci et al. (2015).

5. The total cover of each functional species group was calculated by assuming the random overlap of cover of the individual species, based on the approach proposed by Chytrý et al. (2005) and recently formally described by Fischer (2015).

6. Formal definitions of the EUNIS-3 habitat types (with modifications proposed by Schaminée et al., 2013) were prepared in the form of logical formulae. These formulae combine the total covers of individual species or species groups using the logical operators 'AND', 'OR' and 'NOT', in accordance with the proposals made by Bruelheide (1997). Details of the approach used here are described in Landucci et al. (2015). For example, the logical formula for the habitat type G1.8 Acidophilous *Quercus* woodland is the following:

   ((<#TC Quercus petraea-robur GR15>AND<#TC Quercus petraea-robur GR #TC Trees EXCEPT #TC Quercus

([17]) http://www.sci.muni.cz/botany/vegsci/braun_blanquet.php?lang=en.

petraea-robur>)AND<#TC Quercion roboris GR15>) NOT<#TC Quercus-thermo-herbs GR05>.

This indicates that the total cover (#TC) of the functional species group *Quercus petraea–robur* (includes the deciduous temperate oak species *Quercus petreaea* and *Quercus robur*) is greater than 15% (GR15) and, at the same time, the total cover of this group is greater than the total cover of any other tree species (#TC Trees EXCEPT #TC *Quercus petraea-robur*), and, at the same time, the total cover of the functional group *Quercion roboris* (includes herb species diagnostic of acidophilous *Quercus* woodlands) is greater than 15% and, at the same time, the functional group *Quercus*-thermo-herbs (includes herb species diagnostic of thermophilous *Quercus* woodlands) is not greater than 5%.

7. Lists of species belonging to each functional species group, formal definitions of all EUNIS habitat types, and instructions for handling taxonomic concepts and nomenclature of individual species are included in a single file with a code that can be read by JUICE 7.

8. All vegetation plots in the data set are assessed with regard to whether or not they meet conditions of each logical formula, using JUICE 7, and, based on this, they are assigned to individual EUNIS habitat types.

The advantage of this procedure is that (1) vegetation plots not assigned to syntaxa can be classified; (2) new vegetation plots, obtained since the previous study, can be included; and (3) assignments of vegetation plots to particular habitat types are based on uniform criteria that can be applied consistently across the whole European data set. This data set is then used to create maps of known distributions and to serve as an input for the habitat suitability modelling. For cases in which more than 5 000 vegetation plots were available for a habitat type, the data set was restricted to only one location for each grid cell of 5 km × 5 km.

Habitat suitability modelling
For the EUNIS-3 habitat suitability modelling, the widely used software Maxent (for maximum entropy modelling of species' geographical distributions) is used. Maxent is a general-purpose machine-learning method that employs a simple and precise mathematical formulation. There are a number of aspects that make it well suited to species distribution modelling if only presence (occurrence), but not absence, data are available (Phillips and Dudík, 2008). Because EUNIS habitats have particular species compositions, they are assumed to respond to specific ecological requirements, allowing the generation of correlative estimates of their geographical distributions. The modelling of habitats that have been floristically defined is a well-known procedure for ecological modelling at the local scale, and a promising technique for application at the continental scale. The vegetation plots are classified into EUNIS habitat types based on their floristic composition, as described in Schaminée et al. (2013). The way in which the Maxent model is used for habitat suitability mapping is summarised in Figure 1.5.

The Maxent method considers 'presence data' (i.e. known observations of a given entity) and so-called 'background data'. Background data comprise a set of points used to describe the environmental variation of the study area, according to the available environmental data layers. It is assumed that these layers represent the site conditions of EUNIS-3 habitats on a European scale. These layers were selected from the most meaningful environmental predictors, which are commonly used to model non-tropical plant and vegetation diversity, and are not strongly correlated. The layers in Table 1.1 are used as environmental data for Maxent modelling.

Maxent is expected to perform well with regard to estimating the geographical distribution of EUNIS habitats in Europe. However, this method, as with any other modelling technique, is sensitive to sampling bias (i.e. if the spatial distribution of presence data reflects an unequal sampling effort in different geographical regions). It has been proposed that, for Maxent, the best way to account for sampling bias (if bias is known or expected to occur) is to generate background data that reflect the same bias of the presence data. If a complete set of presence data is available, the general recommendation is that background points should be generated from data on other species/communities that were sampled in a similar way (Elith et al., 2011).

Two different approaches have been followed for the selection of a maximum of 10 000 locations for background data, assuming biased and non-biased presence data. For the first approach, 10 000 locations are randomly selected from the part of the EUNIS classification in the relevant plot database (for this report, the relevant database is the forest plot database), assuming that these locations reflect the general geographical bias of sampling in Europe. The second approach involves a random selection of 10 000 background points in the whole study area, assuming that the presence data are representative of the real distribution range of the target habitat. The two modelling approaches (assuming biased and non-biased data) were evaluated for each EUNIS habitat type in order to estimate which assumption is more likely. This evaluation was based on the expert knowledge, with regard to the distribution of habitat types (i.e. forest types in this case) in Europe, of the team members by assessing (1) the distribution of the available presence data as an estimate of geographical bias; (2) the realism of the habitat suitability maps with regard to reflecting the known distribution of habitat types (i.e. forest types); and (3) the environmental predictors that contribute most substantially to the models. The best performing model was then selected by team consensus for each habitat type.

Figure 1.5 Schematic representation of the methodology used for habitat suitability mapping with Maxent

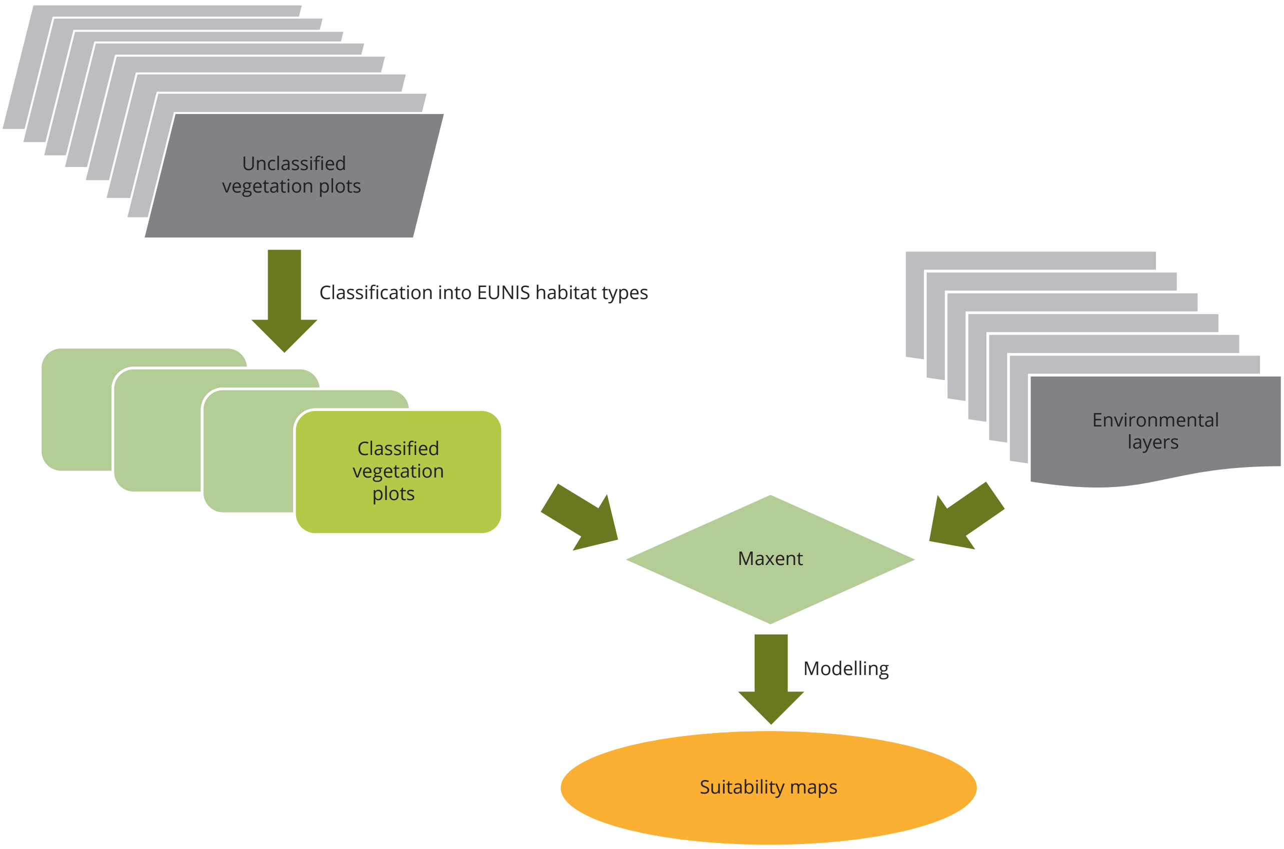


Table 1.1 Environmental data layers used to develop habitat suitability maps for EUNIS-3 habitat types

Layer	Source
Potential evapotranspiration (PET)	http://www.cgiar-csi.org/data/global-aridity-and-pet-database
Topsoil pH (Soil_pH)	http://www.isric.org
Solar radiation (Solar)	http://www.worldgrids.org/doku.php?id=wiki:inmsre3
Temperature seasonality (BioClim 4)	http://www.worldclim.org/bioclim
Mean temperature of wettest quarter (BioClim 8)	http://www.worldclim.org/bioclim
Annual precipitation (BioClim 12)	http://www.worldclim.org/bioclim
Precipitation seasonality (BioClim 15)	http://www.worldclim.org/bioclim
Precipitation of warmest quarter (BioClim 18)	http://www.worldclim.org/bioclim
The maximum NDVI (NDVI peak)	Alterra, HANTS, 2012
Distance to water (i.e rivers, lakes or sea)	Rivers from Bartholomew topographic maps; lakes and sea from Corine Land Cover database, 2006

2 Review of EUNIS forest habitat types

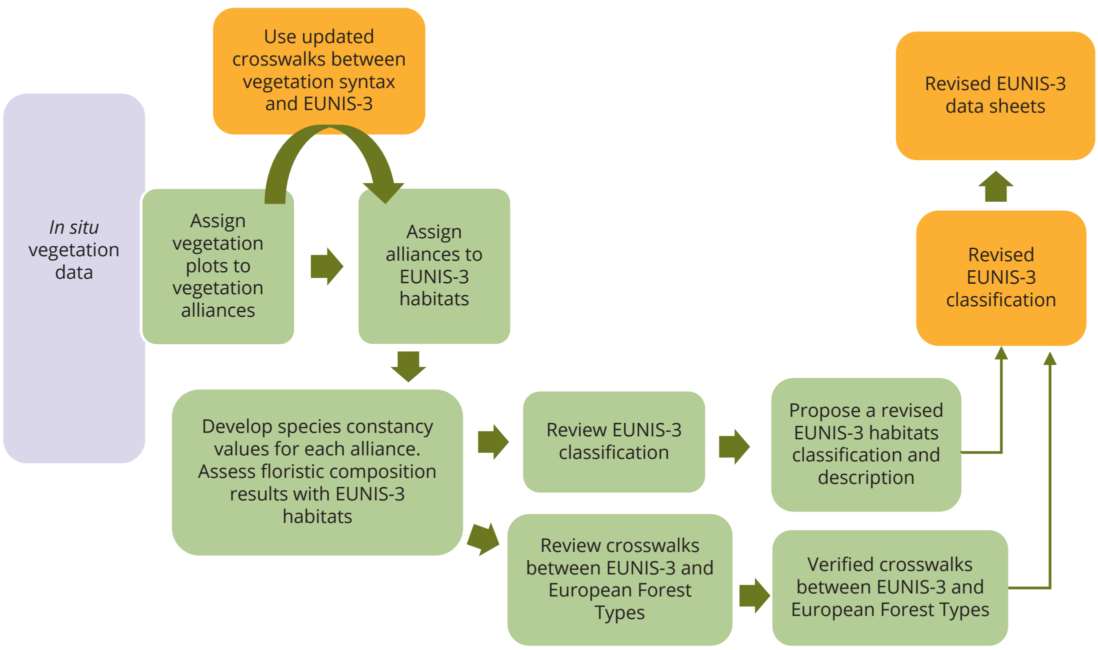
EUNIS-3 forest habitat types were selected as the first category to be reviewed on the basis of vegetation-plot data because of data availability and their well-documented floristic composition. In the review, the following EUNIS types were taken into account: GI (deciduous), G2 (broadleaved evergreen), G3 (coniferous) and one type from the dune group (B1.7: coastal dune woods). The categories G4 and G5 have not been dealt with, as these EUNIS types are based on a mixture of concepts. Some of these categories correspond to physiognomic types that are unrelated to phytosociological types (e.g. various types of mixed vs. non-mixed forests), whereas others are complexes of different vegetation types that describe landscape types containing several habitat types rather than a single habitat type.

The selection of the vegetation plots to be analysed for this review was based on the 2012 crosswalks between EUNIS-3 habitats and vegetation syntaxa. However, from the outset, it was necessary to update the forest part of these crosswalks in in order to correspond with the the EuroVegChecklist (version 2103). This update reflects the merging of some alliances, the division of others, the introduction of new alliances and changes to the delimitation of some alliances that influence established matches with EUNIS-3 habitats. The updated forest habitat crosswalks, including a more detailed description of crosswalk development, are included in Annex 2a and 2b of this report.

The workflows shown in Figure 2.1 were implemented for the review of EUNIS-3 forest habitats.

The first step in the procedure was to compile a database of 670 000 vegetation plots, in Turboveg format, containing data sets from a wide range of data providers from throughout Europe. Vegetation plots of regional and national data sets were classified at the level of EuroVegChecklist (version 2013) alliances by matching regional and national classification systems

Figure 2.1 Flow chart for the review of EUNIS-3 forest habitats on the basis of vegetation-plot data



(to which the vegetation plots in the data sets from the data providers were assigned) with the European overview. At present, about 40% (236 000) of the 670 000 vegetation plots can be assigned to one of the alliances accepted by the EuroVegChecklist (version 2013), 26% (62 000 vegetation plots) of which belong to forest habitats.

In a second step, assignments to EUNIS forest habitat types were performed by merging the alliance data sets to the corresponding EUNIS types according to the updated EUNIS–syntaxa crosswalk. In the crosswalk, 156 EuroVegChecklist (version 2013) forest alliances were assigned to one of the 36 EUNIS forest habitat types. At present, 117 of these alliances have been documented with *in situ* vegetation-plot data (i.e. 76% of the total forest alliances).

With regard to EUNIS forest habitat types, 32 out of 36 are covered by real data (89%). The reasons for not having *in situ* vegetation data for some alliances are indicated below.

1. *Narrow alliance concepts in EuroVegChecklist:* for some deciduous forest types, EuroVegChecklist uses a very narrow concept of alliances, which has rarely been used before. Vegetation plots in the original databases are not classified in accordance with these alliances and, therefore, correct assignment is difficult.

2. *Alliances described from Asia and occurrence in Europe is poorly documented*: several alliances were described from Anatolia, the Near East or Siberia. They probably occur in Greece or the Southern Ural region, but European data are scarce or absent.

3. *Alliances from regions with a general lack of phytosociological data*: some areas are still not well covered by phytosociological data, such as the Boreal zone of Scandinavia, Russia, Ukraine, Caucasus, parts of the Balkans and Cyprus.

4. Macaronesian and Iberian alliances which were not recognised in the Spanish SIVIM (Sistema de Información de la Vegetación Ibérica y Macoronésica) database.

The third step involved calculating species constancy values in the vegetation plots assigned for each alliance. Using the updated crosswalks, the resulting species frequencies above 10 % were attributed to each EUNIS-3 forest habitat. In Annex 3, each reviewed EUNIS forest habitat data sheet contains (1) a name; (2) a list of alliances; (3) a list of species and their frequencies, including species with a frequency of > 10%; (4) a qualifier, such as the origin of the data and the corresponding European Forest Type (EFT); and (5) the possible implications for EUNIS and EFT classifications. These results will be thoroughly presented in a coming EEA report.

2.1 Review and proposal for improvements of EUNIS forest habitat types

The proposed improvements of the content of the EUNIS forest habitat types were derived by comparing the existing EUNIS classification with the phytosociological content of the assigned syntaxa. Based on this, it was found that there are strong grounds for revising EUNIS types G1.6, G1.9, G3.1, G3.4, G3.5 and G.3.9, as described in the sections below. The general recommendations given in Box 1.1, with regard to the naming of habitat types, were considered when proposing the revised EUNIS-3 forest habitat classification. The new names proposed are included in the forest habitat type data sheets in Annex 1. These revisions will ensure that the names are recognisable by users of the EFT classification.

2.1.1 EUNIS G1.6 Fagus *woodland*

The classification of the wide diversity of European beech forests has long been a challenge, with divisions being based sometimes on the soil reaction/trophic state, sometimes on altitudinal range and sometimes on geographical patterns of occurrence. At present, all such beech woods are included within the single G1.6 EUNIS type, which is equivalent, in our crosswalk, to 15 alliances. We propose dividing the G1.6 EUNIS type, on the basis of soil reaction, into 'G1.6a *Fagus* woodland on non-acid soils' (with 12 alliances) and 'G1.6b *Fagus* woodland on acid soils' (with three alliances).

2.1.2 EUNIS G1.9 Non-riverine woodland with Betula, Populus tremula *or* Sorbus aucuparia

EUNIS G1.9 Non-riverine woodland with *Betula*, *Populus tremula* or *Sorbus aucuparia* includes a wide diversity of birch and aspen woodlands. We recommend dividing this EUNIS type into two units, based on the altitudinal and geographical characteristics of the constituent alliances: 'G1.9a Mountain *Betula* and *Populus tremula* woodland on mineral soils' (with seven alliances) and 'G1.9b Lowland Continental *Betula* and *Populus tremula* woodland on mineral soils' (with two alliances).

2.1.3 *EUNIS G3.1* Abies *and* Picea *woodland*

EUNIS G3.1 *Abies* and *Picea* woodland includes all fir and spruce forests. On the basis of the canopy dominants and geographical distribution among the 16 constituent alliances, we recommend dividing this type into three subgroups: 'G3.1a Temperate mountain *Picea* woodland' (with five alliances), 'G3.1b Temperate mountain *Abies* woodland' (nine alliances) and 'G3.1c Mediterranean mountain *Abies* woodland' (three alliances).

2.1.4 *EUNIS G3.4* Pinus sylvestris *woodland south of the taiga and G3.5* Pinus nigra *woodland*

We recommend combining EUNIS G3.4 *Pinus sylvestris* woodland south of the taiga and G3.5 *Pinus nigra* woodland, and then dividing this combined group on the more justifiable basis of climatic and geographical affiliations among the 25 constituent alliances as follows: 'G3.4a Temperate continental *Pinus sylvestris* woodland' (six alliances), 'G3.4b Temperate and Submediterranean montane *Pinus sylvestris–Pinus nigra* woodland' (nine alliances) and 'G3.4c Mediterranean-montane *Pinus sylvestris–nigra* woodland' (six alliances).

2.1.5 *EUNIS G3.9 Coniferous woodland dominated by* Cupressaceae *or* Taxaceae

EUNIS G3.9 Coniferous woodland dominated by *Cupressaceae* or *Taxaceae* comprises 11 alliances. The division of this group, based on phytogeographical affiliations among the constituent alliances, is proposed: 'G3.9a *Taxus baccata* woodland' (with one alliance), 'G3.9b Mediterranean *Cupressaceae* woodland' (five alliances) and 'G3.9c Macaronesian *Juniperus* woodland' (five alliances).

2.2 Descriptions of the revised EUNIS forest habitat types

The development of the existing text descriptions used in the EUNIS habitat classification is detailed in Hill et al. (2004a, b): only 7 out of the 31 forest habitats under consideration in this report retain their original Palaearctic Habitats Classification description; however, changes to the other descriptions appear to have been relatively minor. The text descriptions are variable in length, detail and content. For the forest habitats, they all start with some kind of general statement about the character of the habitat, although some habitats are termed 'woodland' and some 'forest', on the basis, according to the glossary, of whether the tree canopy is open or closed. All descriptions mention one or more tree species, which helps to define the type. In 31% of descriptions, there are some details about structure, often the pattern of dominance, and 2% of descriptions mention the particular species richness of the canopy, or the endemism or composition of the field layer. For 63% of the habitat descriptions, there are references to the biogeographical or bioclimatic zone; for 16%, there are references to the altitudinal level; for 37%, there are references to terrain; and for 9%, there are references to soils. For 16% of the habitats, there are qualifiers to clarify what is excluded from the habitat.

The proposed revised descriptions, in general, have a standardised format, as described below.

- The term 'woodland' has been used throughout the revised descriptions, irrespective of the degree of canopy closure (which is the criterion used in the EUNIS glossary for distinguishing 'woodland' from 'forest'). The argument for this is that canopy closure is not always uniform within a type and these terms have confusing resonances in different parts of Europe. However, this is not compliant with the internationally agreed reference definitions and reporting standards for forests and other wooded land (FAO, 2001, 2006, 2010, 2015; Gabler et al., 2012; see also footnote ([18])).

- A general reference is included with regard to the character of the woodland: whether it is broadleaved, coniferous or deciduous evergreen. Details of species composition are now available through analysis of constituent vegetation plots or data tables for the alliances of each habitat, because it was decided that there is no need to repeat this information in the description unless it has some definitive value.

- Woodland structure or species richness is mentioned only if it is a diagnostic feature of the woodland type.

([18]) Woodland is defined as an area with a high density of trees (McRoberts et al., 2009), whereas forest is defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use. Woodland is the same, except that canopy cover is 5–10% (FAO, 2015).

- Non-technical terms are used, as far as possible, to describe terrain, soil types and altitudinal belts.

- Although it is recognised that local environmental conditions in one biogeographical zone may correspond to those prevailing more widely elsewhere, biogeographical zone terminology is used to refer to the biogeographical zone generally typical of a habitat distribution and, otherwise, any specialised terminology to describe climatic relationships or broad geographical distributions is avoided.

The original and proposed revised descriptions of EUNIS-3 forest habitats are included in Annex 1.

3 Developing spatial information for EUNIS forest habitat types

This chapter presents the workflows used for the production of maps of distribution of phytosociological vegetation plots, and maps of predicted habitat suitability, for the revised EUNIS-3 forest habitats. The workflow is shown in Figure 3.1 and is explained in the subsequent paragraphs.

3.1 Assignment of vegetation plots to each EUNIS forest habitat type

The locations of vegetation plots available for the Braun-Blanquet project ([19]) were used for the habitat suitability modelling for the EUNIS forest types. The selection of vegetation plots belonging to the individual EUNIS forest types was based on a supervised classification of more than 500 000 vegetation plots in JUICE 7.0 (Tichý, 2002). This supervised classification was performed to identify vegetation plots belonging to individual EUNIS forest types.

The procedure followed the steps indicated below.

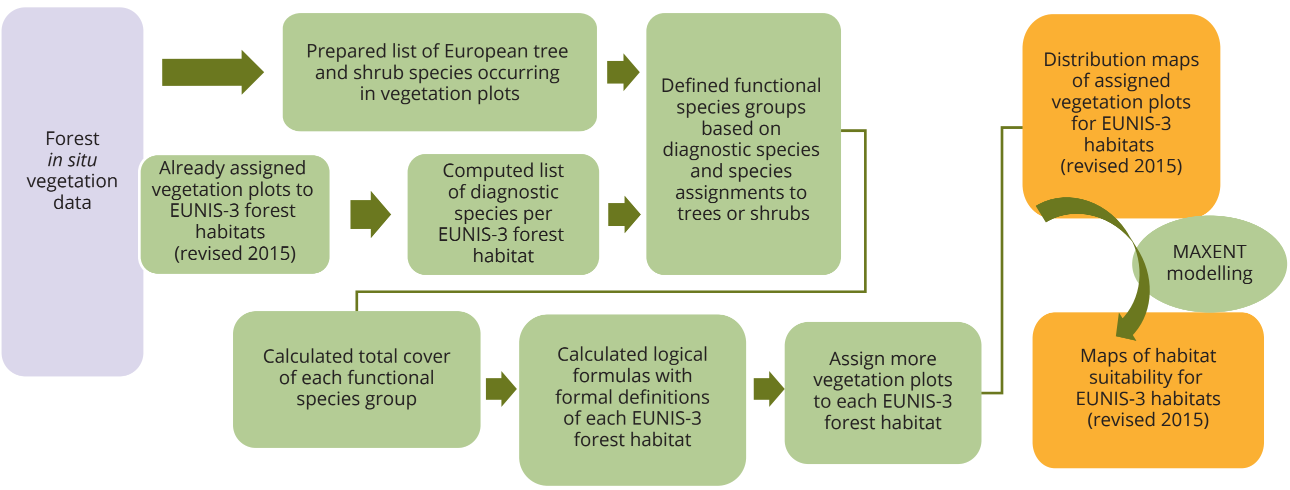
1. Vegetation plots, identified during the preparation of the 2013 report (Schaminée et al., 2013), deemed to belong to particular EUNIS types, based on their syntaxon assignment, were marked and grouped in this data set.

2. The degree of occurrence of each species within each group of vegetation plots (i.e. each EUNIS type) was calculated using the phi (φ) coefficient of association (Sokal and Rohlf, 1995) standardised for an identical number of vegetation plots across all groups, which was arbitrarily set to 1% of the total data set (Tichý and Chytrý, 2006). The species with the highest phi values were considered diagnostic for each EUNIS type.

3. Lists of European species of trees and shrubs occurring in this data set were compiled.

4. Functional species groups were created using expert judgement based on the lists of diagnostic species for EUNIS types and on lists of trees and

Figure 3.1 Steps for the preparation of the modelled suitability maps, which show areas in which conditions are favourable for EUNIS-3 forest habitat types



([19]) http://www.sci.muni.cz/botany/vegsci/braun_blanquet.php?lang=en.

shrubs. These functional groups were defined in such a way that they could clearly separate EUNIS forest habitat types based on their occurrence and the total cover of their species. In general, some functional groups included woody species and others included herb-layer species. Each group includes species with similar ecology and distribution. The concept of functional species groups used here is described in Landucci et al. (2015).

5. The total cover of each functional species group was calculated by assuming the random overlap of cover of the individual species, based on the approach proposed by Chytrý et al. (2005) and recently formally described by Fischer (2015).

6. Formal definitions of all EUNIS-3 forest habitat types (with modifications proposed by Schaminée et al., 2013) were prepared in the form of logical formulae. These formulae combine total covers of individual species or species groups using the logical operators 'AND', 'OR' and 'NOT', in accordance with the proposals made by Bruelheide (1997). Details of the approach used here are described in Landucci et al. (2015). For example, the logical formula for the habitat type G1.8 Acidophilous *Quercus* woodland is the following: *((<#TC Quercus petraea-robur GR15>AND<#TC Quercus petraea-robur GR #TC Trees EXCEPT #TC Quercus petraea-robur>)AND<#TC Quercion roboris GR15>)NOT<#TC Quercus-thermo-herbs GR05*>. This indicates that the total cover (#TC) of the functional species group *Quercus petraea-robur* (includes deciduous temperate oak species *Quercus petreaea* and *Quercus robur*) is greater than 15% (GR15) and, at the same time, the total cover of this group is greater than the total cover of any other tree species (#TC Trees EXCEPT #TC Quercus petraea-robur), and, at the same time, the total cover of the functional group *Quercion roboris* (includes herb species diagnostic of acidophilous *Quercus* woodlands) is greater than 15% and, at the same time, the functional group *Quercus*-thermo-herbs (includes herb species diagnostic of thermophilous *Quercus* woodlands) is not greater than 5%.

7. Lists of species belonging to each functional species group, formal definitions of all EUNIS forest habitat types, and instructions for handling taxonomic concepts and nomenclature of individual species are included in a single file with a code that can be read by JUICE 7.

8. All vegetation plots in the data set were assessed with regard to whether or not they meet conditions of each logical formula, using JUICE 7, and, based on this, were assigned to individual EUNIS forest habitat types.

In total, more than 140 000 vegetation plots were assigned to EUNIS forest habitat types in this way. The advantage of this procedure is that (1) vegetation plots not assigned to syntaxa can be classified; (2) new vegetation plots, obtained since the previous study, can be included; and (3) assignments of vegetation plots to particular habitat types were based on uniform criteria that were applied consistently across the whole European data set. This data set was then used to create maps of known distributions and served as an input for the habitat suitability modelling. For cases in which more than 5 000 vegetation plots were available for a habitat type, the data set was restricted to only one location for each grid cell of 5 km × 5 km (see the example given in Map 3.1 for vegetation plots for EUNIS forest habitat type G1.1 'Temperate and boreal softwood riparian woodland').

Forest types that were located outside the geographical scope (Macaronesia), or that were floristically difficult to define based on national classifications (B1.7, G1.D, G2.8 and G2.9), were excluded from the classification process. However, B1.7 was included by taking into account all forest vegetation plots (selected by the expert system) that are located within the coastal dune area indicated on the map of the natural vegetation of Europe (Bohn et al., 2000), with a buffer of 1 km.

3.2 EUNIS forest habitat type suitability modelling using Maxent

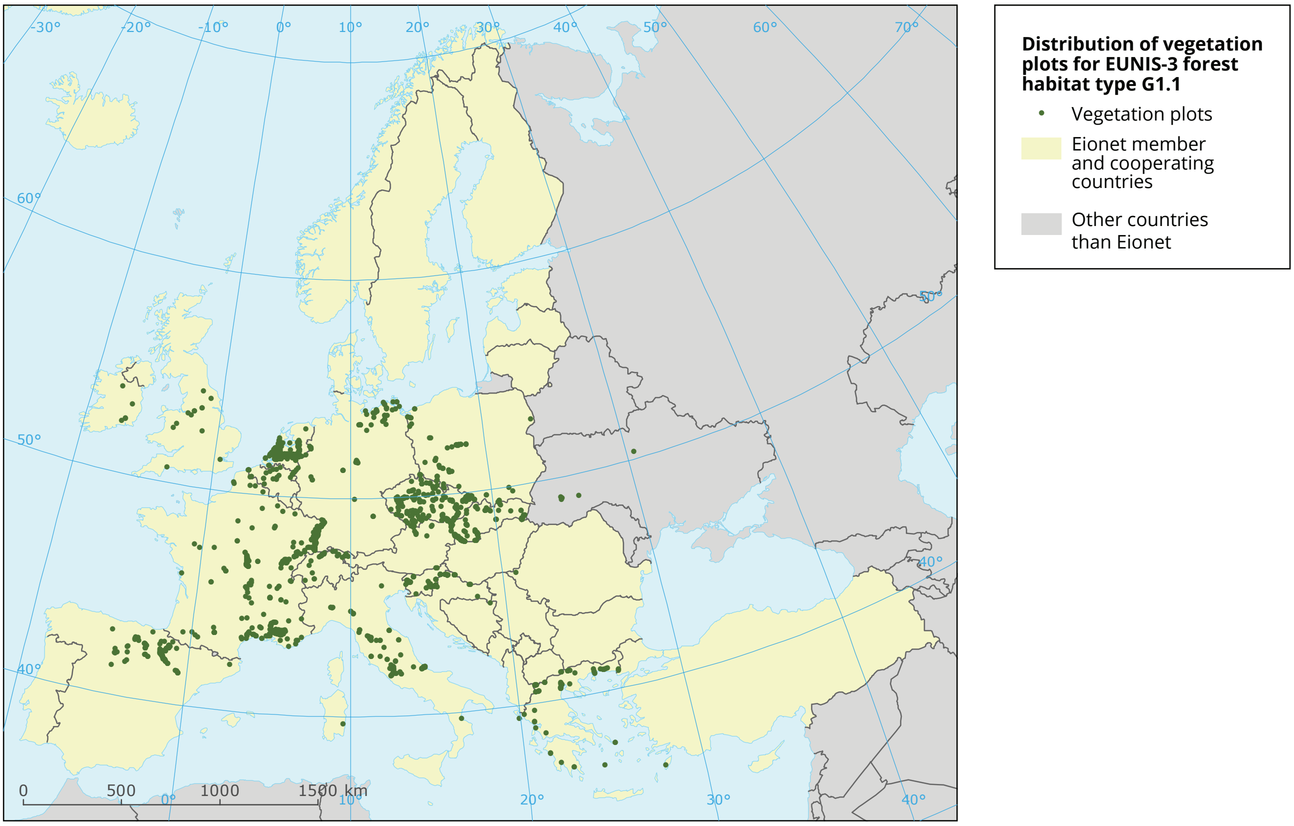
For the EUNIS-3 forest habitat suitability modelling, the widely used software Maxent (for maximum entropy modelling of species' geographical distributions) was used (see Section 1.2.2). The vegetation plots were classified into EUNIS habitat types based on their floristic compositions, as described by Schaminée et al. (2013).

The results of the Maxent modelling are presented in Annex 4, in which, in the overview of forest types on the first page, the preference for one of the two outputs is indicated in the columns 'Forest' (assuming biased data) and 'Random' (assuming non-biased data). Furthermore, for each EUNIS forest type, the data described below are presented.

- A habitat suitability map, such as that shown in Map 3.2, is provided. This indicates increasingly favourable ecological conditions for the type (expressing the logistic output, between 0 and 1, of the model).

- A distribution map (see Map 3.1), showing the location of vegetation plots that have been assigned to a particular EUNIS forest type and, therefore, used as presence data, is provided.

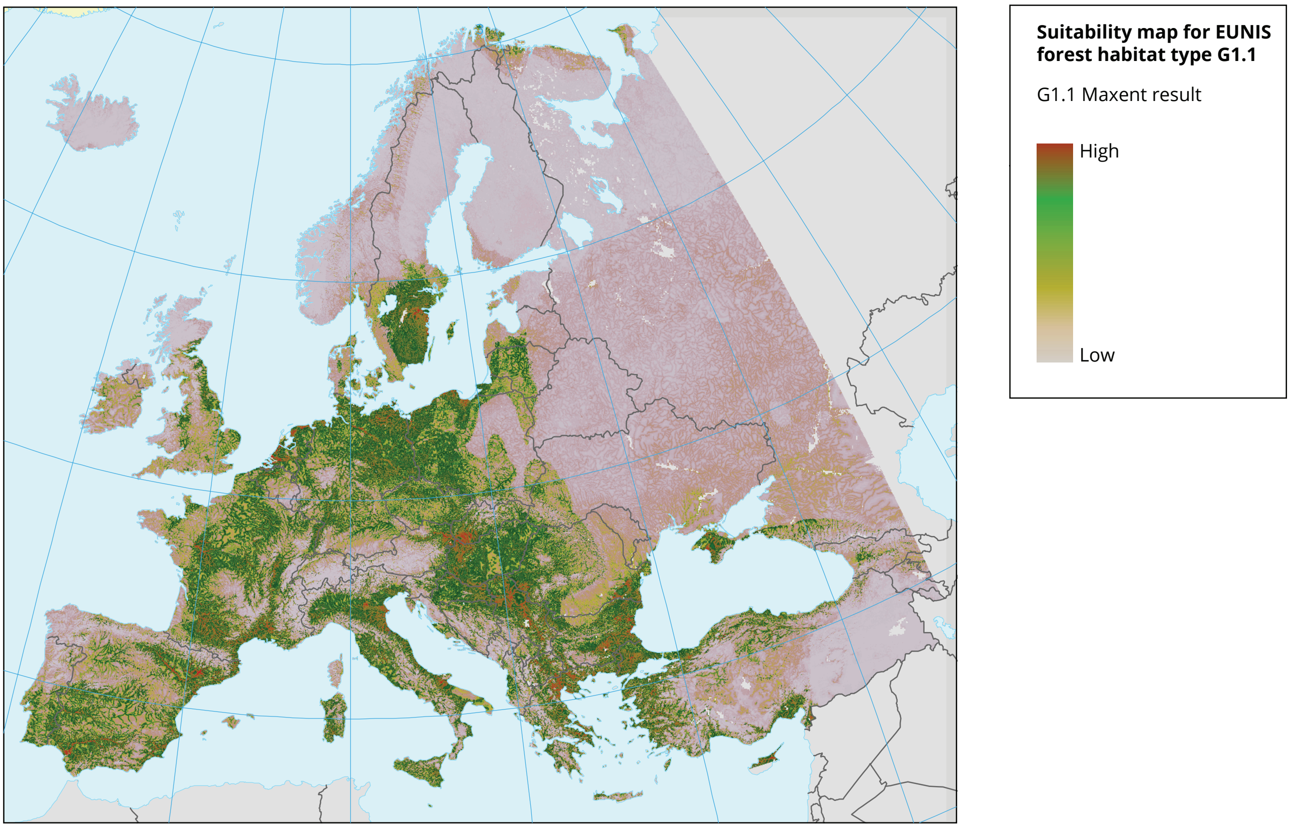
Map 3.1 **Example of the available vegetation plots for EUNIS-3 forest habitat type G1.1 'Temperate and boreal softwood riparian woodland', used as an input for Maxent statistical modelling**



- The area under the curve (AUC), which provides a general estimate of model performance, is given. This is the probability that the classifier correctly orders two points (a random positive example and a random negative example). In general, AUC values in the range of 0.5–0.7 were considered low, values of 0.7–0.9 were deemed moderate and values of > 0.9 were considered high, indicating poor, good and very good model performances, respectively. Two AUC estimates were provided, as calculated by Maxent: 'AUC training' and 'AUC test'. 'AUC training' reflects the internal fit between observed and predicted occurrences in the computed model. 'AUC test' provides the mean AUC obtained from a 10-fold cross-validation procedure in which 10 different models were computed with a random selection of 90% of the data (calibration data set) and 10% of the data were used for testing the model (validation data set).

- The contribution variables (%) used for the Maxent model are given. These data indicate the extent to which individual environmental variables contribute to the model.

Map 3.2 Example of a suitability map, for the EUNIS forest habitat type G1.1 'Temperate and boreal softwood riparian woodland', resulting from Maxent statistical modelling



4 Next steps

The work presented in the previous chapters demonstrates that *in situ* vegetation data, through links to the EUNIS habitat classification, can contribute substantially to the assessment of habitats and ecosystems in Europe. The next steps in the development of the EUNIS habitat classification can be clustered around three themes: (1) the completion of the review of EUNIS-3 terrestrial habitats; (2) the further use of the outcomes of the review to support the assessment of habitats, ecosystems and ecosystem services; and (3) the development of an Eionet strategy for collecting *in situ* vegetation data for multiple purposes.

The paragraphs below present the next steps for each of these themes from the perspective of the EEA, as well as from the perspective of countries (Eionet), as discussed during the expert workshop held in February 2015. During the workshop, experts from 16 countries ([20]) outlined their current state of work with regard to the EUNIS habitat classification and discussed the outcomes of the work presented in this report.

4.1 Review of EUNIS-3 heathland/scrub, grassland and freshwater habitats

Consolidating the EUNIS-3 forest habitat classification with *in situ* vegetation-plot data has helped to characterise the existing units more precisely in terms of their floristic, geographical, physiognomical and environmental parameters. Clearer links have been established between EUNIS forest types and the alliances of the EuroVegChecklist, and this provides further scientific substantiation of EUNIS habitat classification in terms that give access to extensive data, literature and expert knowledge across the whole of Europe.

After the review of forest habitats, which was completed in 2014, work began on EUNIS-3 heathland/scrub (section F) and grassland habitats (section E), following the model flow chart shown in Figure 1.2. The full delivery of outcomes for these two habitat groups is expected in 2016.

Freshwater habitats were included in the 2012 crosswalks between EUNIS-3 habitats and vegetation syntaxa; however, the match between these is rather poor. A review of these EUNIS-3 habitats requires its own methodological approach, and, as an initial step towards this, a scoping study combining vegetation-plot data and typologies relevant to the EU Water Framework Directive has been produced by the ETC/BD.

In most countries, several habitat classifications are used to support the requirements of different policy areas. Fewer countries have established a single, multi-purpose, comprehensive national habitat classification. The country perspectives, with regard to the challenges of EUNIS habitat classification, are presented in Box 4.1.

([20]) Austria, Belgium (Flanders), Finland, Greece, Italy, Norway, Poland, Portugal, Serbia, Slovakia, Slovenia, Spain, Sweden. Switzerland, Turkey and the United Kingdom.

Box 4.1 Country perspectives on the challenges of EUNIS habitat classification (Eionet workshop, February 2015)

The following challenges were identified from the presentations made by the country representatives during the 2015 workshop:

1. the development of coherent criteria for definitions of hierarchical levels, the development of comparative habitat descriptions and the substantial revision of levels 4–6 in a bottom-up approach from countries to level 3;
2. the improvement of consistency with phytosociology, better representation of vegetation dynamics and better representation of ecological processes in the Boreal biogeographical zone;
3. the setting up of a governance scheme, a glossary and a process for testing and maintaining links with national classifications at appropriate levels.

The following points were derived from discussions during the meeting:

1. the approach taken for the review of EUNIS-3 forest habitats is credible and addresses some of the challenges at level 3; a revision of the crosswalks between EUNIS-3 habitats and the habitat types listed in Annex I of the EU Habitats Directive should be carried out as a next step;
2. EUNIS-3 habitats seem to be the most appropriate level for classifications to correspond to at the national level and should be tested with regard to implementing the EU INSPIRE Directive; however, levels 4–6 are the most important for classification and assessment work at country level and, in this regard, more work should be done using Eionet.

4.2 Using revised EUNIS habitat type information for the assessment of habitats, ecosystems and ecosystem services

The information generated by the EUNIS-3 forest habitat review is already being used for work and studies relevant to the assessment of habitats and trends in their quality. For example, the European Red List of Habitats project, funded by the European Commission (Directorate-General for the Environment), will use the EUNIS classification as the habitat typology.

A habitat modelling study tested the refinement of the EUNIS-3 habitat suitability maps with Earth observation data layers and other spatial information (see Box 4.2). The results were promising and there is more testing to be done with regard to using these outcomes in the assessment of the restoration potential of different habitats, as well as in the assessment of the effects of climate change on habitats.

A determining factor for the usability of EUNIS-3 habitat information is the development and maintenance of the relationships between EUNIS-3 habitats and the typologies used for European assessments, such as EFTs, the habitat types of Annex I of the EU Habitats Directive, the habitat types listed by the Bern Convention and the types used in the MAES typology.

Crosswalks from the particular habitat classifications used to the different levels of EUNIS have been developed in a few countries. Crosswalks between national habitat classifications and the habitat types of Annex I of the EU Habitats Directive are used in most EU countries, while EU Water Framework Directive typologies have been taken into account by very few countries for the development of habitat classifications.

A few countries referred to other types of assessments, such as the long-term surveillance of forest habitats, landscape monitoring and habitat mapping, while several countries mentioned activities related to ecosystems and ecosystem services. In addition, the use of the EUNIS habitat classification for the establishment of the Emerald network and the assessment of critical loads of nitrogen was mentioned by several countries. The country perspectives, with regard to using EUNIS classification, are summarised in Box 4.3.

Box 4.2 Testing the use of habitat suitability maps of EUNIS-3 forest habitats for improving the spatial delineation of forest ecosystems

In 2015 ETC-BD developed and tested a methodology for enhancing the identification of spatial distribution of the revised EUNIS-3 forest habitats, which is effectively linking the *in situ* vegetation-plot database available through the European Vegetation Survey to the Copernicus High Resolution Layers (HRL) ([21]).

The habitat suitability maps at a 1 km spatial resolution were refined into habitat probability maps based on the actual land cover, as derived from the HRL-Forest at a 20 metre spatial detail. Further to the Tree Crown Density (TCD) and Forest Types (FTY: broadleaved and coniferous) from the HRL, additional spatial explicit rules were used, such as distance to rivers and tree species maps (TREEMAPS).

The final results were 24 forest habitat probability maps at a 20 metre spatial resolution for the whole of Europe, which were assessed in detail for Slovakia based on national forest data and local environmental knowledge. The independent assessment showed that the modelling approach described in the report is correct, well implemented and useful at the EU level. However, the assessment also showed the limitations, namely, that due to forest management the actual EUNIS forest habitats are often more limited in their extent, and in that sense the produced forest habitat probability maps are often showing their potential distribution within the current forests.

Although the Copernicus HRL Forest still needs to be enhanced by most countries and as such, the currently used HRL is still a draft with small spatial and thematic errors, the major limitation considered in the overall methodology is the limited spatial resolution of the abiotic environmental layers such as the European soil database (scale 1:1M) and the European topographic information on e.g. small rivers, and the lack of *in-situ* habitat data from the Nordic countries. If these problems are solved the method can be easily applied to other EUNIS habitats and could be used amongst others as an input to improve the wall-to-wall European ecosystem map at EUNIS-2 ([22]) as well as in the assessment of ecosystem services at EUNIS-3.

Source: Mücher et al., 2015.

Box 4.3 Country perspectives with regard to using EUNIS habitat classification

1. The EUNIS habitat classification is used as a reference for work performed at the national level and crosswalks to it have been created from national typologies for a number of other projects. A few countries have developed their own national EUNIS habitat classifications.
2. The main activities, in which EUNIS is planned to be used by countries, are related to ecosystem mapping and the MAES initiative of the European Commission, habitat mapping ([23]) and the country-level evaluation of habitats for the European Red List of Habitats.
3. There needs to be greater consideration of the utility of EUNIS-3 terrestrial habitats in relation to bridging Earth observations with their *in situ* component.
4. There needs to be greater consideration of the needs in the area of ecosystem services and the utility of EUNIS to such problems.

Since the EUNIS habitat classification is a European reference of the INSPIRE Directive, it would be very useful to develop a common context for crosslinking with information related to the implementation of the Water Framework Directive and the Marine Strategy Framework Directive, the Common Agricultural Policy and the European Regional Development Fund. A more thorough parameterisation of EUNIS-3 habitats would improve the utility of the classification to this end as well.

([21]) http://land.copernicus.eu/pan-european/high-resolution-layers.
([22]) http://biodiversity.europa.eu/maes/mapping-ecosystems/map-of-european-ecosystem-types.
([23]) For more information see EEA 2014.

4.3 An Eionet strategy for collecting *in situ* vegetation data for multiple purposes

In most countries, phytosociological data support the habitat classifications used by national or regional administration systems for the implementation of specific policies. More often than not, however, phytosociological data are collected for mainly forest ecosystems and other specific vegetation types, or are limited to the habitat types listed in Annex I of the EU Habitats Directive.

During discussions at the February 2015 Eionet workshop, it became clear that there are significant advantages of further advancing with an Eionet strategy for collecting more *in situ* vegetation data for multiple purposes. An initial schema, representing the elements of this strategy, is shown in Figure 4.1.

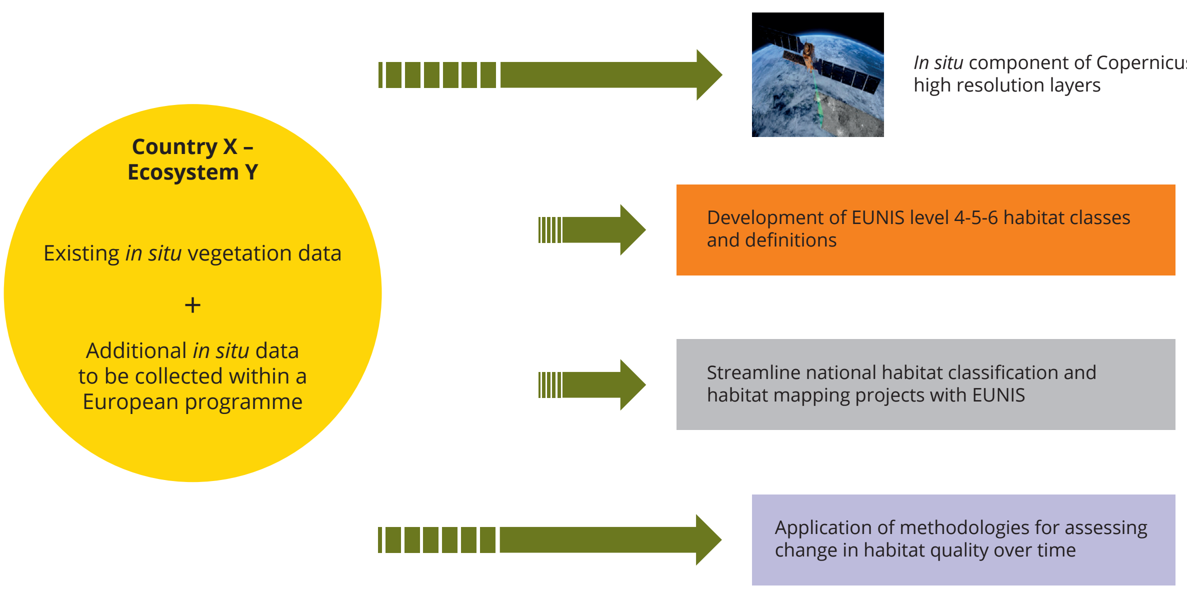
The further collection of vegetation-plot data through Eionet, and the attribution of vegetation plots to EUNIS-3 habitat classes, can significantly enhance the usability of high-resolution layers produced by the Copernicus land monitoring service ([24]) and significantly contribute to the *in situ* component of Copernicus coordinated by the EEA.

The development of EUNIS level 4, 5 and 6 habitat classes and definitions could benefit greatly from such data collection through Eionet. These levels would be defined by sampling in each participating country and then re-processed as EUNIS-3 habitats to give more comprehensive classifications at the European level. Such an activity would also support the establishment and maintenance of linkages between EUNIS-3 and national habitat classifications. The consequent streamlining, at appropriate levels, would allow the simultaneous use of multiple sources of information produced at country levels. Making this data available for analysis at the European level would allow the eventual integration of the EUNIS habitat classification with the Map of the Natural Vegetation of Europe (Bohn et al., 2000).

Box 4.4 discusses whether or not trends in habitat quality can be directly assessed by available vegetation-plot data at the European scale. Based on the conclusions presented, the combined assessment of existing vegetation-plot data and new data collected in a harmonised way through Eionet would enhance the application of methodologies for assessing change in habitat quality over time. To make use of historical data on the European scale, the steps described below might be taken, as proposed in the work of Schaminée et al., 2012.

- A critical review of studies reported in the literature that have analysed vegetation change using historical data in different regions and different habitats could be performed.

Figure 4.1 Elements of an Eionet strategy for collecting *in situ* data for multiple purposes



([24]) http://land.copernicus.eu.

- An inventory of existing, and still marked, permanent plots or repeatedly sampled phytosociological plots across Europe could be compiled. Such a project would require the participation of representatives from individual countries, particularly managers of national vegetation databases, who have relatively easy access to such data and who understand the content of the databases.

- A stratified subset of selected historical phytosociological plots could be revisited. Historical phytosociological plots are available from European vegetation databases (Schaminée et al., 2009; Dengler et al., 2011) and stratification can be performed using European biogeographical regions or existing environmental strata (Metzger et al., 2005; Mücher et al., 2010) on the larger scale, and within EUNIS habitats on the smaller scale. For monitoring future vegetation change, the best strategy would be the establishment of a network of permanent plots, as for example the LTER network, with a spatial arrangement stratified to represent all the regions and major habitats of Europe. The optimal approach would be the establishment of permanent plots at sites of appropriate historical, permanent or phytosociological plots. By doing this, the assessment of past vegetation change and the monitoring of future vegetation change could be realised within a single framework.

Box 4.4 The use of vegetation-plot data for assessing changes in habitat quality over time

Analyses of the Global Index of Vegetation-Plot Databases (GIVD) show that most vegetation plots (> 85%) stored in European databases were obtained after 1970, more than 95% were obtained after 1950 and nearly 100% were obtained after 1920. Therefore, these databases are useful for the assessment of changes in vegetation, especially over various periods within the last 50 years, but also over longer periods for some areas and vegetation types.

The major advantage of this approach is that vegetation-plot data contain information on terrestrial habitats on a very fine scale, based on which change can be assessed. Recording the full species compositions of plant communities can be used for the assessment of changes in occurrence or performance of individual species or target species groups, such as 'Red List' species and alien or invasive species; as general indicators of diversity, such as species richness and diversity indices; and as parameters related to ecosystem services, such as vegetation cover, and change in vegetation or habitat types.

In addition to assessing changes in the occurrence and performance of species over time, the same information can be used to assess the changes in ecosystems induced by anthropogenic environmental influences. For example, the Ellenberg indicator values (Ellenberg et al., 1992), which express the average realised niches of species along seven gradients, namely light, temperature, continentality, soil moisture, soil reaction, nutrient availability and salinity, can be used. Changes in these values provide insight into the drivers that could have forced the observed changes. In many contexts, these advantages make studies based on permanent plots superior to other approaches, such as remote sensing, which does not contain fine-scale biodiversity information at the species level.

A common disadvantage of assessing vegetation change from vegetation plots is observer bias, resulting from the varying skills and experiences of researchers (Lepš and Hadincová, 1992; Klimeš et al., 2001; Vittoz and Guisan, 2007). In particular, the estimates of species cover may vary greatly among observers or depending on the time of the season in which sampling was performed. However, some studies show that, in certain cases, the presence/absence of species may represent vegetation change just as well as data containing species abundances (Bastow Wilson, 2012).

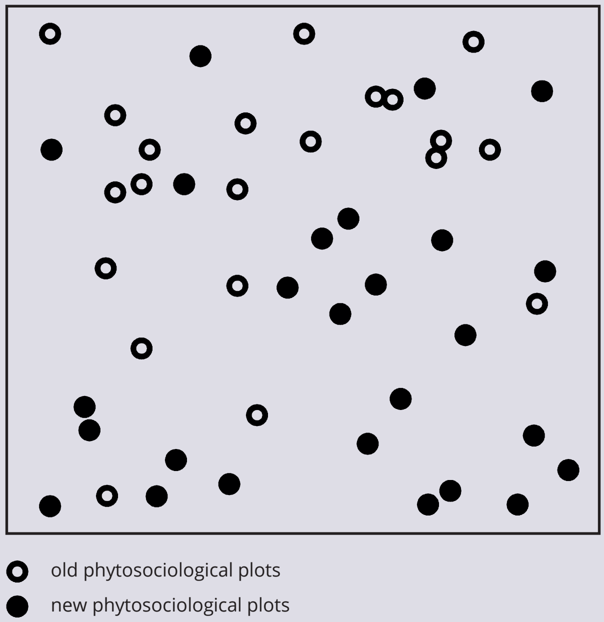
The three basic strategies that can be used to assess trends in vegetation change over time, based on vegetation plots, are (1) the comparison of old and new records from permanent plots; (2) repeated sampling at sites of historical phytosociological plots; and (3) the comparison of large sets of old and new phytosociological plots from the same general area but different sites.

Figure 4.2 represents a map of an area with the positions of old and new phytosociological plots. For the old plots, sampling focused mainly on the upper and left parts of the area, while, for the new plots, sampling was performed mainly in the lower and right parts of this area. (More recently, phytosociologists have preferentially sampled areas with existing gaps.) If there are differences in the vegetation between the upper-left and lower-right parts of the area (e.g. because of slight environmental differences), the results of the comparison of these old and new plots would partly reflect changes in the vegetation over time and partly reflect differences in the vegetation between different parts of the area. Unfortunately, with such data, it is not possible to quantify the relative contributions of changes in the vegetation related to the different parts of the area and those related to the changes that occur over time.

Box 4.4 The use of vegetation-plot data for assessing changes in habitat quality over time (cont.)

Chytrý et al. (2014) performed a methodological study to quantify the error in comparisons of old and new phytosociological data sets. The results show that such comparisons should be treated carefully, as they may produce significant errors in the direction of any trend.

Figure 4.2 A map of 'old' and 'new' phytosociological plots



The conclusions with regard to assessing changes in habitat quality over time using vegetation-plot data are summarised below.

1. Vegetation data from permanent plots are the most reliable existing source of information on past vegetation change, but only if they were established with no intention of documenting a specific type of expected vegetation change. Unfortunately, such data from permanent plots are few and are mainly derived from a few countries/regions and a few vegetation types. Therefore, they do not enable comprehensive analyses of recent vegetation change across large areas of Europe. However, for the assessment of future vegetation change, the establishment of permanent plot networks is the preferred option. The spatial arrangement of plots in such networks should be carried out in accordance with statistical plans, based on landscape and habitat stratification (e.g. stratified random sampling), following the example of established programmes, such as the LTER (Long Term Ecological Research) network ([25]), the British Countryside Survey (Carey et al., 2008) and the Swedish NILS (National Inventory of Landscapes in Sweden) programme ([26]).

2. Repeated sampling of historical phytosociological plots is the most powerful method for detecting vegetation changes that have occurred between specific periods from the past to the present. Some studies have applied this approach in different parts of Europe and for different vegetation types, but many more studies could be performed with the use of the historical phytosociological plots available in European vegetation databases. These plots cover different areas, different habitats and different periods; therefore, their analyses could be relatively comprehensive on the European scale. The system of phytosociological syntaxa, or the EUNIS classification system linked to syntaxa, and the distribution information for syntaxa contained in European vegetation databases can be used to stratify repeated sampling in order to cover all representative European regions and habitats. However, this approach would involve new fieldwork to obtain new records at sites of historical phytosociological plots.

3. Comparisons of old and new phytosociological plots are affected by spatial mismatches between the old and new plots, and by changes in sampling strategies over time. Therefore, in some cases, this approach may erroneously indicate changes in the vegetation different from or even opposite to those that have actually occurred. Therefore, the results of such studies must be interpreted with the utmost caution and verified by independent studies based on repeated sampling or permanent plots. However, they may still be useful for generating hypotheses about what kind of change may have occurred, but such hypotheses must either be treated as mere hypotheses (not interpreted as facts) or further tested using reliable methods and data, if available.

([25]) European Long-Term Ecosystem Research Network, http://www.lter-europe.net.
([26]) National Inventory of Landscapes in Sweden, http://www.slu.se/en/collaborative-centres-and-projects/nils.

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